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Special Issue

The South China Sea: Sustaining ocean productivities, maritime communities and the climate

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Guest Editors

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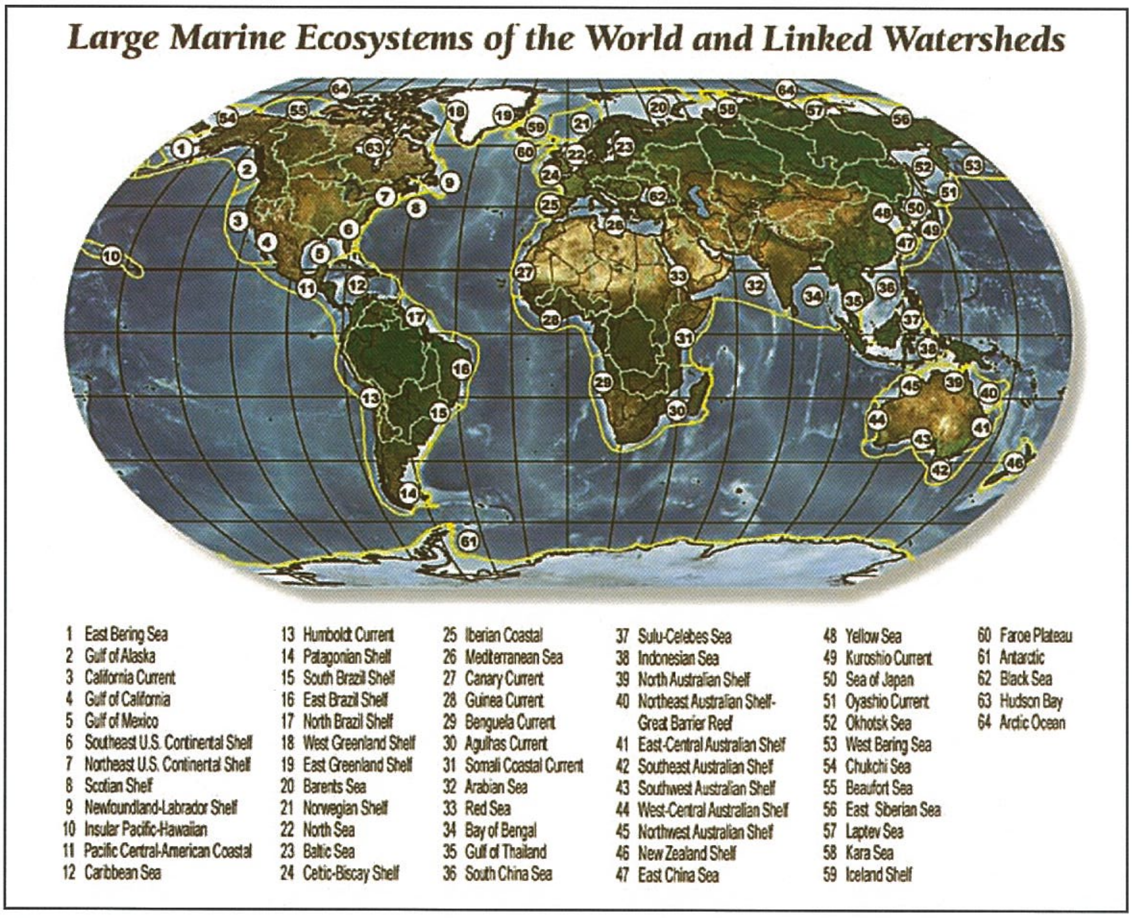

Figure 1. Map of the 64 Large Marine Ecosystems of the world and their linked watersheds [1].

pollution is concentrated, and eutrophication and anoxia are increasing.

The Large Marine Ecosystems (LMEs) of Southeast Asia are presently undergoing change under the influence of growing economic development and human population growth. Four of the region's LMEs – Gulf of Thailand, South China Sea, Sulu-Celebes Sea, and Indonesian Sea – are undergoing ecological disturbances from overfishing, loss of coastal habitats (e.g. sea grasses, mangroves, coral reefs) and biodiversity, nutrient over-enrichment, increasing pollution and vulnerability to climate change. These four LMEs produce an average annual marine fisheries biomass yield of 10.8 mmt representing 15.6 percent of the world's catch valued at nine billion dollars. Recent analyses indicate that climate change and global warming have not adversely affected the continuing rapid rise of fishery biomass yields in the four Southeast Asian LMEs. However, nutrient over-enrichment particularly from dissolved inorganic nitrogen from fertilizers, manure, and sewage estimated at 100,000 to 2.5 million tons per year is entering the four coastal ecosystems at unprecedented rates and contributing to the increased frequency and extent of oxygen depletion events leading to dead zones, harmful algal blooms and fisheries mortalities.

In recognition of the need to introduce ecosystem-based assessment and management actions, countries in the region have requested and have been granted financial assistance from the Global Environment Facility (GEF) and World Bank for implementing a five-module (productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance) LME approach for the recovery and sustainability of depleted fish stocks, the mitigation of nutrient over-enrichment, the conservation of biodiversity and adaptation to climate change.

Since 1995, the GEF has provided substantial funding to support country-driven projects for introducing multisectoral ecosystem-based assessment and management practices for recovery and sustainability of LME goods and services located around the margins of the oceans. Primary

	Pulau Gaya,Kota Kinabalu, Sabah	
	Pantai Bak-Bak, Kudat, Sabah	
	Pulau Tiga,Kota Kinabalu, Sabah	
Tricleocarpa fragilis (Linnaeus) Huisman & Townsend	Kampung Mukut, Pulau Tioman, Pahang	[6]
[Syn: *Galaxaura oblongata* (Ellis & Solander) Lamouroux]		
Family Liagoraceae		
Liagora ceranoides Lamouroux [Syn: *Liagora leprosa* J. Agardh]	Pulau Redang, Terengganu	[5]
Liagora J.V.Lamouroux	Pantai Kuala Abang, Terengganu	[9]
Order Gelidiales		
Family Gelidiaceae		
Gelidiales	Hutan Paya Simpan, Sungai Semarak, Kelantan	[11]
	Kuala Semarak, Bachok, Kelantan	
	Flora Beach Resort, Pulau Perhentian Besar, Terengganu	
Gelidiella acerosa (Forsskal) J. Feldmann & G. Hamel	Tiga Ruang, Pulau Perhentian Besar, Terengganu	
[Syn: *Gelidiopsis rigida* (C. Agardh) Weber-van Bosse]		
Gelidiella Feldmann & G. Hamel	Kuala Semarak, Bachok, Kelantan	[11]
	Pantai Bari, Setiu, Terengganu	
Gelidium pusillum (Stackhouse) Le Jolis	Pulau Rawa, Terengganu	[9],[11]
	Pantai Bari kecik, Terengganu	
	Batu Buruk , Terengganu	
	Pantai Kuala Abang, Terengganu	
	Tanjung Jara, Terengganu	
	Pantai Kemasik , Terengganu	
	Pulau Bidong Laut, Terengganu	
	Pulau Karah, Terengganu	
	Pulau Geluk, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Marine Park, Pulau Pinang, Terengganu	
Gelidium pusillum var. *pacificum* W.R.Taylor	Changar Hutang, Pulau Redang, Terengganu	[9]
Pterocladia caloglossoides (Howe) Dawson	Pulau Rengis, Pulau Tioman	[5],[6]
[Syn: *Pterocladia parva* Dawson]	Pulau Kerengga Besar, Pulau Redang, Terengganu	
	Pulau Kerengga Kecil, Pulau Redang, Terengganu	
Pterocladia nana Okamura	Pantai Bari kecik, Terengganu	[9]
	Batu Buruk, Terengganu	
	Pantai Chendering, Terengganu	
	Tanjung Jara, Terengganu	
	Pulau Bidong Laut, Terengganu	
	Pulau Geluk, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Batu Rakit, Terengganu	
Pterocladiella Santelices & Hommersand	Kuala Semarak, Bachok, Kelantan	[11]
Family Gelidiellaceae		
Gelidiella acerosa(Forsskål) J. Feldmann & G. Hamel	Kampung Mukut, Pulau Tioman, Pahang	[6]
Gelidiella acerosa (Forsskal) J. Feldmann & G. Hamel	Pulau Sibu, Johor	[5],[6]
[Syn: *Gelidiopsis rigida* (C. Agardh) Weber-van Bosse]		
Gelidiella pannosa J. Feldmann & G. Hamel	Panai Bukit Keluang, Terengganu	[9]
	Pantai Bari kecik, Terengganu	
	Pantai Chendering, Terengganu	
	Pantai Kuala Abang, Terengganu	
	Tanjung Jara, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Pantai Universiti Malaysia Terengganu, Terengganu	
Order Gracilariales		
Family Gracilariaceae		
Gracilaria articulata Chang et Xia	Sungai Pulai, Johor	[5]
Gracilaria canaliculata Sonder	Pulau Merambong, Johor	[5]
Gracilaria changii (Xia et Abbott) Abbott, Zhang et Xia	Kukup, Johor	[5]
	Sungai Pulai, Johor	
	Mersing, Johor	
Gracilaria coronopifolia J. Agardh	Pulau Tioman, Pahang	[5],[6]
	Kukup, Johor	
Gracilaria crassa Harvey ex J. Agardh	Pulau Tioman, Pahang	[5]

	Pohon Batu Beach, Pulau Labuan, Sabah	
	Membidai Beach, Pulau Labuan, Sabah	
Gracilaria damaecornis J. Agardh	Pulau Tioman, Pahang	[6]
Gracilaria dura (C. Agardh) J. Agardh	Pohon Batu Beach, Pulau Labuan, Sabah	[5]
	Membidai Beach, Pulau Labuan, Sabah	
Gracilaria edulis (G. Gmelin) P. Silva	Pulau Rengis, Pulau Tioman, Pahang	[5],[6]
	Kukup, Johor	
	Sungai Pulai, Johor	
Gracilaria edulis (S. Gmelin) P. Silva	Tangion Datu, Sarawak	[5]
[*Gracilaria lichenoides* Greville]		
Gracilaria firma Chang et Xia	Tanjung Aru, Labuan, Sabah	[5]
Gracilaria fisheri (B.M.Xia & I.A.Abbott) I.A.Abbott, J.Zhang & B.M.Xia S	Setiu Wetland, Terengganu	[9]
	Pantai Kemasik , Terengganu	
	Pulau Ru, Terengganu	
Gracilaria manilaensis Yamamoto et Trono	Gelah Patah, Johor	[5]
Gracilaria rhodymenioides A.J.K.Millar C	Pantai Chendering, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
	Pantai Kemasik , Terengganu	
Gracilaria salicornia (C. Agardh) Dawson	Pulau Tioman, Pahang	[5],[6]
	Pulau Tiga, Kota Kinabalu, Sabah	
	Pantai Bak-Bak, Kudat, Sabah	
Gracilaria urvillei (Montagne) Abbott, Zhang et Xia	Sabah	[5]
Gracilaria verrucosa (Hudson) Papenfuss	Kuala Terengganu, Terengganu	[5]
[Syn. *Gracilaria confervoides* Greville]	Pulau Redang, Terengganu	
	Kukup, Johor	
Gracilariopsis bailiniae Zhang et Xia	Pulau Bai, Sandakan, Sabah	[5]
Family Pterocladiophilaceae		
Asparagopsis taxiformis (Delile) Trevisan	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
Order Bonnemaisoniales		
Family Falaxauraceae		
Actinotrichia fragilis (Forsskål) Børgesen	Batu Mgong, Pulau Perhentian Kecil, Terengganu	[11]
	Pasir Mas, Pulau Perhentian Kecil, Terengganu	
Order Cryptonemiales		
Family Halymeniaceae		
Cryptonemia crenulata (J. Agardh) J. Agardh	Pulau Dinawan, Kota Kinabalu, Sabah	[5]
Grateloupia filicina (Lamouroux) C. Agardh	Pulau Bai, Sandakan, Sabah	[5]
Grateloupia cf. *livida* (Harvey) Yamada	Pantai Kemasik, Terengganu	[9]
Halymenia dilatata Zanardini	Pulau Tioman, Pahang	[5],[6]
	Pulau Paku Besar, Terengganu	
	Pulau Sulug, Kota Kinabalu, Sabah	
	Pulau Bankawan, Sandakan, Sabah	
	Pulau Burong, Labuan, Sabah	
Halymenia durvillei Bory de Saint-Vincent	Pulau Babi Tengah, Johor	[5]
	Tanjung Data, Pulau Babi Besa, Johor	
	Pulau Sibu, Johor	
	Pulau Nunuyan Laut, Sandakan, Sabah	
	Pulau Gulisan, Sandakan, Sabah	
	Pulau Rusukan Kecil, Labuan, Sabah	
	Tanjung Kaitan, Kota Kinabalu, Sabah	
	Pulau Gaya, Kota Kinabalu, Sabah	
	Pulau Dinawan, Kota Kinabalu, Sabah	
Halymenia floresia (Clemente y Rubio) C. Agardh	Pulau Tioman, Pahang	[5],[6]
Halymenia formosa Harvey ex Kützing	Kampung Mukut, Pulau Tioman, Pahang	[6]
Halymenia maculata J. Agardh	Pulau Tioman, Pahang	[5],[6]
	Pulau Talang-Talang Kecil, Semantan, Sabah	
	Pulau Kuraman, Labuan, Sabah	
	Pulau Satang Besar, Santubong, Kuching, Sarawak	
Family Kallymeniaceae		
Callophyllis heanophylla Setchell	Pulau Kerengga Kecil,Pulau Redang, Terengganu	[5]
Family Peyssonneliaceae		
Peyssonnelia inamoena Pilger	Tanjung Guntong Laut, Pulau Perhentian Kecil, Terengganu	[5]
	Tanjung Batu Lepir, Pulau Perhentian Besar, Terengganu	
	Teluk Gadung, Pulau Perhentian Besar, Terengganu	
	Pasir Panjang Kecil, Pulau Redang, Terengganu	
	Tanjung Pasir China, Pulau Bidong Laut, Terengganu	

Family Rhizophyllidaceae		
Portieria hornemannii (Lyngbye) P. Silva	Kampung Mukut, Pulau Tioman, Pahang	[5],[6]
	Teluk Salang, Pulau Tioman, Pahang	
	Kampung Genting, Pulau Tioman, Pahang	
Order Corallinales		
Family Corallinaceae		
Amphiroa anastomosans Weber-van Bosse	Pulau Bidong Laut, Terengganu	[9]
Amphiroa anceps (Lamarck) Decaisne	Pulau Perhentian Kecil, Terengganu	[5]
	Pulau Redang, Terengganu	
Amphiroa foliaceae Lamouroux	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Kampung Mukut, Pulau Tioman, Pahang	
	Tanjung Layar, Pulau Tioman, Pahang	
	Pulau Perhentian Kecil, Terengganu	
	Pulau Redang, Terengganu	
	Pulau Tiga, Kota Kinabalu, Sabah	
	Pulau Gaya, Kota Kinabalu, Sabah	
Amphiroa fragilissima (Linnaeus) Lamouroux	Pulau Sibu, Johor	[5], [11]
	Pulau Sibu Tengah, Johor	
	Pulau Redang, Terengganu	
	Tiga Ruang, Pulau Perhentian Besar, Terengganu	
	Pasir Mas, Pulau Perhentian Kecil, Terengganu	
	Pantai Bak-Bak, Kudat, Sabah	
	Pulau Tiga,Kota Kinabalu, Sabah	
Amphiroa rigida Lamouroux	Pulau Tioman, Pahang	[5],[6]
	Pulau Sibu, Johor	
Amphiroa tribulus (Ellis et Solander) Lamouroux	Pulau Redang, Terengganu	[5]
	Pulau Tiga, Kota Kinabalu, Sabah	
	Pantai Bak-Bak, Kudat, Sabah	
Amphiroa zonata Yendo	Pantai Chendering, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
	Pantai Kemasik, Terengganu	
	Pulau Karah, Terengganu	
Cheilosporum acutilobum (Decaisne) Piccone	Pantai Chendering, Terengganu	[9]
	Tanjung Jara, Terengganu	
	Pantai Kemasik , Terengganu	
Fosliella dispar Foslie	Pulau Redang, Terengganu	[5]
Jania adhaerens Lamouroux	Teluk Tekek, Pulau Tioman	[5],[6]
	Pulau Redang, Terengganu	
Jania capillacea Harvey	Pulau Redang, Terengganu	[5]
Jania decussato-dichotoma (Yendo) Yendo	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Jania rubens (Linnaeus) Lamouroux	Tanjung Layar, Pulau Tioman	[5],[6]
Jania ungulata (Yendo) Yendo	Batu Buruk, Terengganu	[9]
	Pantai Chendering, Terengganu	
	Tanjung Jara, Terengganu	
	Pantai Kemasik, Terengganu	
	Teluk Kalong, Terengganu	
Melobesia membranacea (Esper) Lamouroux	Sarawak	[5]
Order Gigartinales		
Family Caulacanthaceae		
Catenella nipae Zanardini	Sarawak	[5]
Caulacanthus ustulatus (Turner) Kutzing	Tanjung Sipang, Santubong, Kuching, Sarawak	[5]
Family Gigartinaceae		
Chondracanthus intermedius (Suringar) Hommersand	Tanjung Jara, Terengganu	[9]
Chondracanthus sp. Kützing	Pulau Geluk, Terengganu	[9]
Family Endocladiaceae		
Gloiopeltis cf. *tenax* (Turner) Decaisne	Batu Buruk, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
	Pantai Kemasik, Terengganu	

Family Hypneaceae		
Hypnea charoides-valentiae complex	Panai Bukit Keluang, Terengganu Setiu Wetland, Terengganu Pantai Bari kecik, Terengganu Batu Buruk, Terengganu Pantai Chendering, Terengganu Pantai Kuala Abang, Terengganu Tanjung Jara, Terengganu Teluk Kalong, Terengganu Pulau Bidong Laut, Terengganu Marine Park, Pulau Pinang, Terengganu Batu Rusa, Terengganu Pantai Universiti Malaysia Terengganu, Terengganu	[9]
Hypnea pannosa J. Agardh	Teluk Salang, Pulau Tioman, Pahang Pulau Redang, Terengganu Pulau Sibu, Johor	[5],[6]
Hypnea spinella (C. Agardh) Kutzing	Pulau Kerengga Kecil, Pulau Redang, Terengganu Pulau Pinang, Terengganu	[5]
Hypnea spinella (C. Agardh) Kutzing [Syn: *Hypnea cervicornis* J. Agardh]	Pulau Sibu, Johor Pantai Bak-Bak, Kudat, Sabah	[5]
Hypnea stellulifera (J. Agardh) Yamagishi et Masuda	Batu Manikar, Labuan, Sabah	[5]
Family Phyllophoraceae		
Ahnfeltiopsis pygmaea (J.Agardh) P.C.Silva & DeCew C	Pantai Kemasik, Terengganu	[9]
Family Solieriaceae		
Kappaphycus cottonii (Weber-van Bosse) Doty ex P.Silva	Pulau Sapangar, Kota Kinabalu, Sabah Tanjung Kaitan, Kota Kinabalu, Sabah	[5]
Solieria anastomosa P. Gabrielson et Kraft	Pulau Tikus, Sandakan, Sabah Pulau Bai, Sandakan, Sabah	[5]
Order Rhodymeniales		
Family Champiaceae		
Champia compressa Harvey	Pulau Tioman, Pahang Mak Sinpain, Pulau Redang, Terengganu Pulau Kerengga Besar, Pulau Redang, Terengganu Hujung Tenggara, Pulau Kapas, Terengganu Pulau Nyireh, Terengganu Pulau Tenggol, Terengganu	[5],[6]
Champia parvula (C. Agardh) Harvey	Teluk Salang,Pulau Tioman, Pahang Kampung Mukut,Pulau Tioman, Pahang	[5],[6]
Champia vieillardii Kutzing	Kampung Penaga, Pulau Babi Besar, Johor	[5]
Gastroclonium compressum (Hollenberg) Chang & Xia	Pulau Redang, Terengganu	[5]
Family Lomentariaceae		
Lomentaria monochlamydea (J. Agardh) Kylin	Pulau Rengis, Pulau Tioman, Pahang	[5],[6]
Family Rhodymeniaceae		
Ceratodictyon spongiosum Zanardini	Pulau Sapi, Kota Kinabalu, Sabah Pulau Tiga, Kota Kinabalu, Sabah	[5]
Chamaebotrys boergesenii (Weber-van Bosse) Huisman	Pulau Rengis, Pulau Tioman, Pahang Kampung Genting, Pulau Tioman, Pahang Teluk Gadung, Pulau Perhentian Besar, Terengganu Pasir Panjang Kecil, Pulau Redang, Terengganu Tanjung Pasir China, Pulau Bidong Laut, Terengganu Pulau Tenggol, Pualu Tenggol, Terengganu Pulau Apil, Johor	[5],[6]
Coelarthrum Børgesen	Pulau Bankawan, Sandakan, Sabah	[5]
cf.Coelothrix Borgesen	Teluk Tekek, Pulau Tioman, Pahang	[6]
Gelidiopsis hachijoensis Yamada & Segawa S	Changar Hutang, Pulau Redang, Terengganu Batu Rusa, Terengganu	[9]
Gelidiopsis intricata (C. Agardh) Vickers	Kampung Lalang, Pulau Tioman, Pahang Pulau Rengis, Pulau Tioman, Pahang Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]

Gelidiopsis repens (Kützing) Weber-van Bosse C	Pantai Chendering, Terengganu Pantai Kuala Abang, Terengganu Tanjung Jara, Terengganu Pantai Kemasik, Terengganu Teluk Kalong, Terengganu Pulau Bidong Laut, Terengganu Pulau Karah, Terengganu Pulau Geluk, Terengganu	[9]
Gelidiopsis Schmitz	Kampung Lalang, Pulau Tioman, Pahang Pulau Rengis, Pulau Tioman, Pahang	[6]
Lomentaria cf. *gracillima* Masuda & Kogame C	Pulau Geluk, Terengganu	[9]
Order Ceramiales		
Family Ceramiaceae		
Anotrichium tenue (C. Agardh) Nageli (Syn: *Griffithsia tenuis* C. Agardh)	Pulau Kerengga Kecil, Pulau Redang, Terengganu Pulau Bai, Sandakan, Sabah Pulau Kuraman, Labuan, Sabah Pulau Papan, Labuan, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Mantukud, Kota Kinabalu, Sabah	[5]
Antithamnionella elegans (Berthold) J. Price & D. John [Syn: *Antithamnionella breviramosa* (Dawson) Wallaston in Wolmsley & Bailey]	Pulau Kerengga Kecil, Pulau Redang, Terengganu	[5]
Antithamnionella graeffei (Grunow) Athanasiadis	Pantai Bari Kecil, Terengganu Tanjung Jara, Terengganu	[9]
Centroceras clavulatum (C.Agardh) Montagne	Pantai Bari kecik, Terengganu Batu Buruk, Terengganu Pantai Kuala Abang, Terengganu Pulau Perhentian Kecil, Terengganu	[9]
Centroceras minutum Yamada	Pulau Sibu, Johor	[5]
Centrocerus cf. minutum Yamada	Kuala Semarak, Bachok, Kelantan	[11]
Ceramium californicum J. Agardh	Pantai Kemasik, Terengganu	[9]
Ceramium cimbricum H.E.Petersen	Pantai Kemasik, Terengganu	[9]
Ceramium corniculatum Montagne	Pulau Redang, Terengganu	[5]
Ceramium diaphanum (Lightfoot) Roth [*Ceramium tenuissimum* (Roth) Areschoug nom. illeg.]	Pulau Tioman, Pahang	[5]
Ceramium fimbriatum Setchell & Gardner [Syn: *Ceramium gracillimum* (Kutzing) Griffiths & Harvey]	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Ceramium flaccidum (Kutzing) Ardissone	Pulau Redang, Terengganu Pulau Sibu, Johor	[5]
Ceramium gardneri Kylin	Teluk Kalong, Terengganu Pulau Geluk, Terengganu	[9]
Griffithsia cf. *schousboei* Montagne	Pantai Chendering, Terengganu Pantai Kuala Abang, Terengganu Tanjung Jara, Terengganu Teluk Kalong, Terengganu Pulau Bidong Laut, Terengganu Batu Rusa, Terengganu	[9]
Ptilothamnion codicolum (Dawson) Abbott	Pulau Redang, Terengganu	[5]
Spyridia filamentosa (Wulfen) Harvey	Pulau Tioman, Pahang Pulau Perhentian, Terengganu	[5],[6]
Wrangelia argus (Monatgne) Montagne	Pulau Kerengga Kecil, Pulau Redang, Terengganu	[5]
Wrangelia bicuspidata Børgesen	Pulau Tioman, Pahang	[6]
Wrangelia plumosa Harvey	Pantai Chendering, Terengganu	[9]
Family Dasyaceae		
Dasya iyengarii Børgesen	Pulau Talang-Talang Besar, Semantan, Sarawak Pantai Layang-Layangan, Labuan, Sabah Pulau Gaya, Kota Kinabalu, Sabah Black Rock, Sandakan, Sabah Tanjung Batu Lepir, Pulau Perhentian Besar, Terengganu Teluk Dalam Kecil, Pulau Redang, Terengganu	[5]
Dasya longifila Masuda et Uwai	Pantai Layang-Layangan, Labuan, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Tiga, Kuala Penyu, Kota Kinabalu, Sabah	[5]
Dasya pilosa (Weber-van Bosse) Millar	Pulau Simbang, Johor Tanjung Kaitan, Kota Kinabalu, Sabah	[5]
Heterosiphonia crispella (C. Agardh) Wynne	Mak Simpan, Pulau Redang, Terengganu	[5]

	Kampung Busong, Pulau Babi Besar, Johor Pulau Gador, Semantan, Sarawak Pulau Talang-Talang Besar, Sarawak Batu Manikar, Labuan, Sabah Pulau Bankawan, Sandakan, Sabah	
Family Delesseriaceae		
Delesseria adnata Zanardini [Syn: *Caloglossa bengalensis* (Martens) King & Pullock]	Sarawak (Type Locality)	[5]
Delesseria beccarii Zanardini [Syn: *Caloglossa beccarii* (Zanardini) De Toni]	Stream near Gunung Pueh, Sarawak (Western, Type Locality)	[5]
Hypoglossum caloglossoides Wynne et Kraft	Pulau Karah, Terengganu	[5]
Hypoglossum rhizophorum Ballantine et Wynne	Mak Sinpain, Pulau Redang, Terengganu Pulau Tenggol, Terengganu	[5]
Hypoglossum simulans Wynne, I. Price & Ballantine	Pulau Bidong Laut, Terengganu	[9]
Martensia australis Harvey	Pulau Tikus, Sandakan, Sabah Pulau Bankawan, Sandakan, Sabah Pulau Nunuyan Laut, Sandakan, Sabah Pulau Bai, Sandakan, Sabah	[5]
Martensia fragilis Harvey	Pulau Apil, Pulau Tinggi, Johor Pasir Panjang,Pulau Tinggi, Johor	[5]
Taenioma perpusillum (J. Agardh) J. Agardh	Pulau Bai, Sandakan, Sabah Pulau Sempadi, Santubong, Kuching, Sarawak	[5]
Zellera tawallina Martens	Tanjung Kaitan, Kota Kinabalu, Sabah	[5]
Family Rhodomelaceae		
Acanthophora muscoides (Linnaeus) Bory de Saint-Vincent	Pantai Bukit Keluang, Terengganu Pantai Bari Kecik, Terengganu Batu Buruk, Terengganu Pantai Kemasik, Terengganu Teluk Kalong, Terengganu Pulau Bidong Laut, Terengganu Perhentian Kecil, Terengganu	[9]
Acanthophora spicifera (Vahl) Børgesen	Teluk Tekek, Pulau Tioman, Pahang Pulau Sibu, Johor Teluk Kecil, Pulau Perhentian Besar, Terengganu Flora Beach Resort, Pulau Perhentian Besar, Terengganu Batu Mgong, Pulau Perhentian Kecil, Terengganu Pasir Mas, Pulau Perhentian Kecil, Terengganu De lagoon, Pulau Perhentian Kecil, Terengganu	[5],[6],[11]
Acanthophora spicifera (Vahl) Børgesen [Syn: *Acanthophora thierryi* Lamouroux]	Tangion Datu, Sarawak	[5]
Acrocystis nana Zanardini	Pantai Chendering, Terengganu	[9]
Amansia rhodantha (Harvey) J. Agardh	Pulau Sipadan, Semporna, Sabah Tanjung Kaitan, Kota Kinabalu, Sabah	[5]
Chondria armata (Kutzing) Okamura	Pulau Kerengga Kecil, Pulau Redang, Terengganu Pulau Sibu, Johor	[5]
Chondria decidua Tani & Masuda	Pulau Bidong Laut, Terengganu	[9]
Chondria econstricta Tani & Masuda	Kampung Busong, Pulau Babi Besar, Johor Kampung Penaga, Johor Pulau Sibu Tengah, Johor	[5]
Herposiphonia pacifica Hollenberg	Tanjung Pasir, Pulau Bidong Laut, Terengganu Pulau Ekor Tebu, Terengganu Pantai Kuala Abang, Terengganu Pulau Bidong Laut, Terengganu	[5],[9]
Herposiphonia secunda (C. Agardh) Ambronn [*Herposiphonia tenella*(C. Agardh) Ambronn]	Pulau Redang, Terengganu Pulau Kerengga Besar, Terengganu	[5]
Herposiphonia vietnamica Pham	Pulau Bankawan, Kota Kinabalu, Sabah Pulau Sapangar, Kota Kinabalu, Sabah	[5]
Laurencia articulata Tseng	Pulau Kerengga Besar, Pulau Redang, Terengganu Pulau Kerengga Kecil, Pulau Redang, Terengganu	[5]
Laurencia botryoides (C.Agardh) Gaillon	Pantai Kuala Abang, Terengganu	[5],[9]
Laurencia caduciramulosa Masuda et Kawaguchi	Kampung Mukut, Pulau Tioman, Pahang Pasir Tiga Ruang, Pulau Perhentian Besar, Terengganu	[5],[6]
Laurencia calliclada Masuda	Batu Tokong Daik, Pulau Tenggol, Terengganu	[5]
Laurencia cartilaginea Yamada	Teluk Kalong, Terengganu	[9]
Laurencia concreta Cribb	Tanjung Layar, Pulau Tioman, Pahang	[6]
Laurencia corymbosa J. Agardh	Pulau Tioman, Pahang	[5],[6]

	Pulau Kerengga Besar, Pulau Redang, Terengganu	
	Pulau Sibu, Johor	
Laurencia decumbens Kützing	Pantai Bari Kecik, Terengganu	[9]
Laurencia flexilis Setchell	Tanjung Datu, Kuching, Sarawak	[5]
Laurencia implicata J. Agardh	Pulau Redang, Terengganu	[5]
Laurencia lageniformis Masuda	Tanjung Sipang, Santubong, Kuching, Sarawak Tanjung Datu, Santubong, Kuching, Sarawak Pulau Tikus, Sandakan, Sabah	[5]
Laurencia majuscula (Harvey) Lucas	Teluk Kalong Besar, Pulau Redang, Terengganu	[5]
	Kampung Busong, Pulau Babi Besar, Johor	
	Pulau Satang Besar, Kuching, Sarawak	
	Pulau Sempadi, Sarawak	
	Pulau Tikus, Sandakan, Sabah	
	Pulau Bankawan, Sandakan, Sabah	
	Pulau Nunuyan Laut, Sandakan, Sabah	
	Tanjung Kaitan, Kota Kinabalu, Sabah	
	Pulau Rusukan Besar, Labuan, Sabah	
Laurencia cf. majuscula (Harvey) Lucas	Teluk Juara, Pulau Tioman, Pahang	[6]
Laurencia nangii Masuda	Pulau Bai, Sandakan, Sabah	[5]
	Pantai Layang-Layangan, Labuan, Sabah	
	Pulau Gaya, Kota Kinabalu, Sabah	
	Pulau Sulug, Kota Kinabalu, Sabah	
	Pulau Tiga, Kuala Penyu, Kota Kinabalu, Sabah	
Laurencia pannosa Zanardini	Tangion Datu, Sarawak	[5]
Laurencia papillosa (C. Agardh) Greville, Setchell et Gardner	Pulau Kerengga Besar, Terengganu	[5]
	Pulau Redang, Terengganu	
	Pulau Manukan, Kota Kinabalu, Sabah	
	Pulau Sapangar, Kota Kinabalu, Sabah	
	Sarawak	
Laurencia parvipapillata Tseng	Pulau Tioman, Pahang	[5],[6]
Laurencia patentiramea (Montagne) Kützing	Pantai Kuala Abang, Terengganu	[9]
	Tanjung Jara, Terengganu	
	Pantai Kemasik, Terengganu	
	Teluk Kalong, Terengganu	
	Pantai Marina, Terengganu	
	Marine Park, Pulau Pinang, Terengganu	
	Pantai Universiti Malaysia Terengganu	
Laurencia perforata (Bory de Saint-Vincent) Montagne	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Laurencia similis Nam et Saito	Pulau Gaya, Kota Kinabalu, Sabah	[5]
	Pulau Sepangar, Kota Kinabalu, Sabah	
	Pulau Udar Kecil, Kota Kinabalu, Sabah	
Leveillea junggermanniodes (Herling & G. Martens) Harvey	Pulau Tioman, Pahang	[5],[6]
	Pulau Sibu, Johor	
Murrayellopsis dawsonii Post	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Neosiphonia apiculata (Hollenberg) Masuda et Kogame	Kampung Busong, Pulau Babi Besar, Johor	[5]
	Pulau Gaya, Kota Kinabalu, Sabah	
Neosiphonia flaccidissima (Hollenberg) M.S.Kim & I.K.Lee	Setiu Wetland, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
	Pulau Bidong Laut, Terengganu	
Neosiphonia savatieri (Hariot) M.S.Kim et I.K.Lee	Tanjung Batu Payong, Pulau Perhentian Kecil, Terengganu	[5]
	Teluk Pinang, Pulau Tinggi, Johor	
	Pulau Selingaan, Sandakan, Sabah	
Polysiphonia coacta Tseng	Pulau Redang, Terengganu	[5]
Polysiphonia decussata Hollenberg	Pulau Sibu, Johor	[5]
Polysiphonia fucoides (Hudson) Greville [Syn: *Polysiphonia nigrescens* (Hudson) Greville in W. Hooker]	Pulau Tioman, Pahang	[5],[6]
Polysiphonia scopulorum Harvey	Tanjung Guntong Laut, Pulau Perhentian Kecil, Terengganu	[5]
	Teluk Gadung, Pulau Perhentian Besar,Terengganu	
	Mak Sinpain, Pulau Redang, Terengganu	
	Pulau Tenggol, Terengganu	
Polysiphonia subtillisima Montagne	Pulau Redang, Terengganu, Terengganu	[5]
Polysiphonia violaceae Greville	Pulau Tioman, Pahang	[5],[6]
Tolypiocladia calodictyon (Harvey ex Kutzing) P. Silva	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Tolypiocladia glomerulata (C. Agardh) Schmitz	Pulau Kerengga Kecil, Pulau Redang, Terengganu	[5],[6]

	Teluk Salang, Pulau Tioman, Pahang	
	Pulau Tulai, Pulau Tioman, Pahang	
Division Phaeophyta	Kampung Mukut, Pulau Tioman, Pahang	
Order Ectocarpales		
Family Ectocarpaceae		
Feldmannia columellaris (Børgesen) Islam	Panai Bukit Keluang, Terengganu	[9]
	Pantai Bari kecik, Terengganu	
	Pulau Bidong Laut, Terengganu	
Feldmannia enhali Hamel	Pulau Tioman, Pahang	[5],[9]
Feldmannia indica (Sonder) Wolmsley & Bailey	Pulau Sibu, Johor	[5]
*Feldmannia irregularis (*Kützing) G.Hamel	Pantai Chendering, Terengganu	[9]
	Pantai Kemasik , Terengganu	
	Teluk Kalong, Terengganu	
	Pantai Bidong Laut, Terengganu	
Feldmannia simplex (Crouan & Crouan) Hamel [Syn.: *Ectocarpus cylindricus* Saunders]	Pulau Redang, Terengganu	[5]
Family Ralfsiaceae		
Neoralfsia expansa (J. Agardh) Lim et Kawai comb. Nov	Tanjung Balau, Johor	[7]
	Tanjung Lompat, Johor	
	Desaru, Johor	
Mesospora schmyidtii Weber Van Bosse	Tanjung Balau, Johor	[7]
	Tanjung Lompat, Johor	
	Desaru, Johor	
	Tanjung Sedili Kecil, Johor	
	Tanjung Belumbang, Johor	
Ralfsia expansa (J. Agardh) J. Agardh	Desaru, Johor	[10]
Order Sphacelariales		
Family Sphacelariaceae		
Sphacelaria caespitula Lyngbye	Sarawak	[5]
Sphacelaria novae-hollandiae Sonder	Pantai Bari kecik, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
Order Dictyotales		
Family Dictyoceae		
Dictyopteris deliculata Lamouroux	Kg. Ayer Batang, Pulau Tioman, Pahang	[5],[6]
	Kampung Mukut, Pulau Tioman, Pahang	
	Kampung Genting, Pulau Tioman, Pahang	
	Pulau Kerengga Besar, Pulau Redang, Terengganu	
Dictyopteris jamaicensis W.R.Taylor	Tanjung Jara, , Terengganu	[9]
Dictyopteris repens (Okamura) Børgesen	Pulau Bidong Laut, Terengganu	[9]
	Pulau Karah, Terengganu	
	Pulau Geluk, Terengganu	
	Marine Park, Pulau Pinang, Terengganu	
Dictyopteris woodwardia (R. Brown ex Turner) [Syn: *Haliseris woodwardia* (R. Brown ex Turner) C. Agradh]	Tangion Datu, Sarawak	[5]
Dictyota bartayresiana Lamouroux	Pulau Bidong Laut, Terengganu	[5],[9]
	Teluk Kalong, Terengganu	
Dictyota beccariana Zanardini	Tangion Datu, Sarawak	[5]
Dictyota cervicornis Kutzing [Syn: *Dictyota indica* Sonder ex Kutzing]	Pulau Bidong Laut, Terengganu	[5],[9]
Dictyota cervicornis Kutzing forma *spiralis* Taylor	Pulau Sibu, Johor	[5]
Dictyota cervicornis Kützing	Tanjung Jara, Terengganu	[5]
	Teluk Kalong, Terengganu	
Dictyota ceylanica Kützing	Pulau Bidong Laut, Terengganu	[9]
Dictyota ciliolata Kutzing	Pulau Kerengga Kecil, Pulau Redang Terengganu	[9],[11]
	Pantai Kemasik , Terengganu	
	Pulau Bidong Laut, Terengganu	
	Pulau Karah, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Pulau Rawa, Terengganu	
Dictyota crispata J.V.Lamouroux	Pantai Kuala Abang, Terengganu	[9]
	Tanjung Jara, Terengganu	
	Pantai Kemasik , Terengganu	
	Teluk Kalong, Terengganu	
Dictyota dentata Lamouroux	Pohon Batu Beach, Pulau Labuan, Sabah	[5]
	Kota Kinabalu Coastal Areas, Kota Kinabalu, Sabah	

Dictyota dichotoma (Hudson) Lamouroux	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Pulau Sibu, Johor	
	Tangion Datu, Sarawak	
	Pantai Bak-Bak, Kudat, Sabah	
Dictyota dichotoma var intricata	Pulau Bidong Laut, Terengganu	[9]
	Pulau Karah, Terengganu	
Dictyota divaricata Lamouroux	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Pulau Redang, Terengganu	
	Batu Buruk, Terengganu	
	Pulau Bidong Laut, Terengganu	
	Pulau Karah, Terengganu	
Dictyota friabilis Setchell	Pulau Redang, Terengganu	[5],[9]
Dictyota hauckiana Nizamuddin [Syn: *Dictyota atomaria* Hauck]	Pohon Batu Beach, Pulau Labuan, Sabah	[5]
	Membidai Beach, Pulau Labuan, Sabah	
	Tanjong Aru Beach,Pulau Labuan, Sabah	
	Victoria Off-Shore, Pulau Labuan, Sabah	
Dictyota jamaicensis Taylor	Pulau Sibu, Johor	[5]
Dictyota maxima Zanardini	Tangion Datu, Sarawak	[5]
Dictyota mertensii (Martius) Kützing	Tanjung Jara, Terengganu	[5]
Dictyota mertensii (Martius) Kutzing [Syn: *D. dentata* Lamouroux]	Pulau Sibu, Johor	[5]
	Pulau Sibu Tengah, Johor	
Dictyota submaritima Va Pham Hoang	Pulau Redang, Terengganu	[5]
*Lobophora variegata (*Lamouroux) Wolmsley ex Oliveira [Syn: *Pocockiella variegata* (Lamouroux) Papenfuss]	Teluk Salang, Pulau Tioman, Pahang	[5],[6],[11]
	Kampung Mukut, Pulau Tioman, Pahang	
	Pulau Rengis, Pulau Tioman, Pahang	
	Kampung Ayer Batang, Pulau Tioman, Pahang	
	Kampung Lalang, Pulau Tioman, Pahang	
	Island at Tanjung Paya, Pulau Tioman, Pahang	
	Kampung Genting, Pulau Tioman, Pahang	
	Salang Beach, Pulau Tioman, Pahang	
	Swallow Cave, Salang, Pulau Tioman, Pahang	
	Pantai Mersing, Johor	
	Pulau Sibu, Johor	
	Pulau Rawa, Terengganu	
	Pulau Perhentian, Terengganu	
	Pulau Redang, Terengganu	
	Tg. Genting, Pulau Perhentian Besar, Terengganu	
	Teluk Dalam, Pulau Perhentian Besar, Terengganu	
	Batu Mgong, Pulau Perhentian Kecil, Terengganu	
	Pulau Tiga, Kota Kinabalu, Sabah	
	Pantai Bak-Bak, Kudat, Sabah	
Lobophora nigrescens J.Agardh	Pantai Kuala Abang, Terengganu	[9]
	Tanjung Jara, Terengganu	
Padina antillarum (Kutzing) Piccone [Syn: *Padina tetrastromatica* Hauck]	Batu Mgong, Pulau Perhentian Kecil, Terengganu	[11]
	Kuala Besut Beach, Terengganu	
Padina australis Hauck	Teluk Salang, Pulau Tioman, Pahang	[5],[11]
	Kampung Lalang, Pahang	
	Setiu Wetland, Terengganu	
	Pulau Rawa, Terengganu	
	Pulau Sibu, Johor	
	Pulau Sibu Tengah, Johor	
Padina boergesenii Allender & Kraft	Pulau Sibu, Johor	[5]
Padina boryana Thivy [Syn: *P. commersonii* Bory de Saint-Vincent]	Pulau Tioman, Pahang	[5],[6]
	Pulau Bidong Laut, Terengganu	
	Tangion Datu, Sarawak	
	Layang-Layangan Beach, Pulau Labuan, Sabah	
	Tanjong Aru Beach, Pulau Labuan, Sabah	
	Gaya Bay, Kota Kinabalu, Sabah	
	Pantai Bak-Bak, Kudat, Sabah	
	Pengeraban Beach (Tanjong Kapor) , Sabah	
	Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	
Padina caulescens Thivy	Pulau Redang, Terengganu	[5]

Padina gymnospora (Kutzing) Sonder	Victoria Off-Shore,Pulau Labuan, Sabah Pantai Bak-Bak, Kudat, Sabah Pengeraban Beach (Tanjong Kapor), Sabah Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	[5]
Padina japonica Yamada	Pantai Bari, Setiu, Terengganu	[11]
Padina minor Yamada	Pulau Sibu, Johor Pulau Redang, Terengganu	[5]
Padina tetrastromatica Hauck	Pulau Tioman, Pahang	[5],[6]
Spatoglossum vietnamense Pham	Pantai Bak-Bak, Kudat, Sabah Pulau Tiga, Kota Kinabalu, Sabah	[5]
Order Scytosiphonales		
Family Scytosiphonaceae		
Colpomenia sinuosa (Mertens ex Roth) Derbes & Solier	Teluk Salang,Pulau Tioman, Pahang Kampung Mukut, Pulau Tioman Pahang Kampung Genting, Pulau Tioman Pahang Salang Wreck, Pulau Tioman, Pahang Salang Beach, Pulau Tioman, Pahang Pantai Bak-Bak, Kudat, Sabah Pulau Tiga, Kota Kinabalu, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Sapi, Kota Kinabalu, Sabah Gaya Bay, Kota Kinabalu, Sabah Layang-Layangan Beach, Pulau Labuan, Sabah Membidai Beach, Pulau Labuan, Sabah Tanjong Aru Beach,Pulau Labuan, Sabah Victoria Off-shore,Pulau Labuan, Sabah	[5],[6]
Hydroclathrus clathratus (C. Agardh) Howe [Syn: *Asperococcus clathratus* (C. Agardh) J. Agardh]	Teluk Salang,Pulau Tioman, Pahang Tangion Datu, Sarawak Pulau Tiga, Kota Kinabalu, Sabah Pantai Bak-Bak, Kudat, Sabah Pulau Sapi, Kota Kinabalu, Sabah Layang-Layangan Beach, Pulau Labuan, Sabah Pohon Batu Beach, Pulau Labuan, Sabah Membidai Beach, Pulau Labuan, Sabah Victoria Off-shore,Pulau Labuan, Sabah Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	[5],[6]
Rosenvingea fastigiata (Zanardini) Børgesen [Syn.: *Asperococcus fastigiatus* Zanardini]	Sarawak	[5]
Rosenvingea intricata (J. Agardh) Børgesen	Pulau Bidong Laut, Terengganu Pulau Karah, Terengganu Changar Hutang, Pulau Redang, Terengganu	[9]
Order Fucales		
Family Cystoseiraceae		
Cystoseira trinodis (Forsskal) C. Agardh	Pulau Sibu, Johor	[5]
Hormophysa cuneiformis (J. Gmelin) P. Silva	Pulau Tioman, Pahang De lagoon, Pulau Perhentian Kecil, Terengganu Pulau Sibu, Johor Pantai Bak-Bak, Kudat, Sabah Pulau Tiga, Kota Kinabalu, Sabah Pulau Gaya, Kota Kinabalu, Sabah	[5],[6],[11]
Hormophysa cuneiformis (J. Gmelin) P. Silva [Syn: *Cystoseira prolifera* J. Agardh]	Sarawak	[5]
Hormophysa cuneiformis (J. Gmelin) P. Silva [Syn: *Cystoseira triquetra* C. Agardh]	Pohon Batu Beach, Pulau Labuan, Sabah Suanganlada Beach, Pulau Labuan, Sabah Victoria Off-shore,Pulau Labuan, Sabah Kota Kinabalu Coastal Areas, Sabah Likas Bay, Kota Kinabalu, Sabah Pengeraban Beach (Tanjong Kapor), Kudat, Sabah	[5]
Family Sargassaceae		
Sargassum acutifolium Greville	Tanjung Datu, Sarawak	[5], [8]
Sargassum angustifolium C. Agardh	Tangion Datu, Sarawak	[5],[8]
Sargassum balingasayense Trono	Pulau Gaya, Kota Kinabalu, Sabah	[5],[8]
Sargassum binderi Sonder ex J. Agardh	Batu Chendering, Kuala Terengganu, Terengganu Pulau Tikus, Sandakan, Sabah	[5],[8]

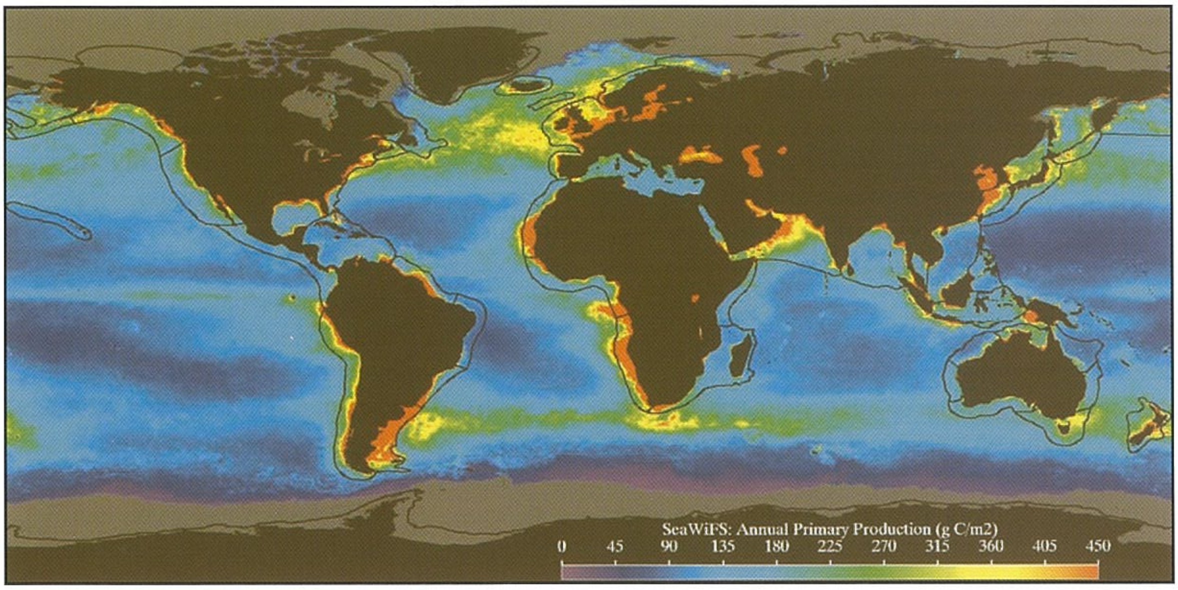

Figure 2. Global map of average primary productivity and the boundaries of the 64 Large Marine Ecosystems (LMEs) of the world, available at www.lme.noaa.gov. The annual productivity estimates are based on SeaWiFS satellite data collected between September 1998 and August 1999, and the model developed by M. Behrenfeld and P.G. Falkowski [18]. The colour-enhanced image provided by Rutgers University depicts primary productivity from a high of 450 gCm2yr-1 in red to less than 45 gCm2yr-1 in purple.

productivity supporting marine populations is higher than in the open ocean (Fig. 2). At present, 110 developing countries are engaged in the preparation and implementation of 16 GEF-LME projects totaling $1.8 billion in start-up funding [4].

THE 5 MODULES – SUITES OF TIME SERIES, LME CONDITION INDICATORS

A five-module indicator approach to assessment and management of LMEs has proven useful in ecosystem-based projects in the USA and elsewhere, using suites of indicators of LME productivity, fish and fisheries, pollution and ecosystem health, socioeconomics, and governance. The suites of LME indicators are used to measure the changing states of LMEs in relation to a driver-pressure-state-impact-response (DPSIR) system in support of adaptive management actions. The effort to better understand climate variability, to improve the long-term sustainability of marine goods and services, and to move in the direction of ecosystem-based ocean management applies to all 64 LMEs and linked watersheds. For example, climate warming of 1° in the North Sea LME can result in a reduction in primary productivity leading to a decline in fisheries biomass yield (Fig. 3).

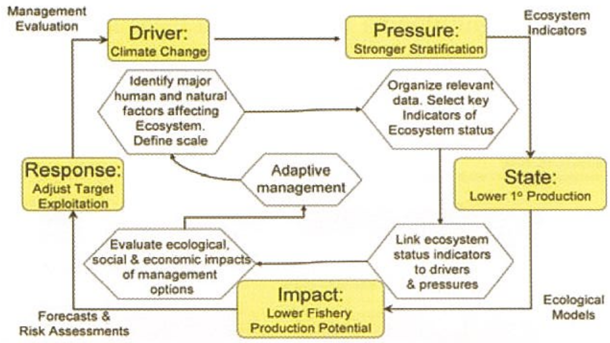

Figure 3. The Driver-Pressure-State-Impact-Response (DPSIR) model of indicators in relation to climate warming of the North Sea LME. Courtesy of Michael Fogarty, NMFS.

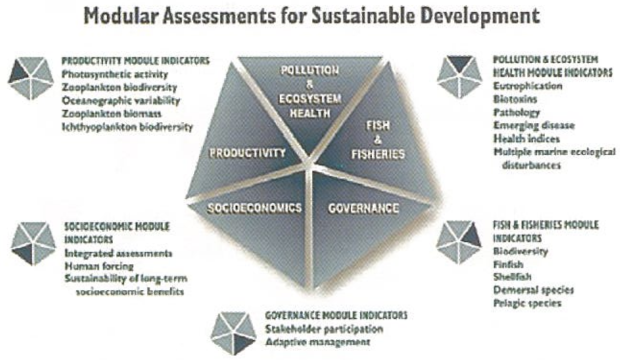

Figure 4. LME modules as suites of ecosystem indicators [5].

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Sargassum cervicorne Greville	Tanjung Lang, Pulau Redang, Terengganu	[5],[8]
Sargassum cinereum J. Agardh	Mersing, Johor Layang-Layangan Beach, Pulau Labuan, Sabah Lubok Termiang Beach, Pulau Labuan, Sabah Pohon Batu Beach, Pulau Labuan, Sabah Membidai Beach, Pulau Labuan, Sabah Suanganlada Beach, Pulau Labuan, Sabah Tanjong Aru Beach, Pulau Labuan, Sabah Victoria Off-Shore, Pulau Labuan, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Sulong, Kota Kinabalu, Sabah Sembulan Beach,Kota Kinabalu, Sabah Pantai Bak-Bak, Kudat, Sabah Pengeraban Beach (Tanjong Kapor), Kudat, Sabah Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	[5],[8]
Sargassum crassifolium J. Agardh [Syn: *Sargassum feldmanii* Pham]	Teluk Dalam, Pulau Tioman, Pahang Pulau Rawa, Johor Tanjung Gua Kawah, Pulau Redang, Terengganu	[5],[6],[8]
Sargassum cristaefolium C. Agardh	Pulau Tioman, Pahang	[5],[6],[8]
Sargassum duplicatum (J. Agardh) J. Agardh	Layang-Layangan Beach, Pulau Labuan, Sabah Suanganlada Beach, Pulau Labuan, Sabah Kota Kinabalu Coastal Areas, Kota Kinabalu, Sabah Likas Bay, Kota Kinabalu, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Sulong, Kota Kinabalu, Sabah Pantai Bak-Bak, Kudat, Sabah Pengeraban Beach (Tanjong Kapor), Kudat, Sabah Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	[5],[8]
Sargassum erumpens Tseng et Lu	Kampung Duku, Pulau Sibu, Johor	[5],[8]
Sargassum filipendula C. Agardh	Membidai Beach, Pulau Labuan, Sabah Kota Kinabalu Coastal Areas, Kota Kinabalu, Sabah Pulau Sulong, Kota Kinabalu, Sabah	[5]
Sargassum fluitans (Borgesen) Borgesen	Pulau Tioman, Pahang	[5],[6]
Sargassum granuliferum C. Agardh	Kampung Tanjung Balau, Pulau Tinggi, Terengganu Nunuyan Laut, Sandakan, Sabah Pulau Bai, Sandakan, Sabah	[5],[8]
Sargassum grevillei J. Agardh	Pulau Manukan, Kota Kinabalu, Sabah	[5],[8]
Sargassum heterocystum (kuetzing) Montagne	Teluk Kalong, Terengganu	[5],[8]
Sargassum hornschuchii C. Agardh	Sabah	[5],[8]
Sargassum ilicifolium (Turner) C. Agardh	Pulau Tioman, Pahang Tg. Pendaras, Sandakan, Sabah	[5],[6],[8]
Sargassum illicifolium (Turner) C. Agardh var *conduplicatum* Grunow	Pualau Tioman, Pahang Kuala Abang, Terengganu	[5],[8]
Sargassum laxifolium Tseng et Lu	Pulau Nunuyan Laut, Sandakan, Sabah	[5],[8]
Sargassum microcystum J. Agardh	Pulau Udar Kecil (Teluk Sapangar), Sabah	[5],[8]
Sargassum myriocystum J. Agardh	Pulau Bai, Sandakan, Sabah	[5],[8]
Sargassum oligocystum Montagne	Kukup, Johor Sg. Pulai, Johor Pulau Tetagan, Kota Kinabalu, Sabah Pulau Dinawan, , Kota Kinabalu, Sabah Creagh Reef, , Kota Kinabalu, Sabah	[5],[8]
Sargassum polycystum C. Agardh	Pulau Sibu, Johor Tanjung Jara, Kuala Terengganu, Terengganu Pulau Tetagan, Kota Kinabalu, Sabah Pulau Dinawan, Kota Kinabalu, Sabah Pulau Gaya,Kota Kinabalu, Sabah Pulau Papan, Labuan, Sabah	[5],[8]
Sargassum siliculosoides Tseng et Lu	Kg. Penaga, Pulau Babi Besar, Johor	[5],[8]
Sargassum siliquosum J. Agardh	Kukup, Johor	[5],[8]

	Pulau Gulisan, Sandakan, Sabah Batu Manikar, Labuan, Sabah Pantai Layang-Layangan, Labuan, Sabah Kota Kinabalu, Sabah Pulau Gaya, Sabah	
Sargassum tenerrimum J. Agardh	Layang-Layangan Beach, Pulau Labuan, Sabah Lubok Termiang Beach, Pulau Labuan, Sabah Pohon Batu Beach, Pulau Labuan, Sabah Membidai Beach, Pulau Labuan, Sabah Suanganlada Beach, Pulau Labuan, Sabah Tanjong Aru Beach, Pulau Labuan, Sabah Victoria Off-Shore, Pulau Labuan, Sabah Gaya Bay, Kota Kinabalu, Sabah Kota Kinabalu Coastal Areas, Kota Kinabalu, Sabah Likas Bay, Kota Kinabalu, Sabah Pulau Gaya, Kota Kinabalu, Sabah Sembulan Beach, Kota Kinabalu, Sabah Tanjung Aru Beach, Kota Kinabalu, Sabah Pantai Bak-Bak, Kudat, Sabah Pengeraban Beach (Tanjong Kapor), Kudat, Sabah Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	[5],[8]
Sargassum torvum J. Agardh	Pulau Tioman, Pahang	[6],[8]
Sargassum wightii Greville	Tanjung Kaitan, Kota Kinabalu, Sabah	[5],[8]
Turbinaria conoides (J. Agardh) Kutzing	Tanjung Keramat, Pulau Tioman, Pahang Pulau Sibu, Johor Pantai Bak-Bak, Kudat, Sabah Pulau Tiga, Kota Kinabalu, Sabah Gaya Bay, Kota Kinabalu, Sabah Pulau Gaya, Kota Kinabalu, Sabah Pulau Sulong, Kota Kinabalu, Sabah Pohon Batu Beach, Pulau Labuan, Sabah Suanganlada Beach, Pulau Labuan, Sabah Tiga Ruang, Pulau Perhentian Besar, Terengganu Flora Beach Resort, Pulau Perhentian Besar, Terengganu Batu Mgong, Pulau Perhentian Kecil, Terengganu Pasir Mas, Pulau Perhentian Kecil, Terengganu	[5],[6],[11]
Turbinaria deccurrens Bory de Saint-Vincent	Pulau Susu Dara, Terengganu Pulau Perhentian Kecil, Terengganu	[5]
Turbinaria ornata (Turner) J. Agardh	Kampung Mukut, Pulau Tioman, Pahang Teluk Juara, Pulau Tioman, Pahang Pulau Perhentian Kecil, Terengganu Pulau Redang, Terengganu Pulau Sibu, Johor	[5],[6]
Order Scytothamnales		
Family Scytothamnaceae		
Asteronema breviarticulatum (J. Agardh) Ouriques & Bouzon	Pantai Kemasik, Terengganu	[9]

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Isolation and screening of *Schizochytrium* microalga from Vietnamese coasts for polyunsaturated fatty acid production

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Abstract Twenty strains of *Schizochytrium* alga were successfully isolated from decomposed mangroves floating leaves in Vietnamese coasts such as Thai Binh, Thanh Hoa province (northern part of Vietnam) and Phu Quoc Island, Kien Giang province (southern part of Vietnam). They were screened for growth rate (determined by cell density, dry cell weight), total lipid content and fatty acids composition, especially docosahexaenoic (DHA, C22:6ω-3) and docosapentaenoic acids (DPA, C22:5ω-6) production. Three strains (*Schizochytrium* sp. PQ7, TB17, and TH16) which are representative of three sampling provinces were chosen based on their highest cell density, dry cell weight, total lipid content and fatty acids composition among the total isolated strains. Total lipid content reached 37.07, 30.44 and 35.75% of dry cell weight for PQ7, TH16, and TB17 strains, respectively after 5 days of cultivation. The main fatty acids in all the three strains were palmitic acid (ranging from 36.95 to 42.6% of total fatty acids) and DHA (ranging from 38.07 to 43.50% of total fatty acids). Both TH16 and TB17 strains possessed high DPA content (8.74 and 8.13% of total fatty acids, respectively). The results in this study indicate that *Schizochytrium* isolated from Vietnamese coasts is a potential source of polyunsaturated fatty acids which possess high value for pharmaceutical and agricultural purposes.

Keywords docosahexaenoic acid – docosapentaenoic acid – lipid – polyunsaturated fatty acids – *Schizochytrium* – marine microalgae

INTRODUCTION

Polyunsaturated fatty acids (PUFAs) are important components of cellular structures and functions in a wide variety of organisms [1]. Many studies have shown that the consumption of lower amount of ω-3 PUFAs enhance incidence of cardiovascular, cancer, diabetes, and neuropsychiatric diseases [2]. Among ω-3 PUFAs, DHA (docosahexaenoic acid, C22:6 ω-3) plays a key role in improving neural and retinal development in infants and lowering the incidence of certain cardiovascular diseases [3, 4]. However, humans lack enzymes needed to synthesize ω-3 PUFAs, so DHA cannot be synthesized and must be supplied through the diet [4]. Marine fish is the essential source of general PUFAs including DHA. Because of oxidative stability, the presence of undesirable fatty acids, typical fishy smell, unpleasant taste as well as the possibility of heavy metal contamination, fish oil is not an ideal source of PUFAs [5, 6]. Therefore, the finding of other alternative sources is very important to be carried out not only in Vietnam but also in the world.

Schizochytrium is a heterotrophic marine micro-algal genus belonging to Stramenopiles kingdom, Labyrinthulomycota phylum, Thraustochytriidae (thraustochytrid) family. These algae are spherical and unicellular. The ectoplasmic network forms a branched network of plasma membrane extensions, associated with an organelle termed sagenogenetosome at the periphery of the cell [7-9]. Currently, apart from *Crypthecodinium cohnii* and *Ulkenia, Schizochytrium* is considered as a potential source for commercial DHA production because of fast growth, high lipid and fatty acid content, especially DHA. Many studies have been carried out on the isolation, optimization conditions and DHA production of this microalga [2, 5].

Vietnam has a coastline of about 3200 km with the climate varying from subtropical in the northern to tropical in the southern part of the country. This climate type contributes to the diversity of marine organisms including marine microalgae such as *Labyrinthula* and *Schizochytrium* [10-15]. In this paper, we present some results of isolation and bio-characteristics of *Schizochytrium* strains from the northern coasts (including Thai Binh and Thanh Hoa provinces) and the southern part of Vietnam (Phu Quoc island, Kien Giang province). These results will contribute to the fundamental scientific research output in order to carry out future studies for their utilization in aquaculture and supplementary foods.

MATERIALS AND METHODS

Materials

This study made use of the samples which were the fallen mangrove leaves of *Rhizophora apiculata* Blume (black and brown colour) floating in the coastal area of Diem Dien, Thai Binh province (20^0 33' N, 106^0 33' E); Tinh Gia, Thanh Hoa province (19^0 26', 10^0 01' N, 105^0 46', 104^0 01' E); Phu Quoc Island, Kien Giang province (10^0 01'N, 104^0 01' E) from 2005-2007 (Fig. 1).

The basal medium GPYc – glucose (2 g/L), polypepton (1 g/L), yeast extract (0.5 g/L) in artificial seawater containing 50% salt [50% ASW, approximately 1.5% NaCl (Tropic Marine Aquarientechnik, Wartenberg, Germany)], chloramphenicol (50 mg/L), and agar (10 g/L) – was used for isolation of *Schizochytrium*.

After isolation, *Schizochytrium* was cultivated in M1 medium – glucose (30 g/L), yeast extract (10 g/L), ASW (17.5 g/L) – in 250 mL Erlenmayer flask. The cultures were shaken at 200 rpm at 28^{0}C for five days without light.

Three strains – PQ7, TH16 and TB17 – from the sampling places (Kien Giang, Thanh Hoa, Thai Binh provinces) having high growth rate, dry cell weight (DCW) and lipid content were selected for further studies.

Methods

Schizochytrium was isolated using the modified pine pollen baiting technique [16]. Floating-decomposed leaves collected in the coast were washed three times with sea water and cut into three square pieces of about 5 mm. The cut samples were then transferred into the test tube containing 5 mL sterilized 50% ASW added with small amounts of pine-pollen. The test tubes were incubated at 28^{0}C in the dark. After 24 hours of incubation, the pine pollens floating on the surface of the tubes were transferred by loop and streaked onto the GPYc medium plates. The plates were sealed with sealing film and incubated at 28^{0}C in the dark. *Schizochytrium* was easily observed around the pine pollens after several days of incubation. The *Schizochytrium* colonies were transferred to GPYc

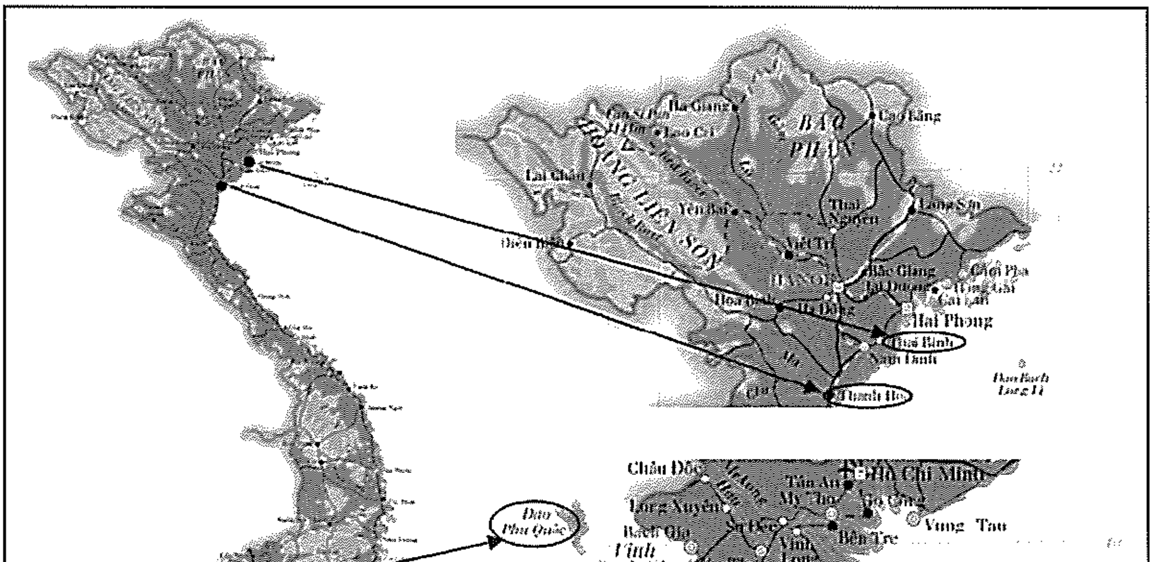

Figure 1. Map showing the sampling places of *Schizochytrium* sp.

media for several times to suppress the bacterial and fungal growth. Isolated strains were kept on GPY medium (without chloramphenicol) as monoxenic cultures.

As part of the morphological observation, the isolated strains were grown in liquid M1 medium at 28^{0}C, 200 rpm for five days. Cell suspension was diluted and observed with a BX51 light microscope from Japan.

Preservation of *Schizochytrium*, as well as microorganism or microalgae, was carried out by monthly sub-cultivation on agar plates. However, this technique has several disadvantages including being labour-intensive and risking the loss of genetic stability due to mutation and selection. In this study, we used glycerol for cryopreservation of isolated *Schizochytrium* strains. Glycerol as a cryoprotectant was added to the culture medium to obtain a final concentration of 15%. Then, this medium was sterilized. Square pieces of the cultivated agar medium (5 mm) containing *Schizochytrium* were cut off. These pieces were transferred to sterile polypropylene tube having 3 mL broth GPY medium containing 15% glycerol. These tubes were put into isopropanol solution at -80^{0}C for 2 hr. Then, the tubes were removed from this solution and kept at - 80^{0}C. After two months of cryopreservation, viability of strains was estimated.

The growth rate of *Schizochytrium* in broth medium was determined by cell density and dry cell weight (DCW). The cell density was counted using a Burker-Turk chamber. For DCW determination, 10 mL of cell suspension was centrifuged at 10,000 rpm for five minutes and the supernatant was discarded afterwards. Harvested biomass was then washed three times with distilled water, and then dried at 105^{0}C for three hours before weighing.

The total lipid content was extracted in chloroform:methanol (2:1, v/v) using the method described by Bligh and Dyer [17].

For the analysis of the composition and content of PUFAs, 10 mg fresh biomass was extracted with n-hexane. Then, 25 μL sodium methylate(CH_3ONa) solution in methanol (2 mol/L) was added and shaken for one minute. After adding 1 mL of distilled water, the mixture was shaken and centrifuged at 3000 rpm for one minute. The non-reacted phase below was discarded and added with 100 μL HCl. The mixture was separated by centrifugation at 3000 rpm for one minute. Then, the bottom layer was discarded afterwards. The upper solvent was dried over anhydrous Na_2SO_4 and separated by centrifugation at 3000 rpm for one minute. After methyl-esterification, the sample was applied to a gas chromatography HP-6890 (Hewlett-Packard, Palo Alto, CA) equipped with a Mass selective detector Agilent 5973. Separation was carried out on a 0.25 μm x 0.25 mm x 30 m fused silica capillary column (film 0.32μm) HP-5MS with helium as carrier gas at a flow rate of 3.5 mL/min. The column temperature was programmed at an initial temperature of 80^{0}C for 1 minute; raised to 150^{0}C at 4^{0}C/min; raised to 260^{0}C at 10^{0}C/min and maintained for 10 minutes. Library of mass spectrophotometer WILEY275.l and NIST98.L was carried out as described by Dang Diem Hong *et al.* [13].

RESULTS

Isolation of *Schizochytrium*

Twenty *Schizochytrium* strains were isolated successfully from 60 fallen mangrove leaves collected in Diem Dien (Thai Binh province), Tinh Gia (Thanh Hoa province) and Phu Quoc Island (Kien Giang province). Table 1 summarizes the results of the isolated strains. The colonies and cell morphology of three strains which were representative of the sampling places are illustrated in Figure 2.

Schizochytrium was found in all the sampling places with different salinity. This result concurs with other reports [5, 7, 18] that thraustochytrids including

Table 1. Sampling places, some characteristics and number of successfully isolated strains of *Schizochytrium*.

Sampling places	Designation of isolated strains	Salinity (%)	Number of leaves	Number of strains
Phu Quoc (Kien Giang province)	PQ6, PQ7	1.0-35.0	7	2
Tinh Gia (Thanh Hoa province)	TH 9; TH11; TH12; TH13; TH14; TH16; TH17; TH21; TH22; TH23	25.0	27	10
Diem Dien (Thai Binh province)	TB11; TB16; TB17; TB18; TB23; TB25; TB27; TB30	22.0	26	8

Schizochytrium genus possess a broad salinity tolerance. As all the *Schizochytrium* strains were isolated from decayed mangrove leaves, they may play an important role as decomposer microorganism in the marine food chain.

Cryopreservation of *Schizochytrium*

After two months of cryopreservation, the viability of all the strains isolated was not significantly different, ranging from 95 to 100% (detail data not shown here).

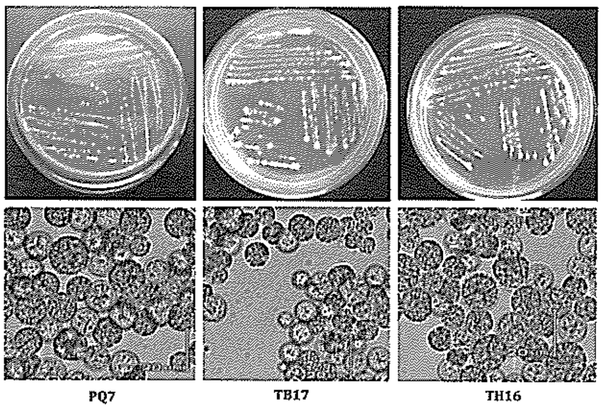

Figure 2. Colonies (A) and cell (B, x 400 magnification) morphology of *Schizochytrium* sp. strain PQ7, TB17 and TH16 on GPY agar and liquid M1 media after five days of cultivation.

Table 2. Cell density, dry cell weight and lipid content of *Schizochytrium* strains after five days of cultivation in liquid M1 medium.

Strain	Cell density ($x10^6$ cells/mL)	Dry cell weight (g/L)	Lipid content (% DCW)
PQ6	35.35	11.13	38.67
PQ7	36.85	17.99	37.07
TH9	40.57	10.87	19.08
TH11	46.00	13.60	21.78
TH12	48.75	11.10	14.23
TH13	48.00	13.25	22.61
TH14	39.15	12.25	20.86
TH16	30.63	16.60	30.44
TH17	35.0	13.14	16.48
TH21	39.25	11.49	16.67
TH22	15.23	8.17	13.12
TH23	18.92	8.98	15.26
TB11	20.48	10.19	17.56
TB16	18.29	9.81	25.83
TB17	39.31	18.60	35.75
TB18	15.95	8.91	23.43
TB23	17.17	10.04	13.85
TB25	14.32	8.93	13.98
TB27	15.34	8.95	12.54
TB30	14.96	9.96	12.42

Some characteristics of *Schizochytrium* strains

The growth rate, DCW, total lipid content and fatty acids content and composition of the strains after isolation and stable cultivation on solid agar medium are summarized in Table 2.

Fatty acid composition in isolated *Schizochytrium* strains

The fatty acid composition of three strains which were representative of the sampling places from different ecological regions in Vietnam is presented in Table 3.

The lipid content of PQ7 strain was the highest with 37.07% of DCW (Table 2), followed by TB17 (35.75% of DCW) and TH16 strains (30.44% of DCW). These strains produced high content of palmitic acid (C16:0) and DHA, accounting for 36.95-42.60% and 38.07-43.50% of total fatty acids, respectively. However, there were some differences in the profiles of the fatty acid in these strains. DPA (C22:5ω-6) was absent in PQ7 strain while TH16 and TB17 strains possessed high content of this fatty acid (8.74 and 8.13% of total fatty acid, respectively). In addition, the fatty acid profiles in TB17 and TH16 strains were simpler than PQ7.

DISCUSSION

Schizochytrium strains which were isolated from different ecological areas in Vietnam (Thai Binh, Thanh Hoa and Kien Giang provinces) possessed high growth rate, lipid content and diversity in fatty acid composition. The DHA content of all strains was more than 38.07 % of total fatty acid while the lipid content reached more than 30% dried cell weight. In comparison with potential DHA producers for industrial use, the lipid and fatty acid content of these wild strains was not so very high. However, many studies have shown that the composition of fatty acid could be changed by variation of culture conditions [2, 5, 14]. Hence, it is necessary to carry out further studies in order to establish optimum conditions in which potential strains can accumulate high lipid and PUFAs content such as EPA, DHA and DPA for the use as animal feed in aquaculture and functional food for human.

Six different PUFAs profiles have been reported in thraustochytrids [5, 7, 11] – (1) DHA; and DPA; (2) DHA, DPA, and EPA; (3) DHA and EPA; (4) DHA, DPA, EPA, and ARA; (5) DHA,

Table 3. Fatty acid composition of *Schizochytrium* sp. strain PQ7, TH16 and TB17 after five days of cultivation.

Order	Fatty acid	Scientific name	Common name	Fatty acids content (% total fatty acids)		
				PQ7	TH16	TB17
1	C14:0	Tetradecsnoic acid	Myristic	3.38	2.44	2.21
2	C15:0	Pentadecanoic acid	-	7.39	-	
3	C15:1(ω-5)	Dodecanoic acid	Lauric	-	3.18	2.85
4	C16:1 (ω-7)	9-Hexadecanoic acid	Palmitoleic	0.58	-	-
5	C16:0	Hexadecanoic acid	Palmitic	36.95	41.9	42.60
6	C17:0	Heptadecanoic acid	Magric	1.80	0.86	-
7	C18:1(ω-9)	Cis-9-Octadecanoic acid	Oleic	2.40	-	-
8	C18:2(ω-6)	9,12-Octadecadienoic acid	Linolelaidic	0.33	-	-
9	C18:0	Octadecanoic acid	Stearic	1.72	0.87	0.68
10	C20:4(ω-6)	5,8,11,14-Eicosatetraenoic acid	Arachidonic acid AA	0.46	-	-
11	C22:5ω-6	7,10,13,16,19-docosapentaenoic acid	DPA	-	8.74	8.13
12	C22:6(ω-3)	4,7,10,13,16,19-Docosahexaenoic acid	DHA	38.07	42.00	43.50
13		Others		6.82	0.01	0.03
		Total saturated fatty acid		51.24	46.07	45.49
		Total unsaturated fatty acid		41.84	53.92	54.48

DPA, EPA, ARA, and DTA; and (6) DHA/EPA/ARA. These fatty acids profiles were used for identification of thraustochytrid species [5]. Our results presented in this report will serve as fundamental data in order to utilize efficiently the *Schizochytrium* biomass for feed purposes in aquaculture and for production of nutrient food in Vietnam in the near future. In this regard, we have carried out initial experiments on using *Schizochytrium* biomass for enriching rotifer (*Brachionus plicatilis*), *Artemia* or direct feeding to animal such as Snout otter clam (*Lutraria rhyncheana*), oyster or *Bostrichthys siensis*. The results of this study will be reported in due course.

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REFERENCES

1. Morita E., Kumon Y., Nakahara T., Kagiwada S. and Noguchi T. (2006) Docosahexaenoic acid production and lipid-body formation in *Schizochytrium limacinum* SR21. *Marine Biotechnology* **8**: 319-327
2. Chi Z., Liu Y., Frear C. and Chen S. (2009) Study of a two-stage growth of DHA-producing marine algae *Schizochytrium limacinum* SR21 with shifting dissolved oxygen level. *Applied Microbiology and Biotechnology* **81**: 1141-1148.
3. Crawford M.A., Costeloe K., Ghebremeskel K., Phylactos A., Skirvin L. and Stacey F. (1997) Are deficits of arachidonic and docosahexaenoic acids responsible for the neural and vascular complications of preterm babies? *American Journal of Clinical Nutrition* **66**: 1032S–1041S.
4. Wu S.T., Yu S.T. and Lin L.P. (2005) Effect of culture conditions on docosahexaenoic acid production by *Schizochytrium* sp. S31. *Process Biochemistry* **40**: 3103-3108.
5. Raghukumar S. (2008) Thraustochytrid marine protists: production of PUFAs and other emerging technologies. *Marine Biotechnology* **10**: 631-640.
6. Ward O.P. and Singh A. (2005) Omega-3/6 fatty acids: alternative sources of production. *Process Biochemistry* **40**: 3627-3652.
7. Raghukumar S. (2002) Ecology of the marine protists, the Labyrinthulomycetes (Thraustochytrids and Labyrinthulids). *European Journal of Protistology* **38**: 127–145.
8. Cavalier-Smith T., Allosopp M.T.E.P. and Chao E.E.

(1994) Thraustochytrids are chromist, not fungi: 18S rRNA signatures of Heterokonta. *Philosophical Transaction of Royal Society London B Biological Science* **346**: 387-397.

9. Porter D (1990) Phylum Labyrinthulomycota. In Margulis L., Corliss J.O., Melkonian M. and Chapman D.J. (eds) *Handbook of Protoctista* pp. 388-398. Jones and Bartlett Publisher, Boston, USA.
10. Dang D.H. and Hoang M.H. (2004) Nutritional analysis of Vietnamese seaweeds for food and medicine. *BioFactors* **22**: 323-325.
11. Dang D.H. and Nakahara T. (2008) Comparison of Labyrinthulid strains L4 and L75 by fatty acid composition and characteristics. *Journal of Fisheries Science and Technology* **11** (3): 149-158.
12. Nguyen D.H., Hoang S.N., Hoang L.A. and Dang D.H. (2007) Some bio-characteristics of Labyrrinthula from the North coast of Viet Nam. *Journal of Biology* **28**(2): 67-77 (Vietnamese).
13. Dang D.H., Hoang M.H., Nguyen D.H., Hoang S.N., Hoang L.A., Ngo H.T. and Dinh K.C. (2007) Study on DHA biosynthesis from *Labyrinthula, Schizochytrium* – a new heterotrophic marine algae and their utilizations. *Journal of Science and Technology* **45**(1B): 144-154 (Vietnamese).
14. Dang D.H., Hoang M.H., Hoang S.N., D.H., L.A., Ngo H.T. and Dinh K.C. (2007) Biodiversity of heterotrophic microalgal *Labyrinthula* sp. and *Schizochytrium* sp. of Vietnam. *Proceedings of the 2nd National Scientific Conference on Ecology and Biological Resources. Hanoi, 26 October, 2007 (Sections of Biological Resources & Biodiversity and Conservation)* pp. 332-338.
15. Dang D.H., Hoang L.A. and Ngo .H.T. (2008) Successful isolation of *Schizochytrium* – a new heterotrophic marine microalga containing high polyunsaturated fatty acid – DHA from Phu Quoc Distric coast. *Journal of Biology* **30**(2): 50-55 (Vietnamese).
16. Yokochi T., Nakahara T., Higashihara T., Yamaoka M. and Kurane R. (2001) A new method for labyrinthulids using a bacterium, *Psychrobacter phenylpyruvicus. Marine Biotechnology* **3**: 68-73.
17. Bligh E.G. and Dyer W.J. (1959) A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology* **37**: 911-917.
18. Unagul P., Assantachai C., Phadungruenglui S., Pongsuteeragul T., Suphantharika M. and Verduyn C. (2006) Biomass and docosahexaenoic acid formation by *Schizochytrium mangrovei* Sk-02 at low salt concentrations. *Botanica Marina* **49**: 182-190.

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Toxicity of diatom *Pseudo-nitzschia* (Bacillariophyceae) analyzed using high performance liquid chromatography (HPLC)

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Abstract Amnesic shellfish poisoning (ASP) is a type of shellfish poisoning due to the consumption of shellfish mollusks contaminated with domoic acid (DA). The toxin was first reported in the chain-forming pennate diatom, *Pseudo-nitzschia* and subsequently in other diatom species. In this study, clonal cultures of *Pseudo-nitzschia* were established from plankton samples collected from Sarawak and Sabah coastal waters. Clonal cultures were maintained in SWII medium with the addition of silicate at 25°C, 30 PSU and under 12:12 light-dark photoperiod. Fifteen milliliters of late exponential phase cultures were collected for toxin analysis and subsamples were taken for cell count. Cellular toxin was extracted by boiling in medium at 100°C for 5 minutes. The extracts were filtered to remove cell debris before being analyzed with HPLC using standard domoic acid, isodomoic A and B as reference toxins. All the 32 strains of *Pseudo-nitzschia* sp. analyzed in this study showed the absence of peaks corresponding to the three ASP toxins. This implies that non-toxic strains of *Pseudo-nitzschia* sp. are common in Malaysian waters. Further study will be carried out to include more strains along the coastal waters of Borneo as well as selected sites with shellfish farming activities in Peninsula Malaysia.

Keywords domoic acid – amnesic shellfish poisoning (ASP) – *Pseudo-nitzschia* sp. – HPLC

INTRODUCTION

Amnesic shellfish poisoning (ASP) was first reported in Prince Edward Island, Canada in 1987 with density of the pennate diatom *Pseudo-nitzschia multiseries* (previously described as *Nitzschia pungens*) reaching up to 15×10^6 cells/L [1]. The shellfish poisoning caused three deaths and 105 cases of acute human intoxication after the consumption of contaminated blue mussels (*Mytilus edulis*) containing 900 µg/kg domoic acid [2]. A toxic bloom of *Pseudo-nitzschia pseudodelicatissima* was later reported at mussel cultivation areas in 1989 [3, 4].

In subsequent years, bloom event of *Pseudo-nitzschia australis* (7×10^5 cells/L) in Monterey Bay, California in 1991 was reported with mortality of 100 brown pelicans and cormorants [5]. In the same year, dozens of cases of human illness were reported along the Pacific coasts of Washington and Oregon, where razor clams, Dungeness crabs, blue mussels and oyster were found to contain up to 154 µg/g of domoic acid [6]. The victims exhibited gastrointestinal disorders after digestion of any contaminated shellfish. The symptoms include nausea, vomiting abdominal cramps, headache, diarrhea, and memory loss [6]. The loss of memory in patients intoxicated with ASP appeared to be similar to patients with Alzheimer's disease [7].

Domoic acid (DA) is the compound responsible for ASP (Fig. 1). It is a water soluble tricarboxylic amino acid with a molecular weight of 311.14, ($C_{15}H_{21}NO_6$). DA acts as an analogue of the neurotransmitter glutamate and is a potent glutamate receptor agonist [8] that has high binding affinity towards both kainate and AMPA (α-amino-3-hydroxy-5-methyl-4-isoxazol propionic acid) [9].

Currently, shellfish poisoning and plankton monitoring by the related authority in Malaysia is only focused mainly on the west coast of Sabah and selected locations in Peninsula Malaysia, and only paralytic shellfish poisoning and its related causative organisms are monitored. Little is known about the status of ASP in Malaysia though *Pseudo-nitzschia* has been commonly found in coastal waters. In this study, clonal cultures of *Pseudo-nitzschia* sp. were established from five locations along the coast of Sabah and Sarawak, Malaysia. Toxin analysis was carried out using high performance liquid chromatography (HPLC) with fluorescence detection method on all the strains in the collection.

MATERIALS AND METHODS

Phytoplankton samples

Plankton samples were collected from four sampling locations in Sarawak *viz.* Santubong, Muara Tebas, Semariang Batu, and Bintulu and one sampling location in Sabah i.e. Kota Kinabalu (Fig. 2). They were collected using a 20 μm vertical plankton net.

Pseudo-nitzschia cultures

Each single chain cells of *Pseudo-nitzschia* sp. found in the plankton net sieved samples was isolated using micropipette under an Olympus inverted light microscope (Olympus IX51). The single chain cells were inoculated into Nunc's multiwell plates with filtered seawater. SWII (Si) medium at 30 PSU was added to the wells after any observation of cell division. The culture strains established were then grown in the SWII (Si) medium (Iwasaki, 1979) in 250 mL Erlenmeyer flasks with cool fluorescence illumination at 25°C on a 12:12 hr light-dark photoperiod.

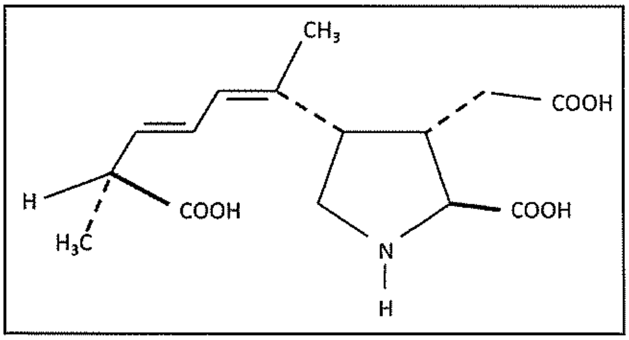


Figure 1. Structural formula of domoic acid (DA).

Toxin analysis

The 150 mL clonal cultures of *Pseudo-nitzschia* sp. were harvested during late exponential phase and boiled in 15 mL screwed centrifuge tubes for 5 minutes. Another 15 mL of cultures were kept in 15 mL screwed centrifuge tubes and cell densities were determined through microscopy count.

The HPLC analysis was performed by pre-column derivatization with 9-fluorenylmethylchlorofromate (FMOC) followed by reversed-phase HPLC with fluorescence detection. Subsample (1 mL) of each strain was filtered through a 0.22 μm disposable filter. Samples were treated using 50 μL borate buffer, 10 μL DHKA internal standard solution followed by 250 μL FMOC-CL reagent solution. The mixture was then extracted with 500 μL ethyl acetate. The aqueous bottom layer was transferred to a vial for HPLC analysis [10].

RESULTS AND DISCUSSION

Since the first incidence of ASP in Canada, DA-producing *Pseudo-nitzschia* species have been increasingly reported from other parts of the world. To date, 10 species of *Pseudo-nitzschia* are known to produce DA [11, 12]. They are *P. australis,*

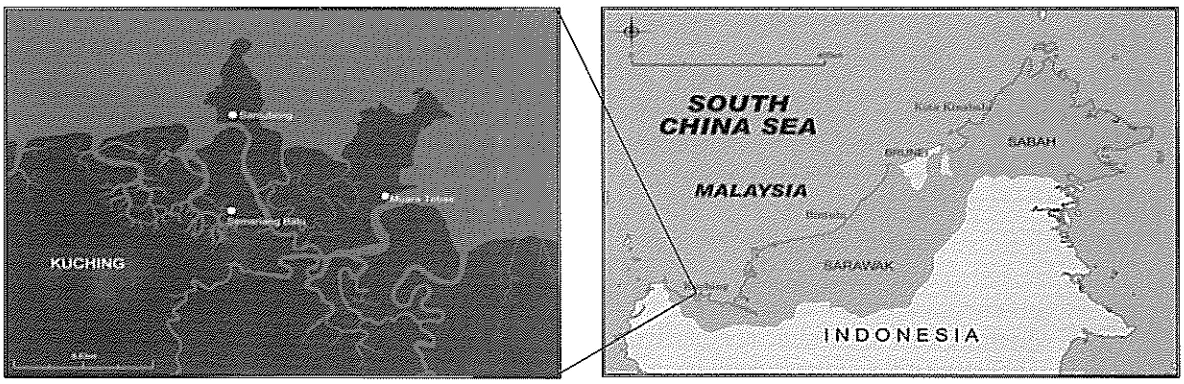


Figure 2. Sampling locations on the west coasts of Sabah and Sarawak.

Since 1984, NOAA's Large Marine Ecosystems (LME) Program has been engaged in the development of an ecosystem-based approach to support the assessment and management of marine resources and their environments. The approach uses modules of indicators and metrics to determine the changing states of LMEs and support actions for the recovery, sustainability, and management of marine resources and their habitats (Fig. 4).

Productivity Module Indicators

Primary productivity can be related to the carrying capacity of an ecosystem for supporting fish resources [6]. It has been reported that the maximum global level of primary productivity for supporting the average annual world catch of fisheries has been reached and that further large-scale increases in biomass yields from marine ecosystems are likely to be at trophic levels below fish in the marine food web [7]. Measurements of ecosystem productivity can be useful indicators of the growing problem of coastal eutrophication. In several LMEs, excessive nutrient loadings of coastal waters have been related to harmful algal blooms implicated in mass mortalities of living resources, emergence of pathogens (e.g., cholera, vibrios, red tides, and paralytic shellfish toxins), and explosive growth of non-indigenous species [8, 9].

The ecosystem parameters measured and used as indicators of changing conditions in the productivity module are zooplankton biodiversity and species composition, zooplankton biomass, water-column structure, photosynthetically active radiation, transparency, chlorophyll *a*, nitrite, nitrate, and primary production. Plankton can be measured over decadal time scales by deploying continuous plankton recorder systems monthly across ecosystems from commercial vessels of opportunity [10]. Advanced plankton recorders can be fitted with sensors for temperature, salinity, chlorophyll, nitrate, nitrite, petroleum, hydrocarbons, light, bioluminescence, and primary productivity, providing the means for in situ monitoring and for calibrating satellite-derived oceanographic data (Fig. 5). Properly calibrated satellite data can provide information on ecosystem conditions including physical state (i.e., surface temperature), nutrient characteristics, primary productivity, and phytoplankton species composition [11, 12]. Trends in chlorophyll and primary productivity from 1998-2006 are shown in Figures 6 through 9. Surface thermal fronts for the Southeast Asian LMEs are shown in Figure 10.

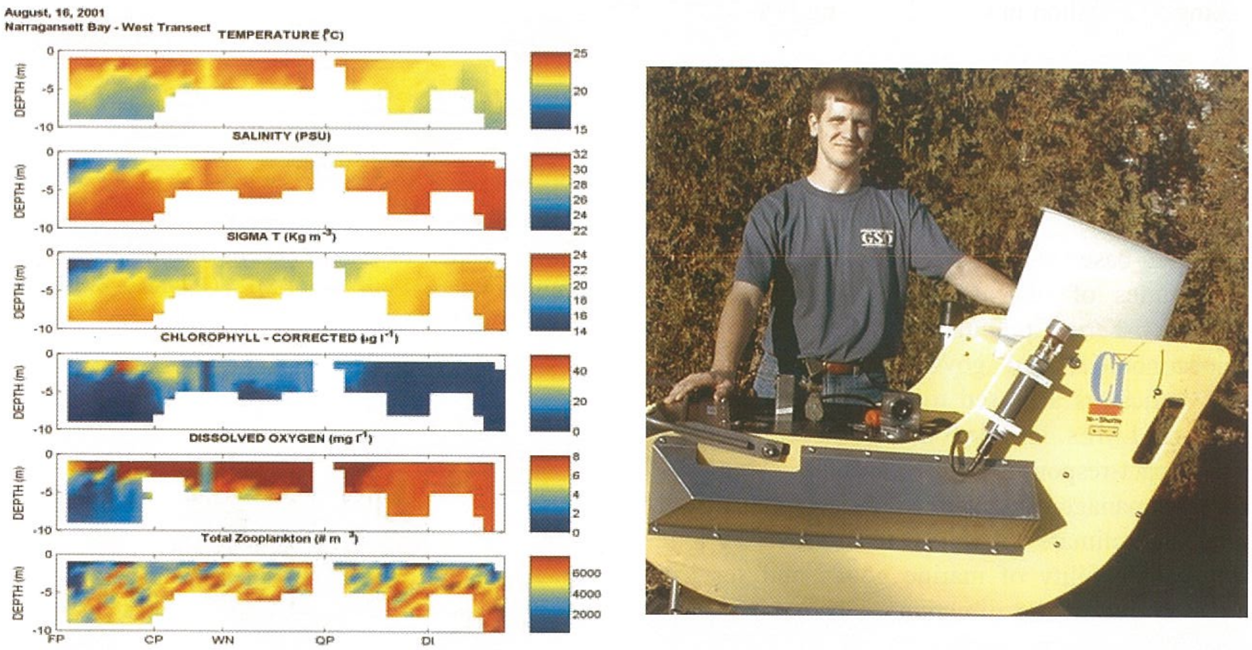
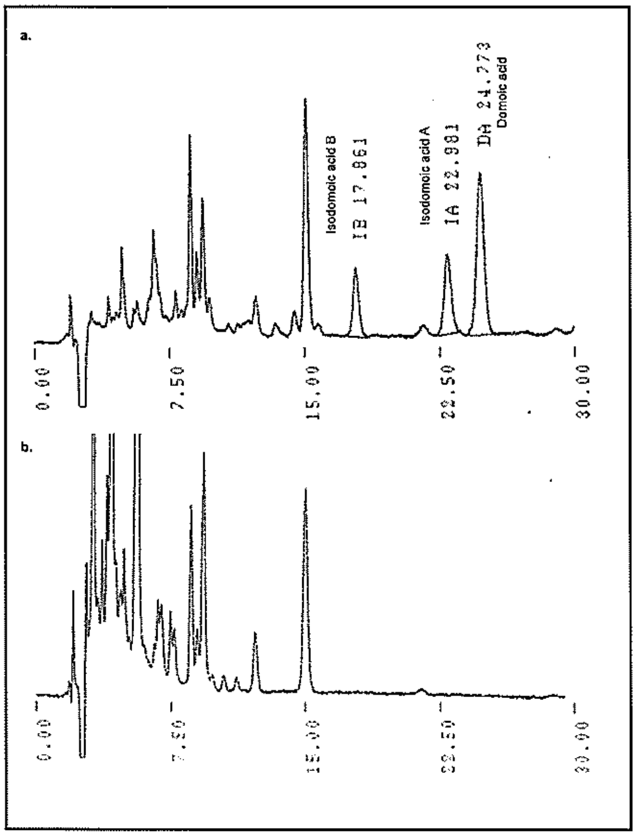


Figure 5. Northeast Fisheries Science Center Systematic measurements are made of LMEs by using towed bodies such as the Mariner Shuttle, depicted here. The electronically produced outputs from Mariner Shuttle sensors show vertical profiles of depth, temperature, salinity, chlorophyll, oxygen, and sigma T (density) based on undulating continuous sampling [12].

P. calliantha, P. cuspidate, P. delicatissima, P. fraudulenta, P. galaxiae, P. multiseries, P. multistriata, P. pungens, P. seriata and *P. turgidula* [11, 12]. Almost all toxigenic species are primarily coastal species, although some may be found up to 150 km offshore. Most of the DA-producing *Pseudo-nitzschia* species are cosmopolitan except *P. seriata*, which is a potentially toxic species that has caused toxic blooms restricted to cold water of the North Atlantic Ocean [13]. This implies that *Pseudo-nitzschia* diatoms involved in ASP are widely distributed in the world. However, there has been no documentation on ASP neither has any survey been conducted in Malaysian coastal waters.

In total, 37 strains of *Pseudo-nitzschia* sp. were cultured in June, July and August 2008. All of the cultures were extracted and analyzed for DA toxin. There were five strains from Santubong, eight from Semariang Batu, 16 from Muara Tebas, five from Bintulu and three from Kota Kinabalu. Among the strains, none of the extracts showed significant DA-like peak identical to the retention time of standard DA (Fig. 3).



Figur 3. HPLC chromatograms of domoic acid analysis. (a) Domoic acid (DA) standard, and (b) *Pseudo-nitzschia* with no significant DA-like peak.

In this study, some cultures with small cell dimension could grow up to 568,000 cells mL^{-1} while the density of large cells was only about 3000 cells mL^{-1}. Low cell density in some of these cultures used for toxin extraction might contribute to undetectable DA in the samples. Cell density of *Pseudo-nitzschia* sp. will be increased to 100,000 cells mL^{-1} in future toxin analysis.

According to Kotaki *et al.* 14] *P. multiseries* produced DA during late stationary phase. The production of domoic acid increased remarkably when it reached the late stationary phase. Similar characteristic was also reported in *P. autralis* [6]. Several studies have shown that DA production by *Pseudo-nitzchia* sp. can be very high when either phosphate or silicate level is low while nitrogen level is high 15]. Depletion of silicate or phosphate content in water enhances and triggers the production of DA in *P. multiseries* [16] and *P. pungens* [17]. Cell division is reduced during limiting amounts of phosphorus, causing deficiency of phospholipids and reduced cell integrity by slowing the membrane forming processes. Silicate limitation also inhibits *Pseudo-nitzschia* from the normal progression of the cell cycle. These two limitations enhance DA production [18].

According to Lundholm *et al.* [19], *P. seriata* and *P. multiseries* produce a small amount of DA during the exponential phase, and toxin production is enhanced during stationary phase. In contrast, *P. australis* begins to produce DA during the exponential phase and remains either stable or declines during the stationary phase under similar culture conditions [6]. The differential production of DA by the same diatom species under the same culture condition may be related to their genetic makeup.

CONCLUSION

Our preliminary study indicated that non-toxic *Pseudo-nitzschia* strains/species are more common in Borneo waters. However, further study is needed with more samples and cultures from more locations.

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REFERENCES

1. Bates S.S., Bird C.J., Defrietas A.S.W., Foxall R.A., Gilgan M., Hanic L.A., Johnson G.R., McCulloch A.W., Odense P., Pocklington R., Quilliam M.A., Sim P.G., Smith J.C., Subba R.D.V., Todd E.D.C., Walter J.A. and Wright J.L.C. (1989) Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from Eastern Prince Edward Island, Canada. *Canada Journal of Fisheries Aquatic Science* **46**: 1203-1215.
2. Subba R.D.V., Quilliam M.A. and Pocklington R. (1988) Domoic acid – a neurotoxic amino acid produced by the marine diatom *Nitzschia pungens* in culture. *Canada Journal of Fisheries Aquatic Science* **45**: 2076-2079.
3. Addison R.F. and Stewart J.E. (1989) Domoic acid and the Eastern Canadian molluscan shellfish industry. *Aquaculture* **77**: 263-269.
4. Todd E.C.D. (1989) Amnesic shellfish poisoning – a new seafood toxin syndrome. In Graneli E., Sundstrom B.G., Edler L. and Anderson D.M. (Eds) *Toxic marine phytoplankton* pp. 504-508. Elsevier, New York.
5. Work T.M., Beale A.M., Fritz L., Quilliam M.A., Silver M.W., Buck K.R. and Wright J.L. (1992) Domoic acid intoxication of brown pelicans and cormorants in Santa Cruz, California. In Smayda T. J. (Ed.) *Fifth International Conference on Toxic Phytoplankton* pp. xx-xx. Elsevier, New York.
6. Garrison D.L., Conrad S.M., Ellers P.P. and Waldron M. (1992) Confirmation of domoic acid production by *Pseudo-nitzschia australis* (Bacillariophyceae) cultures. *Journal of Phycology* **28**: 604-607.
7. McKhann G., Drachman D., Folstein N., Katzman R., Price D. and Stadlan E.M. (1984) Clinical diagnosis of Alzheimer's disease: report of the NINCDS-ADRDA work group under the auspices of Department of Health and Human Services Task Force on Alzheimer's disease. *Neurology* **34**: 939-944.
8. Frances M.V.D. (2000) Diversity of marine and freshwater toxins. In Luis M.B. (Ed.) *Seafood and freshwater toxins. Pharmacology, physiology and detection* pp. xx-xx. Marcel Dekker, New York.
9. Hampson D.R., Huang X., Wells J.W., Walter J.A. and Wright J.L.C. (1992) Interaction of domoic acid and several derivatives of kainic acid and AMPA binding sites in rat brain. *Europe Journal of Pharmacology* **218**: 1-8.
10. Pocklington R., Milley J.E., Bates S.S., Bird C.J., de Freitas A.S.W. and Quilliam M.A. (1990) Trace determination of domoic acid in seawater and phytoplankton by high-performance liquid chromatography of the flourenylmethoxycarbonyl (FMOC) derivative. *International Journal of Environmental Analytical Chemistry* **38**: 351-368.
11. Lundholm N., Moestrup Ø., Hasle G.R. and Hoef-Emden K. (2003) A study of the *Pseudo-nitzschia pseudodelicatissima/cuspidata* complex (Bacillariophyceae): What is *P. pseudodelicatissima*? *Journal of Phycology* **39**: 797-813.
12. Bill B., Lundholm N., Connell L., Baugh K.A. and Trainer V.L. (2005) Domoic acid in *Pseudo-nitzschia cuspidata* from Washington State coastal waters. *The 3rd Symposium on Harmful Algae in the US.* Monterey, CA. Oct, 2-7, 2005: 77 (abstract).
13. Hasle G.R. (2002) Are most of the domoic acid-producing species of the diatom genus Pseudo-nitzschia cosmopolites? *Harmful Algae* **1**: 137-146.
14. Kotaki Y., Koike K., Sato S., Ogata T., Fukuyo Y. and Kodama M. (1999) Confirmation of domoic acid production of *Pseudo-nitzschia multiseries* isolated from Ofunato Bay, Japan. *Toxicon* **37**: 677-682.
15. Bates S. S., de Freitas A.S.W., Milley J.E., Pocklington R., Quilliam M.A., Smith J.C. and Worms J. (1991) Controls on domoic acid production by the diatom *Nitzschia pungens* f. *multiseries* in culture: nutrients and irradiance. *Canada Journal of Fisheries Aquatic Science* **48**: 1136-1144.
16. Smith J.C., Cormier R., Worms J., Bird J.C., Quilliam M.A., Pocklington R., Angus R. and Hanic L. (1990) Toxic blooms of the domoic acid containing diatom *Nitzschia pungens* in the Cardian River, Prince Edward Island. In Graneli E., Sundsrotm B., Edler L. and Anderson D.M. (Eds) *Toxic Marine Phytoplankton* pp. 227-232. Elsevier, New York.
17. Bates S.S., Worms J. and Smith J.C. (1993) Effects of ammonium and nitrate on domoic acid production by *Nitzschia pungens* in batch cultures. *Canada Journal of Fisheries Aquatic Science* **50**: 1248-1254.
18. Brzezinski M.A., Olson R.J. and Chisholm S.W. (1990). Silicon availability and cell cycle progression in marine diatoms. *Marine Ecology Progress Series* **67**: 83-96.
19. Lundholm N., Skov J., Pocklington R. and Moestrup Ø. (1994). Domoic acid, the toxin amino acid responsible for amnesic shellfish poisoning, now in *Pseudo-nitzschia seriata* (Bacillariophyceae) in Europe. *Phycologia* **33**: 475-478.

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Macrofungi of Pulau Redang, Terengganu and Pulau Aur, Johor in the South China Sea

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Abstract The macrofungi of Pulau Redang, Terengganu and Pulau Aur, Johor were surveyed on 11-13 May 2008 and 18-21 August 2008, respectively. This is the first report of the macrofungi of Pulau Redang and Pulau Aur. A total of 74 specimens from 19 families were collected and recorded from Pulau Redang. Thirty-eight collections were identified to species level, while 22 specimens were identified to genus level with 14 specimens remaining to be determined. In comparison, 55 collections from 14 families were obtained from Pulau Aur. Of these collections, 13 were identified to species level and 27 identified to genus with 15 specimens not yet assigned to any family or genus. Collections from these islands were made from decaying plant materials (branches, trunks, roots, twigs, fruits) and from the soil.

Keywords macrofungi – Pulau Redang – Pulau Aur – Malaysia

INTRODUCTION

A comprehensive checklist of the literature on the macrofungi of Malaysia was compiled in 2008 by Lee *et al.* [1]. This checklist aids researchers in their search for relevant literature in the study of Malaysian macrofungi. From this checklist, it can be seen that research on Malaysian macrofungi began in the 1800s but the number of macrofungi recorded is still few. Up to date, more than 3000 species of fungi have been reported for Malaysia including 1473 basidiomycetes or macrofungi, 894 anamorphic fungi and 584 ascomycetes [2]. The number of fungi is expected to increase with further study and input from local mycologists. A book on Malaysian fungal diversity with information on fungi collected from Malaysia since the 19th century was published in 2007 [2]. Topics covered in the book include aspects of history, taxonomy, ecology, as well as applied mycology. In the chapter on boletes, Halling *et al.* [3] stated that the true number of bolete diversity in Malaysia is not known for certain but estimated that the number of species could reach 300. Up to now only 18 genera of the Boletaceae from the 31 genera recorded worldwide are known to occur in Malaysia. In the same volume, Hattori *et al.* [4] expected more than 300 species of polypores to occur in Malaysia with some of them being important plant pathogens in Malaysian forests. Another contributor, Tan *et al.* [5] reporting on members of the genus *Marasmius*, recognize approximately 50 species in Peninsular Malaysia of which one third are new to science. Sumaiyah *et al.* [6] who described the distribution of *Lentinus* species in Malaysia listed about 20 species with two species being new records and expect that many more species await discovery. It is therefore evident that much more research needs to be conducted on Malaysian fungal diversity as many families have yet to be studied and new discoveries continue to be made even in those groups that have been well studied, such as the polypores, boletes and *Lentinus*.

Pulau Redang, Terengganu and Pulau Aur, Johor are among some of the well-known holiday islands surrounded by pristine blue seawater off the east coast of Peninsular Malaysia in the South China Sea. Apart from being tourist destinations, these two islands which are located in two separate marine parks are also important sites for turtle conservation. The vegetation on the two islands appears to be different. Dipterocarp forest is dominant on Pulau Redang, while secondary forest is more dominant on Pulau Aur with Dipterocarp forest located only in the hilly centre of the island.

Surveys of the macrofungi of both islands were conducted during two expeditions organized by the

University of Malaya in 2008. The main objectives of the expeditions were to study the biogeography of flora and fauna in Malaysia and to update the checklist of species for Malaysia. Our surveys were conducted as part of a larger study of the biodiversity of macrofungi of Peninsular Malaysia under the Forest Research Institute Malaysia (FRIM) project, "Survey, Inventory and Documentation of the Flora and Fauna Biological Diversity of Malaysia". In this paper the results of a survey of the macrofungi of Pulau Redang and Pulau Aur are reported. This data will contribute to a better understanding of the macrofungal diversity of Malaysia as these are the first fungal collections made from these two islands.

MATERIALS AND METHODS

The macrofungi surveys were conducted in conjunction with the University of Malaya expeditions to Pulau Redang, Terengganu and Pulau Aur, Johor in May and August 2008, respectively. Collections of macrofungi were made around the Coral Redang chalets, the Berjaya Spa track, and Laguna track in Pulau Redang from 11 to 13 May 2008 and Kampung Berhala and Pantai Pasir Teluran in Pulau Aur (Fig. 1) from 18 to 21 August 2008. Macrofungi were collected from decaying plant materials and soil from both islands. Samples were photographed in the field, kept in wax paper bags and brought back to the chalet area for description

Figure 1. Map of Peninsular Malaysia showing the collection sites – Pulau Redang, Terengganu (top right) and Pulau Aur, Johor (bottom right).

of macroscopic characters. Spore prints were also made from the fresh specimens. The specimens were then dried at 45 °C in a ventilated portable dryer overnight. Dried specimens were packed and transported back to the Mycology and Pathology Laboratory at FRIM, Kepong for further microscopic analysis such as measurement of spore size, shape and ornamentation, basidia and cystidia for identification of the specimens. The specimens are stored in the Mycology Herbarium FRIM, Kepong.

RESULTS AND DISCUSSION

A total of 74 specimens from 19 families were collected and documented from Pulau Redang, whereas 55 collections from 14 families were recorded from Pulau Aur (Table 1). From Pulau Redang, the collections consisted of 28 Polyporaceae, 7 Fomitopsidaceae, 3 Ganodermataceae, 2 each for Agaricaceae, Sclerodermataceae, Boletaceae, Cortinariaceae, Physalacriaceae and Inocybaceae, and 1 each for Coniophoraceae, Dacrymycetaceae, Entolomataceae, Gomphaceae, Hymenochaetaceae, Marasmiaceae, Meripilaceae, Meruliaceae, Sarcosomataceae, and Stereaceae with 14 specimens remaining to be determined. Thirty-eight collections were identified to species level, while 22 specimens were identified to genus level.

From Pulau Aur, the 55 collections included 13 Polyporaceae, 8 Agaricaceae, 6 Xylariaceae, 2 Marasmiaceae and Physalacriaceae, and 1 each for Auriculariaceae, Entolomataceae, Hericiaceae, Lyophyllaceae, Meruliaceae, Thelephoraceae, Schizophyllaceae, Sclerodermataceae and Sarcoscyphaceae, with 15 specimens not yet assigned to any family or genus. Of these collections, 13 were identified to species level and 27 identified to genus. Many collections have yet to be identified as there are few suitable keys and monographs for the identification of tropical fungi.

During the surveys, immature and old or rotting specimens were not collected as these would not be suitable and/or inadequate for identification purposes. The fungi collected here do not represent the actual number of fungal species on the islands as regular collections need to be made over a period of at least 10 years to obtain a more accurate representation of the macromycota. Here we do not attempt to compare the macromycota from these two islands as it is misleading to do so based on just one

Table 1. Number of collections of macrofungi from Pulau Redang, Terengganu and Pulau Aur, Johor.

Fungus	Pulau Redang	Pulau Aur	Substrate
ASCOMYCOTA			
Order Pezizales			
Family Sarcoscyphaceae			
Cookeina sulcipes (Berk.) Kuntze	-	1	on rotted wood
Family Sarcosomataceae			
Galiella sp.	1	-	on soil
Order Xylariales			
Family Xylariaceae			
Xylaria spp.	-	6	on soil and rotted wood
BASIDIOMYCOTA			
Order Agaricales			
Family Agaricaceae			
Agaricus sp.	-	2	on soil
Coprinus sp.	-	5	on soil
Cyathus striatus (Huds.) Willd.	-	1	on rotted wood
Lepiota sp.	1	-	on soil
Leucocoprinus fragilissimus (Berk. & M.A. Curtis) Pat.	1	-	on soil
Family Cortinariaceae			
Gymnopilus sp.	2	-	on decayed trunk
Family Entolomataceae			
Entoloma sp.	1	-	on soil
Clitopilus sp.	-	1	on soil
Family Inocybaceae			
Inocybe sp.	2	-	on soil
Family Lyophyllaceae			
Termitomyces sp.	-	1	on soil
Family Marasmiaceae			
Anthracophyllum sp.	1	-	on decayed branch
Marasmiellus sp.	-	1	on twig
Marasmius sp.	-	1	on branch
Family Schizophyllaceae			
Schizophyllum commune Fr.	-	1	on decayed branch
Family Physalacriaceae			
Mucidula sp.	2	2	on decayed trunk
Order Auriculariales			
Family Auriculariaceae			
Auricularia sp.	-	1	on decayed trunk
Order Boletales			
Family Boletaceae			
Austroboletus longipes (Massee) Wolfe	1	-	on soil
Tylopilus sp.	1	-	on soil
Family Coniophoraceae			
Gyrodontium versicolor (Berk. & Broome) Maas Geest.	1	-	on decayed trunk
Family Sclerodermataceae			
Scleroderma sinnamariense Mont.	1	-	on soil
Scleroderma sp.	1	1	on soil
Order Dacrymycetales			
Family Dacrymycetaceae			
Dacrymyces sp.	1	-	on decayed trunk

Order Gomphales			
Family Gomphaceae			
Gloeocantharellus sp.	1	-	on decayed branch
Order Hymenochaetales			
Family Hymenochaetaceae			
Phellinus sp.	1	-	on trunk
Order Polyporales			
Family Fomitopsidaceae			
Fomitopsis feei (Fr.) Kreisel	2	-	on decayed trunk
Daedalea sp.	1	-	on decayed trunk
Daedalea pseudodochmia (Corner) T. Hatt.	1	-	on decayed trunk
Fomitopsis dochmia (Berk. & Broome) Ryvarden	3	-	on decayed trunk
Family Ganodermataceae			
Ganoderma lucidum complex	1	-	on decayed trunk
Amauroderma rugosum (Blume & T. Nees) Torrend	2	-	on soil
Family Meripilaceae			
Rigidoporus sp.	1	-	on decayed trunk
Family Meruliaceae			
Cymatoderma sp.	-	1	on branch
Climacodon sp.	1	-	on root
Family Polyporaceae			
Coriolopsis badia (Berk.) Murrill	-	1	on decayed branch
Coriolopsis sp.	-	1	on decayed branch
Earliella scabrosa (Pers.) Gilb. & Ryvarden	-	2	on decayed trunk
Hexagonia cf. *tenuis*	5	2	on decayed branch
Lentinus connatus Berk in Hook	3	1	on decayed branch
Lentinus polychrous Lev.	1	0	on decayed branch
Lentinus sajor-caju (Fr.)Fr	2	0	on decayed branch
Lentinus sp.	0	2	on decayed branch
Microporus vernicipes (Berk.) Kuntze	-	1	on decayed branch
Microporus xanthopus (Fr.) Kuntze	3	-	on decayed trunk
Nigroporus vinosus (Berk.) Murrill	2	-	on decayed trunk
Perenniporia sp.	1	-	on decayed trunk
Polyporus sp.	2	1	on decayed wood
Polyporus cf. *tenuis*	1	-	on decayed wood
Pycnoporus sanguineus (L.) Murrill	1	1	on decayed trunk
Trametes modesta (Kunze ex Fr.) Ryvarden	1	-	on decayed trunk
Trametes cf. *modesta*	1	-	on decayed trunk
Trametes elegans (Spreng.) Fr.	1	1	on decayed trunk
Trametes lactinea (Berk.) Sacc.	2	-	on decayed trunk
Trametes menziesii (Berk.) Ryvarden	1	-	on decayed trunk
Trichaptum cf. *sprucei*	1	-	on decayed trunk
Order Russulales			
Family Hericiaceae			
Hericium cf. *ramosum*	-	1	on decayed trunk
Family Stereaceae			
Stereum sp.	1	-	on decayed branch
Order Theleporales			
Family Thelephoraceae			
Thelephora sp.	-	1	on soil
Unknown specimens	10	12	on decaying plant materials
Unknown specimens	4	3	on soil
Total specimens	74	55	

visit. Moreover the two islands were visited during different months and seasons of the year.

Wood inhabiting species of the order Polyporales were dominant on both islands. More than 76% of the collections from these islands were made from decaying plant materials (branches, trunks, roots, twigs, fruits). The fruiting bodies of polypore fungi are mostly tough and woody to flexible. It has been suggested that the polypores are species-rich in Malaysia [4]. Among the collections from Pulau Redang, members of the Polyporaceae were the most numerous (Table 1). A similar trend was obtained at Pulau Aur. *Pycnoporus sanguineus* and *Earliella scabrosa* which are common species in tropical countries [7,8] were also found in this study; the former on both islands while the latter on Pulau Aur only. Members of the family Fomitopsidaceae made up the second largest collection with seven specimens collected from Pulau Redang. Less than three collections from other families of the Polyporales, e.g. Ganodermataceae, Meruliaceae, Meripilaceae were obtained from both islands.

Approximately 24% of the macrofungi collections from Pulau Redang were found growing on soil and this was also quite similar for Pulau Aur with about 22%. Most of the agarics in the present study were found growing from the soil but a few were also found on rotten wood. Members of putative ectomycorrhizal genera such as *Gloeocantharellus, Inocybe, Tylopilus* and *Scleroderma* were also found on Pulau Redang. These fungi were found growing in the dipterocarp forest in close proximity with timber trees. Since ectomycorrhizal fungi occur in this forest we can also expect other common putative ectomycorrhizal fungi such as *Amanita* spp., *Lactarius* spp., and *Russula* spp. to be present. However, they were not found on this visit probably due to differences in fruiting season.

A total of eight families from the order Agaricales were found from Pulau Redang and Pulau Aur. These fungi are generally fleshy and/or delicate, and have gills on the underside of the cap. *Leucocoprinus fragilissimus* from Pulau Redang is a very delicate fungus and deteriorates very quickly once collected. Thus, this fungus needs to be handled carefully and described immediately after collecting. Members of the family Agaricaceae were the second largest collections made from Pulau Aur. Eight specimens from three genera were obtained from Pulau Aur, namely, *Agaricus*, *Coprinus* and *Cyathus*, while only two genera were found from Pulau Redang, namely, *Lepiota* and *Leucocoprinus*. The identification of these specimens is still on-going.

Pycnoporus sanguineus, Mucidula sp., *Agaricus* sp., *Lentinus connatus, Hexagonia* cf. *tenuis, Polyporus* sp. and *Scleroderma* sp. were found on both islands. Many macrofungi collected on both islands were single specimens and most of them were only found at one location.

Seven collections of the Ascomycota from the Xylariales were obtained from Pulau Aur but only one from Pulau Redang. On Pulau Aur three specimens of *Xylaria* sp. were found growing from the soil and another three were attached to decaying wood. The *Xylaria* specimens could not be identified to species level as they were immature. The other species of ascomycete collected from Pulau Aur was *Cookeina sulcipes* which was found growing on rotted wood. The only ascomycete collected from Pulau Redang, namely, *Galiella* sp. was found growing on a decayed branch. This species could be a new species for Malaysia as the fruiting body colour and microscopic features such as spore size, shape and ornamentation did not match the species described in keys for species from Japan, China and Indonesia (Java) [9].

Several factors may affect the number of collections of macrofungi encountered at different locations. For example, the frequency of sampling, sampling time and number of sampling sites could account for differences in the abundance, occurrence and higher number of fungi at certain locations [8, 10]. In the present study, it is premature to make any prediction or conclusion about the macrofungal diversity on the two islands since they were visited only once and at different times of the year.

The best time to collect mushrooms in the tropical forest is at the beginning of the wet season after a prolonged dry spell [11-13]. However, since we did not have access to climatic data, in particular rainfall data before the expeditions, we did not know whether we conducted the macrofungal survey at the best time for fungal fructification. Often small mushrooms are overlooked and it is difficult to collect macrofungi in the best condition due to their ephemeral nature [14]. Further sampling should be carried out on a regular basis and at different times of the year at the same location for at least 5 to 10 years to get a clear picture of the diversity of macrofungi at that location.

In summary, as far as we are aware, this is the first time macrofungi were collected from Pulau

Redang and Pulau Aur and we now have some idea of the macrofungi diversity on these islands. However, the list of fungi reported here does not represent the overall macrofungal diversity of the two islands as one collection is insufficient to give a clear picture of the mycota of the islands. We believe that many more macrofungi remain to be discovered on these two islands.

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REFERENCES

1. Lee S.S., Horak E., Alias S.A., Thi B.K., Nazura Z., Jones E.B.G. and Nawawi A. (2008) *Checklist of literature on Malaysian macrofungi*. Online literature at: http://www.frim.gov.my/chm/Publications2.html.
2. Jones E.B.G. (2007) Introduction to Malaysian fungal diversity. In Jones E.B.G., Hyde K.D. and Vikineswary S. (eds) *Malaysian Fungal Diversity* pp. 1-24. Mushroom Research Centre, University of Malaya and Ministry of Natural Resources and Environment, Kuala Lumpur.
3. Halling R.E., Chan H.T. and Lee S.S. (2007) Basidiomycota: Boletaceae. In Jones E.B.G., Hyde K.D. and Vikineswary S. (eds) *Malaysian Fungal Diversity* pp. 41-53. Mushroom Research Centre, University of Malaya and Ministry of Natural Resources and Environment, Kuala Lumpur.
4. Hattori T., Noraswati M.N.R. and Salmiah U. (2007) Basidiomycota: Diversity of Malaysian polypores. In Jones E.B.G., Hyde K.D. and Vikineswary S. (eds) *Malaysian Fungal Diversity* pp. 55-68. Mushroom Research Centre, University of Malaya and Ministry of Natural Resources and Environment, Kuala Lumpur.
5. Tan Y.S., Dejardin D.E., Vikineswary S. and Noorlidah A. (2007) Basidiomycota: The genus *Marasmius* in Peninsular Malaysia. In Jones E.B.G., Hyde K.D. and Vikineswary S. (eds) *Malaysian Fungal Diversity* pp. 69-81. Mushroom Research Centre, University of Malaya and Ministry of Natural Resources and Environment, Kuala Lumpur.
6. Sumaiyah A., Noorlidah A., Vikineswary S. and Grand E. (2007) Basidiomycota: Distribution and new records of *Lentinus*. In Jones E.B.G., Hyde K.D. and Vikineswary S. (eds) *Malaysian Fungal Diversity* pp. 83-93. Mushroom Research Centre, University of Malaya and Ministry of Natural Resources and Environment, Kuala Lumpur.
7. Ryvarden L. and Johansen I. (1980) *A Preliminary Polypore Flora of East Africa*. Fungiflora, Oslo.
8. Salmiah U. and Jones E.B.G. (2001) Occurrence of wood inhabiting fungi in forest of Peninsular Malaysia. *Journal of Tropical Forest Science* **13**: 237-245.
9. Bi Z.S., Zheng G.Y., Li T.H. and Wang Y.Z. (1993) *The macrofungus flora of China's Guangdong Province, Hong Kong*. The Chinese University Press, Hong Kong.
10. Noorlidah A., Vikineswary S., Yusoff M. and Desjardin D.E. (2005) Higher fungi of northeast Langkawi. *Malaysian Journal of Science* **24**: 95-102.
11. Corner E.J.H. (1935) The seasonal fruiting of agarics in Malaya. *Gardens' Bulletin, Straits Settlements* **9**: 79-88.
12. Corner E.J.H. (1988) Higher fungi. In Gathorne-Hardy G. Earl of Cranbrook (ed.) *Key Environments: Malaysia* pp. 88-101. IUCN, Pergamon Press, Oxford, UK.
13. Lee S.S., Watling R. and Noraini Sikin Y. (2002) Ectomycorrhizal basidiomata fruiting in lowland rain forests of Peninsular Malaysia. *Bois et Forêts des Tropiques* **274**: 34-43.
14. Lee S.S. and Chang Y.S. (2003) Macrofungal diversity: the poor state of knowledge in Malaysia. In Shimura J. (ed.) *Global Taxonomy Initiative in Asia* No. 175: 212-216. Research Report from the National Institute for Environmental Studies, Japan.

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Shallow coastal waters of Pahang, Peninsular Malaysia as fish nursery grounds

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Abstract This paper reports on the fishes of the coastal shallow waters of the state of Pahang on the east coast of Peninsular Malaysia. Sampling were conducted from Tanjung Geliga to the mouth of the Pahang River (northern coastal waters) and from the Pahang River mouth to Sg. Endau and Acheh Island (southern waters). The water depth ranged from 4 to 13 metres and the sampling gear utilized was the otter trawl. 171 taxa of fish were sampled from the shallow coastal waters with the Leiognathidae most represented, either in terms of abundance and species richness. Species richness (Margaleff's D) for fish ranged from 4.09 to 7.75 while the heterogeneity index (Shanon-Weiner, H') ranged from 2.0 to 3.19. These values are much lower when compared to other coastal habitats. A large proportion of the fish species sampled are juveniles suggesting that the shallow coastal waters of Pahang function as nursery grounds for fish. This is supported by the size classes of the fish sampled.

Keywords fish – nursery ground – coastal waters – trawl – Pahang

INTRODUCTION

Coastal habitats like mangroves, seagrasses and coral reefs are well known for their function as nursery, feeding and breeding grounds for a large variety of marine organisms [1-13]. These habitats are spatial as well as temporal sites for exchange of nutrients and energy between the biotic and the abiotic components of coastal ecosystems. In areas where habitat heterogeneity is high, coastal organisms like fish tend to migrate between habitats and become nutrient links. Mangrove roots, leaves of seagrasses and corals increase structural heterogeneity and function as refugia for coastal organisms which may either be migrants or residents.

Structural heterogeneity of habitats of the coastal waters on the west coast of Peninsular Malaysia is much higher as compared to the east of the peninsula. This difference is mainly due to the presence of larger areas of coastal and riverine mangroves on the west coast as compared to the riverine limited mangroves on the east coast [14]. The shallow coastal waters of the east coast, especially Pahang appear structurally to be homogeneous with the seabed mainly being composed of mud and sand, or mud, and in some instances interspersed with minor rocky outcrops. Notwithstanding this, the coastal waters of Pahang are rich in macrobenthos [15, 16] comprising mainly polychaetes followed by crustacea. This study attempts to show that the shallow coastal waters of Pahang in spite of their lower structural heterogeneity function as nursery grounds for fish.

MATERIALS AND METHODS

Trawling area

This study was conducted from June 2000 to July 2000 and June 2005 to August 2005 within the shallow coastal waters of the state of Pahang, covering a distance of approximately 88 nautical miles (nm) (163 kilometres) from Tanjung (Tg.) Geliga in the north to the islands bordering Sg. (River) Endau in the south (Fig. 1). The trawling areas were divided into North Pahang (Tg. Geliga and Sg. Pahang) and South Pahang (between Sg. Pahang and the islands south of Endau River – P. Lalang, P. Tengah, Pulau Acheh).

Trawling activity

Fishes were sampled using an otter trawl with a cod end mesh size of 23 mm and a head rope length between 46 m to 52 m. In total, 30 trawls were conducted and the trawling areas and specific trawling sites are given in Table 1. The trawling time ranged from 15 to 20 minutes, with an average trawling time of 15 minutes. The water depth at the trawling sites ranged between 4 to 13 m while the distance from shore ranged between 0.6 to 3.5 nm. The data presented were pooled from both the North Pahang and South Pahang trawl samples.

Figure 1. General trawling area of the shallow coastal waters of Pahang, Peninsular Malaysia.

Fish identification and measurements

All fish samples were stored in ice and later enumerated in the laboratory. The following main texts were used for species identification: Carpenter and Niem (1998) [17], De Bruin *et al.* (1994) [18], Fishcher and Whitehead (1974) [19], Mohsin and Ambak (1996) [20] and Munro (1955) [21]. The abundance and standard length (cm) of all fishes were recorded.

Measurement of Species Diversity

The following diversity indices with the usual notations were computed for fish and invertebrates sampled: Margalef's species richness (D) = (s-1)/$\log_e$ N; Shannon-Weiner diversity index H' = $-\Sigma\, p_i \log_e p_i$; Maximum diversity (H' max) = $\log_e$ s; and Pielou's equitability or evenness, J = H'/H'max.

RESULTS

General description of physical and chemical parameters of trawling areas

The seabed structure at the trawling sites included sand, sand-mud and mud substratum. Interspersed within the area were also rocky outcrops and islands. The surface water temperature at 1 m depth ranged between 28.5°C to 30.2°C while the bottom temperature ranged between 29.5°C to 30°C. Surface

Table 1. The general and specific trawling sites (N = 30) in the Pahang shallow coastal waters.

General trawling area	North Pahang coastal waters (N=15)	South Pahang coastal waters (N=15)
Tg. Geliga - Kg. Pak Siah	Tg. Geliga - Tg. Batu Pak Mok	Kuala Sg. Pahang - Tg. Agas
Tg. Cerating - Kg. Gebeng	Kg. Cendur - Kg. Pak Siah	Tg Agas - Sg. Miang
Kg. Sg Karang – Beserah	Tg. Cerating - Kg. Baharu	Sg. Miang - Kuala Sg. Miang
Tg. Pelindung Tengah &	Kg. Baharu - Kg. Gebeng	Sg. Nibong - Sg. Tering
Tg. Tembeling	Kg. Sg. Karang - Beserah	Sg. Tering - Kuala Sg. Bebar
Sg. Kuantan	Tg. Cempedak	Kuala Sg Bebar - Kuala Merchong
Tg. Tembeling - Sg. Pahang	Sg. Kuantan	Kuala Merchong - Kuala Rompin (North)
Kuala Pahang	Kg. Kempadang	Kuala Merchong - Kuala Rompin (South)
Kuala Sg. Pahang –	Kg. Sg. Dua	Kuala Rompin - Kuala Pontian
Kuala Sg. Bebar	Kg. Sepat	Sg. Endau - Duchong Laut
Kuala Sg. Bebar –	Sg. Penur	Duchong Laut - Kuala Pontian
Kuala Rompin	Kg. Hijrah - Ceruk Paluh	Sg. Endau - P. Lalang
Kuala Rompin - Sg. Endau	Ceruk Paluh - Tg. Selangor	P. Lalang - P. Tengah
Sg. Endau –	Pasir Putih	P.Tengah - P. Acheh
P. Acheh /P.Kaban	Sg. Pahang (mouth)	P. Acheh & P. Tengah

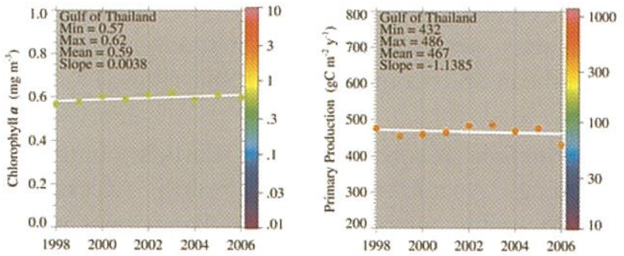

Figure 6. Southeast Asian LMEs, trends in chlorophyll-*a* (left) and primary productivity (right), 1998-2006 for the Gulf of Thailand. Values are color coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde.

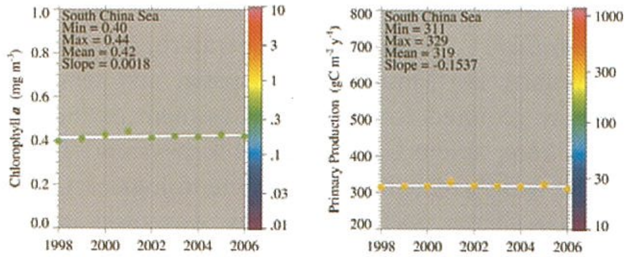

Figure 7. Southeast Asian LMEs, trends in chlorophyll-*a* (left) and primary productivity (right), 1998-2006 for the South China Sea LME. Values are color coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde.

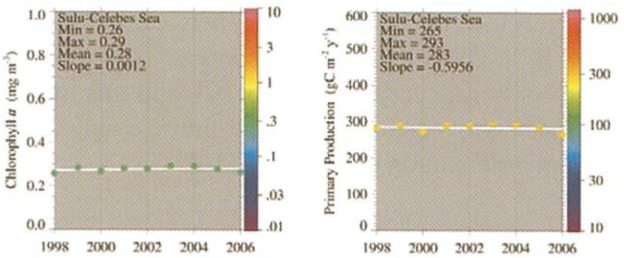

Figure 8. Southeast Asian LMEs, trends in chlorophyll-*a* (left) and primary productivity (right), 1998-2006 for the Sulu-Celebes Sea LME. Values are color coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde.

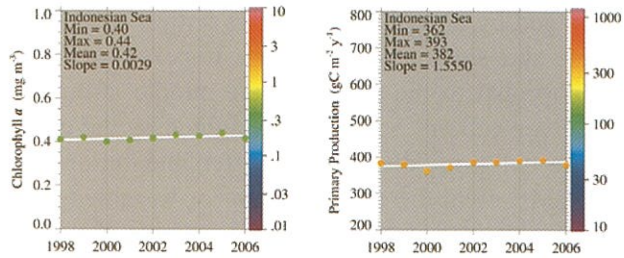

Figure 9. Southeast Asian LMEs, trends in chlorophyll-*a* (left) and primary productivity (right), 1998-2006 for the Indonesian Sea LMEs. Values are color coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde.

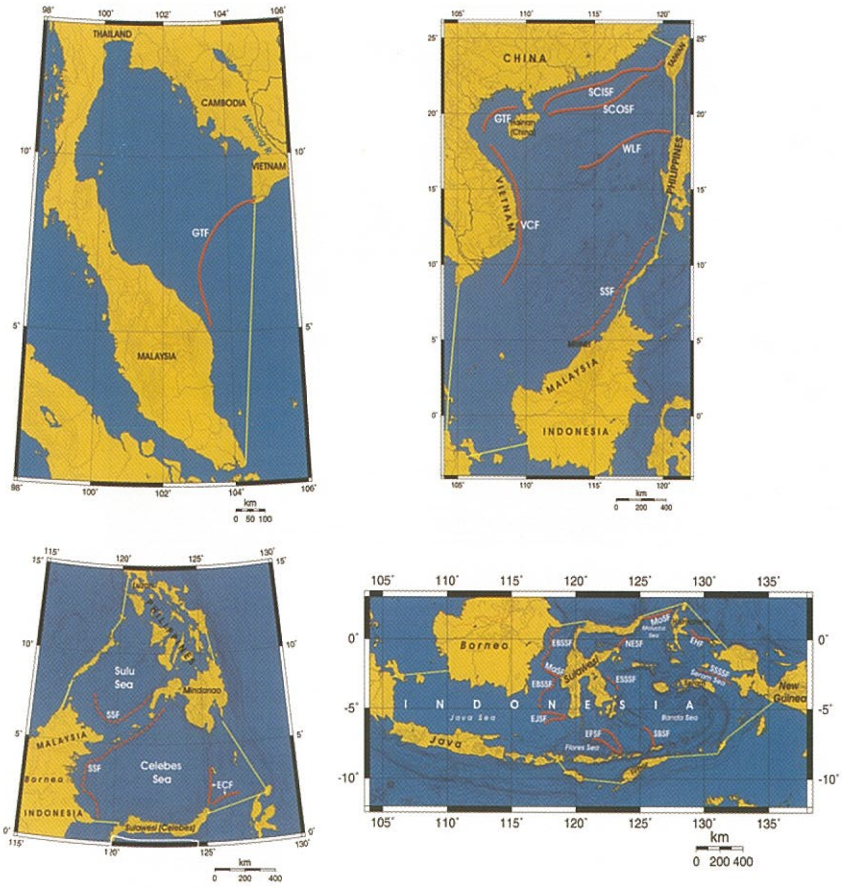

Figure 10. Fronts of the **Gulf of Thailand** LME (upper left) GTF, Gulf of Thailand Front. Yellow line, LME boundary. Fronts of the **South China Sea** LME (upper right). Gulf of Tonkin Front; SCISF, South China Inner Shelf Front; SCOSF, South China Outer Shelf Front; SSF, Shelf-Slope Front (the most probable location); VCF, Vietnam Coastal Front; WLF, West Luzon Front. Yellow line, LME boundary. Fronts of the **Sulu-Celebes Sea** LME (lower left). ECF, East Celebes fronts; SSF, Shelf-Slope Front (most probable location); Yellow line, LME boundary. Fronts of the **Indonesian Sea** LME. EBSSF, East Borneo Shelf-Slope Front; EFSF, East Flores Sea fronts; EHF, East Halmahera Front; EJSF, East Java Sea fronts; ESSSF , East Sulawesi Shelf-Slope Front; MaSF, Makassar Strait Front; MoSF, Molucca Sea Front; NESF, Northeast Sulawesi Front; SBSF, South Banda Sea Front; SSSSF, Seram Sea Shelf-Slope Front. Dashed lines show most probable locations of shelf-slope fronts. Yellow line, LME boundary. After Belkin et al. [13] and Cornillon (2003).

salinity ranged from 28.0 to 33.5 parts per thousand (ppt) while bottom salinity ranged between 29.0 to 33.8 ppt. The rivers that empty into the Pahang coastal waters are Sg. Cherating, Sg. Ular, Sg. Balok, Sg. Kuantan, Sg. Pahang, Sg. Miang, Sg. Api-Api, Sg. Nibong, Sg. Tering, Sg. Bebar, Sg. Rompin, Sg. Pontian and Sg. Endau. The larger rivers however, are Sg. Kuantan, Sg. Pahang and Sg. Endau. Most of these rivers are lined with mangroves.

Community analysis

A total of 171 taxa of fish and 61 taxa of invertebrates were recorded from the shallow coastal waters of Pahang, of which 122 fish and 30 invertebrate taxa from 54 families, and 107 fish and 31 invertebrate taxa from 46 families were sampled from the north and south Pahang coastal waters respectively. The dominant fish families were Apogonidae, Ariidae, Bothidae, Carangidae, Haemulidae, Leiognathidae, Mullidae, Nemipteridae, Plotosidae and Synodontidae with the Leiognathidae most represented. The dominant invertebrate families were Holothuroidea, Loligonidae, Portunidae and Sepiidae. Higher fish taxa numbers were recorded from Tg. Tembeling to Sg. Pahang, Kuala Pahang, Kuala Sg. Pahang to Sg. Bebar, Kuala Rompin to Sg. Endau, and Sg. Endau to the islands (Fig. 2). The highest fish taxa numbers were between Sg. Endau to the islands (59) while for invertebrates it was between Sg. Pahang and Sg. Bebar (22).

Higher Margalef's D and Shanon-Weiner's, H' for fish were recorded from Tg. Geliga to Kg .Pak Siah,

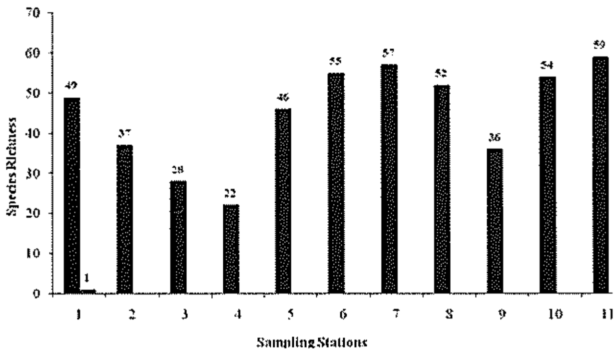

Figure 2. Fish taxa numbers sampled from shallow coastal waters of Pahang. 1, Tg Geliga – Kg Pak Siah; 2, Tg Cerating – Kg Kebing; 3, Kg Sg Karang – Beserah; 4, Tg Pelindung Tengah and Tg Tembeling; 5, Sg Kuantan; 6, Tg Tembeling – Sg Pahang; 7, Kuala Pahang; 8, Kuala Sg Pahang – Kuala Sg Bebar; 9, Kuala Sg Bebar – Kuala Rompin; 10, Kuala Rompin – Sg Endau; 11, Sg Endau – P. Acheh.

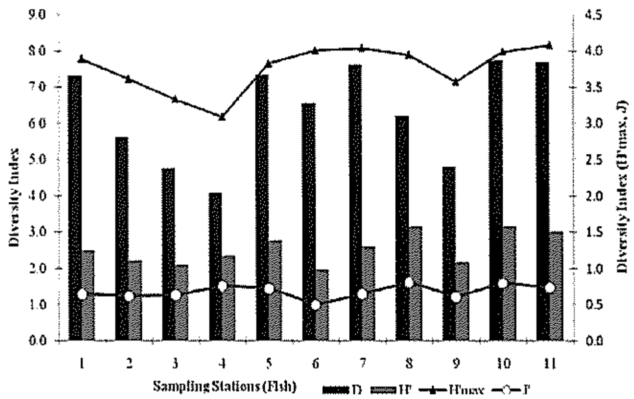

Figure 3. Diversity indices of fish sampled from shallow coastal waters of Pahang. 1, Tg Geliga – Kg Pak Siah; 2, Tg Cerating – Kg Kebing; 3, Kg Sg Karang – Beserah; 4, Tg Pelindung Tengah and Tg Tembeling; 5, Sg Kuantan; 6, Tg Tembeling – Sg Pahang; 7, Kuala Pahang; 8, Kuala Sg Pahang – Kuala Sg Bebar; 9, Kuala Sg Bebar – Kuala Rompin; 10, Kuala Rompin – Sg Endau; 11, Sg Endau – P. Acheh.

Table 2. Diversity indices and species richness of fish and invertebrates sampled from shallow coastal waters of Pahang. D = Margalef's species richness; H' = Shannon-Weiner diversity index; J = Pielou's equitability or evenness.

	Fish species diversity				
Sampling area	D	H'	H'max	J'	Fish taxa
North Pahang					
Tg. Geliga - Kg. Pak Siah	7.32	2.52	3.89	0.65	49
Tg. Cerating - Kg. Gebeng	5.63	2.23	3.61	0.62	37
Kg. Sg Karang - Beserah	4.76	2.11	3.33	0.63	28
Tg. Pelindung Tengah & Tg. Tembeling	4.09	2.35	3.09	0.76	22
Sg. Kuantan	7.35	2.78	3.83	0.73	46
Tg. Tembeling - Sg. Pahang	6.56	2.00	4.01	0.50	55
Kuala Pahang	7.62	2.62	4.04	0.65	57
South Pahang					
Kuala Sg. Pahang - Kuala Sg. Bebar	6.23	3.18	3.95	0.81	52
Kuala Sg. Bebar - Kuala Rompin	4.82	2.18	3.58	0.61	36
Kuala Rompin - Sg. Endau	7.75	3.19	3.99	0.80	54
Sg. Endau - P. Acheh	7.70	3.03	4.08	0.74	59

Sg. Kuantan to Kuala Sg. Bebar and Kuala Rompin to the southern islands (Fig. 3, Table 2) (D ranged from 4.09-7.75 while H' ranged from 2.0-3.19). The eveness index, J for the northern Pahang coastal waters ranged from 0.5-0.76 and 0.61-0.81 in the southern coastal waters (Table 2).

Size distribution of fish

A majority of the fish taxa sampled from the shallow coastal waters were mainly juveniles or sub-adults as shown by the ratio (%) of their mid-length to their maximum attainable length (Table 3, Fig. 4). The data presented here are based on the 30 most abundant fishes sampled. Fish lengths were generally below 50% of their maximum length except for *Grammathobothus polyopthalmus, Sardinella gibbosa, Stolephorus indicus,* Leiognathidae (*L. daura, L. elongatus, L. leuciscus, Gazza minuta,* and *Leiognathus* sp.) and *Saurida tumbil.* This suggests that these fishes may be sub-adults since none of their lengths approached the maximum attainable size (Table 3). Juvenile fish are also an integral part of the community of the shallow coastal waters. This is shown for the commercially exploited fishes like *Arius thallasinus,, Lutjanus lutjanus, L. malabaricus, Scolopsis taeniopterus,* and *Pomadasys maculatus* where their percentage mid-length size to their maximum attainable size is low amounting only to 9%, 28%, 10%, 28% and 17% respectively (Table 3).

DISCUSSION

Fish species richness (range, D = 4.09-7.7) and the diversity index (range, H' = 2.0-3.19) of the Pahang coastal waters from the current study are comparatively lower as compared to other coastal habitats like Matang, Sg. Dinding, Lekir, Sg. Johor, Sg. Pulai and Klang (Table 4). The common factor contributing to the larger diversity from the above places is the habitat structure which is mainly mangroves, coastal mudflats or estuaries. Mangroves however, are not the only factor responsible for high fish diversity or species richness because conjoint habitats like seagrass beds do play important roles in increasing habitat heterogeneity, and this was apparent at Sg. Pulai [7]. Vegetation type (mangroves,

Table 3. Mid length and maximum attainable size of 30 abundant fish taxa sampled from Pahang shallow coastal water. MaxS – maximum attainable size [17, 20, 21].

Fish taxa	N	Range (cm)	Mid Length (cm)	MaxS (cm)
Alepes djedaba	178	10.2 - 12	11.1	30
Apogon quadrifasciatus	160	2 - 7.5	4.75	12
Arius thalassinus	21	11 - 15.7	15.7	180
Atule mate	11	11.2 - 15	13.1	30
Carangoides armatus	22	7 - 11.5	9.3	30
Chirocentrus dorab	12	20 - 55.5	37.8	100
Dussumieria acuta	47	9.1 - 12.5	10.8	22
Gazza minuta	24	6.7 - 10	8.35	14
Grammatobothus polyophthalmus	78	4.8 - 18	11.4	20
Leiognathus brevisrostris	30	6.7 - 10.3	8.5	13.5
Leiognathus daura	58	7.7 - 11	9.4	14
Leiognathus elongatus	402	3.5 - 10.9	7.2	12
Leiognathus leuciscus	758	4 - 9.2	6.6	12
Leiognathus splendens	3675	2.3 - 8.9	5.6	14
Lutjanus lutjanus	64	7.6 - 9.4	8.5	30
Lutjanus malabricus	17	8.3 - 11.5	9.9	100
Nemipterus furcosus	125	5.7 - 12.7	9.2	23
Pomadasys maculatus	18	6.8 - 10.2	8.5	50
Pseudotriacanthus strigilifer	22	7.2 - 15.5	11.3	25
Sardinella gibbosa	27	8.7 - 12.5	10.6	17
Saurida tumbil	140	6.5 - 22.4	14.4	40
Scolopsis taeniopterus	53	4 - 8.5	6.2	22
Secutor insidiator	450	3 - 7.2	5.1	11
Secutor rucornius	241	2.5 - 5.7	4.1	8
Siganus canaliculatus	12	9.3 - 11.5	10.4	30
Stolephorus indicus	13	7.3 - 13.2	10.2	16
Triacanthus biculeatus	11	12 - 13.5	12.8	30
Upeneus bensasi	35	5.7-7.7	6.7	20
Upeneus sulphereus	604	4.5 - 11.8	8.1	23
Upeneus sundaicus	74	6.4 - 11.2	8.8	22

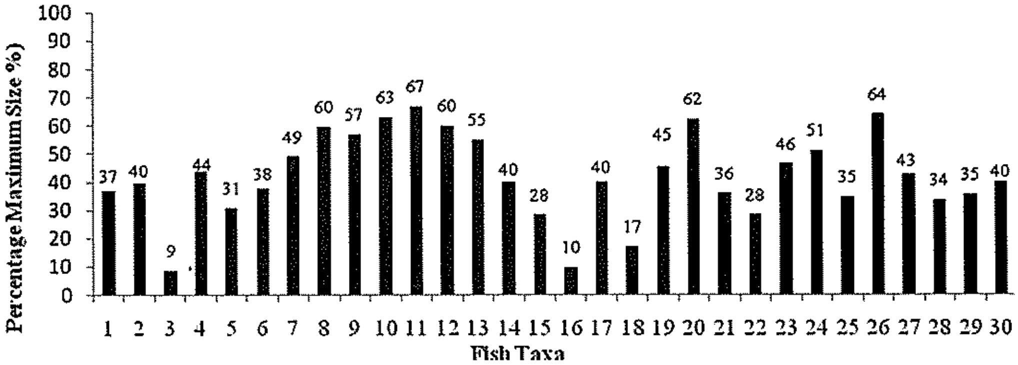

Figure 4. Percentage ratio fish length to maximum attainable size of fishes sampled in the shallow coastal waters of Pahang. 1, *Alepes djedoba*; 2, *Apogon quadrifasciatus*; 3, *Arius thalassinus*; 4, *Atule mate*; 5, *Carangoides armatus*; 6, *Chirocentrus dorab*; 7, *Dussumieria acuta*; 8, *Gazza minuta*; 9, *Grammatobothus polyopthalamus*; 10, *Leiognathus brevisrostris*; 11, *Leiognathus daura*; 12, *Leiognathus elongatus*; 13, *Leiognathus leuciscus*; 14, *Leiognathus splendens*; 15, *Lutjanus lutjanus*; 16, *Lutjanus malabricus*; 17, *Nemipterus furcosus*; 18, *Pomadasys maculatus*; 19, *Pseudotriacanthus strigilifer*; 20, *Sardinella gibbosa*; 21, *Sarida tumbil*; 22, *Scolopsis taeniopterus*; 23, *Secutor insidiator*; 24, *Secutor rucornius*; 25, *Siganus canaliculatus*; 26, *Stolephorus indicus*; 27, *Triacanthus biculeatus*; 28, *Upeneus bensasi*; 29, *Upeneus sulphereus*; 30, *Upeneus sundaicus*.

Table 4. A comparison of the diversity indices from various mangroves or mangrove related habitats in Malaysia. Adapted from [7].

Place	Habitat type	Species richness	Diversity
Matang, Perak	estuary	7.58	3.66
Matang, Perak	coastal mudflat	8.12	3.53
Sg. Dinding, Perak	estuary	-	2.87
Lekir, Perak	coastal mudflat	11.10	3.04
Klang, Selangor	estuary	11.82	2.59
Klang, Selangor	coastal mudflat	8.65	3.24
Sg. Johor, Johor	estuary	15.59	3.50
Sg. Pulai, Johor	estuary	14.09	2.86

seagrass and reed beds) and substrata are important in determining the community structure and species composition of fish fauna [22].

Mangrove cover along the coast of Pahang is small and amounts to only 2.3% (2482 hectares) of the total cover in Peninsular Malaysia (107,720 hectares) unlike that in Johor (22.9%), Perak (40%) and Selangor (24.1%) [14]. The lower cover of mangroves as well as low significance of conjoint habitats in the Pahang coastal waters probably reflect the lower values of species richness (D) and diversity (H'). Past studies support the hypothesis that bottom habitats with greater habitat heterogeneity harbour higher fish density and species richness compared to those with homogeneous habitats [22-26]. Hajisamae *et al.* [27] showed that seagrass beds and a combination of seagrass and seaweed beds had a greater fish density compared to those of relatively less vegetated bottom characteristics, including sites near to mangrove and muddy bottom sites.

The fish species in the shallow coastal waters of Pahang is mainly represented by the Leiognathidae (*Leiognathus, brevirostris, L. elongatus, L. splendens, L. rucornis*) which were largely juveniles and sub-adults. Besides the Leiognathidae, the Pahang coastal waters also harbour many other juvenile fish species suggesting that the shallow coastal waters function as nursery areas. Juveniles and families of small-sized fishes, such as Leiognathidae, Centropomidae, Siganidae and Engraulidae are typical for fish communities in tropical shallow coastal waters [4, 28-31].

Structural heterogeneity of habitats is important as refugia offering shelter for juveniles. The "refuge function hypothesis" [11] is based on the premise that habitat heterogeneity provides microhabitats for juveniles to shelter from predators as well as increased food availability [32, 33]. Predator avoidance, shelter and food availability are strong selection criteria for some fish taxa. The Pahang coastal waters however, lack the complex structural heterogeneity but the spatial scale [34] of the coastal waters may provide shelter and predator avoidance for juvenile fish. This coupled with the rich benthos composed of polychaetes and crustaceans [15, 16] may be food of the juvenile fish. This lends supports to the role for the shallow coastal waters as nursery grounds. The abundance of juvenile fishes in the shallow waters nonetheless, may also be important food items and trophic links in the food chain where they may be prey for larger piscivore predators. Solahuddin and Lotfi [15] showed that the coastal waters of south Pahang and Johor recorded the highest density of macrobenthos and they relate the macrobenthos abundance to nutrient output from rivers. The southern Pahang coast is flushed by many rivers lined by mangroves (Sg. Pahang, Sg. Miang, Sg. Api-Api, Sg. Nibong, Sg. Tering, Sg. Bebar, Sg. Rompin, Sg. Pontian and Sg. Endau).

Notwithstanding the fact that a large proportion of the fish catch from the Pahang coastal waters are juveniles, and that there is low structural heterogeneity, what aspect of the coastal waters then allows for the juveniles to utilize the habitat? Further studies are thus needed to elucidate the role of benthos as fish diets, large space as refugia and for predator avoidance of juvenile fish. The general distribution of fishes in the shallow coastal waters is probably also related to seabed geomorphology, tidal patterns and freshwater outflow from rivers.

REFERENCES

1. Sasekumar A. (1974) Distribution of macrofauna on a Malayan mangrove shore. *Journal of Animal Ecology* **43**: 51-69
2. Ashton E.C. (1999) *Biodiversity and community ecology of mangrove plants, mollusks and crustacean in two mangrove forests in Peninsular Malaysia in relation to local management practices*. PhD Thesis, University of York.
3. Sasekumar A. and Chong V.C. (1998) Faunal diversity in Malayan mangroves. *Global Ecology and Biogeography Letters* **7**: 57-60.
4. Sasekumar A., Chong V.C., Leh M.U. and D'Cruz R. (1992) Mangroves as a habitat for fish and prawns. *Hydrobiologia* **247**: 195-207.
5. Sasekumar A., Chong V. C., Singh H.R., and Lim K.H. (1994) The fish community of Matang Waters. In Sudara, S. *et al.* (Eds). *Proc 3rd ASEAN-Australia Symposium On Coastal Living Resources, Research Papers* Vol. **2**: 420-444.
6. Singh H.R., Chong V.C. and Sasekumar A. (1994) Value of Mangroves as Nursery and Feeding Grounds. In: Wilkinson, C. *et al.* (eds.). *Proc 3rd ASEAN-Australia Symposium On Coastal Living Resources, Research Papers* Vol. **2**: 105-122.
7. Chong V.C. and Sasekumar A. (2002). Fish communities and fisheries of Sungai Johor and Sungai Pulai Estuaries (Johor, Malaysia). *Malayan Nature Journal* **56**(3): 279-302
8. Singh H.R. (2004) *The Biology of the Estuarine Ariid Catfishes (Fam: Ariidae) of the Matang Mangrove Ecosystem* (*Perak, Malaysia*). PhD Thesis, University of Malaya.
9. Singh H.R (2005) The diets of the estuarine catfishes (Fam: Ariidae) of the Matang Mangrove Ecosystem, Perak, Malaysia. *KUSTEM 4th Annual Seminar on Sustainability Science and Management: Meeting Challenges in Sustainable Agrotechnology*.
10. Chong V.C. (1999) The mangrove fisheries of the Sg. Johor estuarine system. *A report for the JSFD/ DANCED/DARUDEC: Preparation of an Integrated Management Plan for Sustainable Use of the Johor Mangrove Forests.*
11. Chong V.C. (2007) Mangroves-fisheries linkages – *the Malaysian perspective. Bulletin of Marine Science* **80**(3): 755–772.
12. Chong V.C. and Sasekumar A. (2002) Fish communities and fisheries of Sungai Johor and Sungai Pulai Estuaries (Johor, Malaysia). *Malayan Nature Journal* **56**(3): 279-302.
13. Aguilar-Perera A. and Appeldoorn R.S. (2008) Spatial distribution of marine fishes along a cross-shelf gradient containing a continuum of mangrove, seagrass and coral reefs off southwestern Puerto Rico. *Estuarine, Coastal and Shelf Science* **76:** 378-394.
14. Jaharah Y. and Chenayah S. (2004) Coastal resource development in Malaysia: Is there a need for sustainable Mangrove Forest Management? *Malaysian Journal of Science* **23**(2): 149-164.
15. Solahuddin A.R. and Lotfi W.M (2001) Macrobenthos Abundance in the Waters of Peninsular Malaysia, West Sabah and Sarawak In Mohd-Taupek M.-N. and Mansor M. I. (Eds) *Fisheries Resources Survey in the Exclusive Economic Zone of Malaysia 1997-1999: Biology and Environmental Conditions* (Supplementary Volume) pp. 247-267. Department of Fisheries, Ministry of Agriculture Malaysia.
16. Ahmad A., Solahuddin A.R., Jamaludin I. and Mahyam M.I. (2002) Distribution of Macrobenthos in the Coastal Waters of the East Coast of Peninsular Malaysia. In Mansor M.I. (Ed.). *Thirteenth Trawl*

Survey of the Coastal Waters off the East Coast of Peninsular Malaysia (April-June 2001) pp. 83-107. Ministry of Agriculture Malaysia.

17. Carpenter K.E. and Niem V.H. (1998) *The living marine resources of the Western Central Pacific,* Vol.2. *FAO Species Identication Guilde for Fishery Purposes.* FAO, Rome.
18. De Bruin G.H.P., Russel B.C. and Bogusch A. (1994) *The marine fishery resources of Sri Langka. FAO Species Scientific Field Guide for Fishery Purposes.* FAO, Rome.
19. Fishscher W. and Whitehead P.J.P. (Eds) (1974) *FAO species identification sheets for fishery purposes. Eastern Indian Ocean and Western Central Pacific,* Vol. 1-4. FAO, Rome.
20. Mohsin A.K.M. and Ambak M.A. (1996) *Marine fishes and fisheries of Malaysia and neighbouring countries.* Universiti Pertanian Malaysia Press, Serdang, Malaysia.
21. Munro I.S.R. (1955) *The marine and freshwater fishes of Ceylon.* Department of External Affairs, Canberra, Australia.
22. Blaber S.J.M. (2000) *Tropical Estuarine Fishes – Ecology, Exploitation and Conservation.* Blackwell Science.
23. Heck Jr. K.L., Able K.W., Fahay M.P. and Roman C.T. (1989) Fishes and decapods crustaceans of Cape Cod eelgrass meadows: species composition, seasonal abundance patterns and composition with unvegetated substrates. *Estuaries* **12**: 59-65.
24. Sogard S.M. and Able K.W. (1991) A comparison of eelgrasses, sea lettuce macroalgae and marsh creeks as habitat for epibenthic fishes and decapods. *Estuarine, Coastal and Shelf Science* **33**: 501-519.
25. Ferrell D.J. and Bell J.D. (1991) Differences among assemblages of fishes associated with Zostera capriconi and bare sand over a large spatial scale. *Marine Ecology Progress Series* **72**: 15-24.
26. Dean T.A., Halderson L., Laur D.R., Jewett S.C. and Blanchard A. (2000) The distribution of nearshore fishes in kelp and eelgrass community and physical habitat characteristics. *Environmental Biology of Fish* **57**: 271-287.
27. Hajisamae S, Yeesin S. and Chaimongkol S. (2006) Habitat utilization by fishes in a shallow, semi-enclosed estuarine bay in southern Gulf of Thailand. *Estuarine Coastal and Shelf Science* **68**: 647-655.
28. Chong V.C., Sasekumar A., Leh M.U.C. and D'Cruz R. (1990) The fish and prawn community of a Malaysian coastal mangrove system, with comparison to adjacent mud flats and inshore waters. *Estuarine, Coastal and Shelf Science* **31**: 703-722.
29. Tongnunui P., Ikejima K., Yamane T., Horinouchi M., Medej T., Sano M., Kurokura H. and Taniuchi T. (2002) Fish fauna of the Sikao Creek mangrove estuary, Trang, Thailand. *Fisheries Science* **68**: 10-17.
30. Ikejima K., Tongnunui P., Medej T. and Taniuchi T. (2003) Juvenile and small fishes in mangrove estuary in Trang province, Thailand: seasonal and habitat preferences. *Estuarine Coastal and Shelf Science* **56**: 447-457.
31. Hajisamae S. and Chou L.M. (2003) Do shallow water habitats of an impacted coastal strait serve as nursery ground for fish? *Estuarine, Coastal and Shelf Science* **56**: 281-290.
32. Laegdsgaard P. and Johnson C. (2001) Why do juvenile fish utilize mangrove habitats? *Journal of Experimental Marine Biology and Ecology* **257**: 229-253.
33. Huxham H. M., Kimani E. and Augley J. (2004) Mangrove fish: a comparison of community structure between forested and cleared habitats. *Estuarine, Coastal and Shelf Sci*ence **60**: 637-647.
34. Molles Jr. M.C. (2008) *Ecology: Concepts and Applications.* 4th Ed. McGraw Hill, NY.

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Green rough-backed puffer (*Lagocephalus lunaris*) as a tourism product in Betong, Sarawak, Malaysia

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Abstract This paper discusses, in general, the types of Tetraodontidae found around the world, and focuses on the green rough-backed puffer found specifically in Sarawak. The discussion includes biological conditions, physiology, and the characteristics of this species. In addition, explanation is given on the differences of the poison content of the green rough-backed puffer and other puffer fish. Furthermore, this paper discusses the method of catching the green rough-backed puffers, called *membuntal* by the villagers of Kampung Manggut at the riverside of Saribas River, Betong, Sarawak. The different dishes made from the green rough-backed puffers, well-loved by the locals and tourists alike, are also discussed in this paper. The final part of this paper deals with the "Puffer Fish Festival" held by Betong Resident's Office, an effort to make the puffer fish a tourism product in Sarawak.

Keywords Green rough-backed puffer – membuntal – dishes – tourism – Betong – Sarawak

INTRODUCTION

Sarawak is well known as a one of the main tourist destinations in Malaysia. The historical heritage, shopping complexes, the richness of various ethnics and cultures, and most importantly, the natural environment preserved in the national parks which draw tourists to the state every year. By developing tourism industry, the state is able to increase revenue with foreign currency exchange, provide job opportunities, diversifying the economy and so on.

Saribas River, which flows to the South China Sea, is visited by a kind of unique fish twice a year to lay its eggs, a fish known as the green rough-backed puffer. During the green rough-backed puffer season, this fish can be found in large amount in between Tanjung Nangka and Tanjung Matu which is near to Kampung Manggut, Spaoh. Locals consume this fish as their source of protein. Capturing the fish is easy and only requires simple and cheap equipment. The locals also know how to remove the poison from the fish making it safe to eat.

The presence of the green rough-backed puffers in huge quantity is awaited by the locals. When the season comes, at night hundreds of locals, holding torch light, go to the river to capture the fish. It seems as if there is a Festival of Light in Saribas River. The lively night where the locals come out to fish is promoted by the Betong Resident's Office as a tourism agenda in Betong District. To attract more tourists and to make the "Puffer Fish Festival" livelier, the Resident's Office as the organizer holds other supplementary activities like mini-expo, water sports, fish catching competition, cooking competition, boat race, evening shows like singing competition, Malay drum performance, *tandak* dancing and other activities. Now, the "Puffer Fish Festival" is an annual agenda listed in the Sarawak Tourism Calendar.

GREEN ROUGH-BACKED PUFFER

There are puffers in almost every part of the world. Puffers are categorized into three main families, Ostraciidae, Diodintidae and Tetraodontidae. From the Ostraciidae, there are main species like the long- horned cowfish (*Lactoria cornuta*), yellow boxfish (*Ostracion cubicus*), longnosed boxfish (*Rhynchostracion nasus*), horned-nose boxfish (*Rhynchostracion rhinorhynchus*), turretfish (*Tetrasomus concatenates*) and helmet cowfish (*Tetrosomus gibbosus*). From the Diodintidae, the main species are the birdbeak burrfish (*Chilomycterus orbicularis*), spot-fin porcupinefish (*Diodon hystrix*), long-spine porcupinefish (*Diodon holocanthus*) and black-blotched porcupinefish (*Diodon liturosus*).

From the Tetraodontidae, there are immaculate puffer (*Arothron immaculatus*), spiny blaasop (*Amblyrhynchotes spinosissimus*), star puffer (*Arothron stellatus*) and fugu (*Torafugu robripes*, Fig. 1). A large number of puffers from the Tetraodontidae are able to emit a kind of dangerous poison known as tetrodontoxin. This poison is lethal to human and able to cause death in just a few minutes after consumption. However, a small number of puffers like the green rough-backed puffer contain a kind of poison known as neurotoxin. The locals of Saribas River remove the poisonous part of the fish and make the puffer a source of food [1]. The green rough-backed puffer is further divided into three species, the blowfish (*Lagocephalus lunaris*), silver toadfish (*Lagocephalus sceleratus*) and half-smooth golden pufferfish (*Lagocephalus spadiceus*).

The green rough-backed puffer, a migrant species originated from the South China Sea, is a species that has high commercial value, especially in certain areas in Sarawak. This species migrates to the Saribas River or Batang Saribas in Sarawak to hatch the eggs. The migration is caused by different reasons. First, to maintain the independence of the species, the green rough-backed puffer chooses to hatch the eggs in a shallow river. The green rough-backed puffer needs to ensure the safety of the eggs and the young, and if it is in the ocean, they would become preys of other aquatic animals; but in the Saribas River they would become the predators instead. Second, the yellowish muddy river creates a camouflage for the young. Since there are few capes in the Saribas River, many green rough-backed puffers can be found from Tanjung Nangka to Tanjung Matu. These capes are protected from swift water flow, so they are able to protect the hatching eggs and the young.

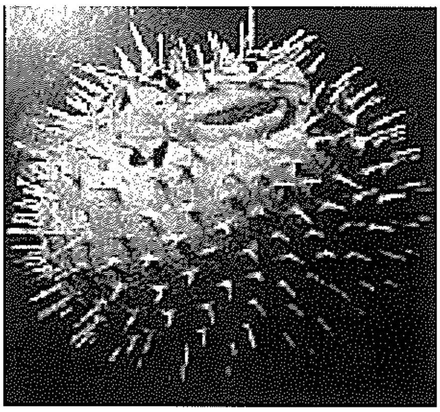

Figure 1. Fugu with erecting spikes [2].

The green rough-backed puffers migrate 30 km to the Saribas River upstream. Other than in the Saribas River, the puffers can also be found along the sea, rivers and river mouth between Sematan, southwest end of the state and Tanjung Sirik, Batang Lupar, Sungai Krian and Batang Sadong. However, the quantity of the puffers found in these places is less [3].

There are two types of green rough-backed puffer: the first is the blowfish and the second is the blaasop, which is further divided into common blaasop and toadfish. In Sarawak the green rough-backed puffers can only be found in large quantity twice a year during their migratory seasons, that is during the *Pasang Purnama* in the middle of the month, and *Pasang Leman* at the end of the month according to the Islamic or Arab Calendar. This type of puffer fish has large and straight dorsal spine. A large number of these fish are tropical saltwater fish, and some of them are quite colourful.

The green-backed puffer (*Lagocephalus lunaris*) has the shape of a banana. It has huge head and eyes, and also thick lips [4]. Its body is slightly thorny to protect itself from predators; while its head looks chubby and dull. On the side of its body, there are two different lines of which the upper line is a broken, curved line stretching to its tail fin. A puffer has an air bag formed by its digestive tract (Fig. 2). The air bag can be filled with air or water so that the fish can expand its size as if it is a spiked balloon [5].

The lower line is thick, straight to its tail; its scales are round-shaped. Generally, the whole body of the green-backed puffer is yellow, yet its head is dark green. The blowfish has shining yellowish stripes on its body and can be found in the South China Sea, and in large quantity in the Saribas River, Sarawak, next to Batang Lupar the homeland of Bujang Senang, the legendary crocodile. Normally, the largest size of the fish is 30 cm.

Another species of puffer is the common blaasop (*Lagocephalus sceleratus*) [4]. There is a large quantity of this type of fish in the Saribas River, Sarawak [6]. Like the blowfish, the blaasop is like an elliptical sphere and is smaller but longer than the blowfish. The head of the blaasop is chubby, and the lower part of its body is full of erected spikes when it senses threat of predators. Its eyes are round, and its mouth is rather large and full of equal and beak-shaped teeth. Like the blowfish, it has two obvious lines on its side; these lines are like boundary markers dividing the upper body and the lower body like stomach (Fig. 3).

The head and the upper part of the fish are brown and grey, with a lot of small black spots. The whole body, including the fin, is yellow. There is also a shining line in the middle part of this fish when observed from afar. This fish can also be found in the Indian Ocean, North Japan and South Australia. Normally the largest size of a blaasop is 30 cm. The locals categorize the fish into two types, the 'mother', which is a grown up blaasop and the 'child', a blaasop with the size from 10 cm to 15 cm [6].

Another type of blaasop is the toadfish (*Logocephalus spadiceus*). This type of fish can be found in the Saribas River as well. It looks similar with the blaasop but larger and bigger. Its eyes are big and round-shaped, and it has an average-sized mouth with beak-shaped teeth. Its jaw is covered with hard membrane. This species of blowfish also has curved and straight lines stretching to its back of its tail (Fig. 4).

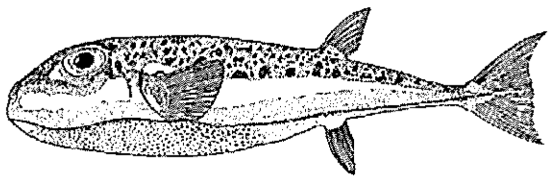

Figure 2. Blowfish (*Lagocephalus Lunaris*) [4].

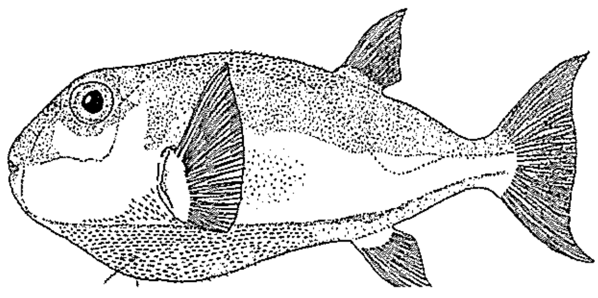

Figure 3. Silver toadfish (*Lagocephalus sceleratus*) [4].

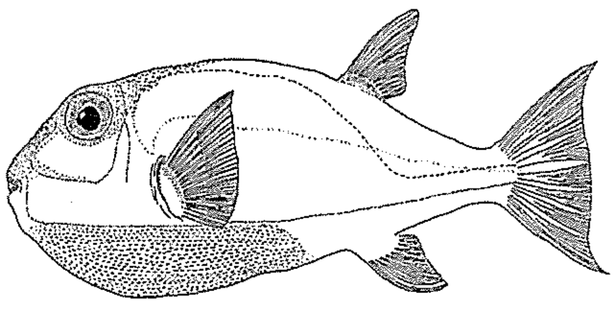

Figure 4. Half-smooth golden pufferfish ***(Logocephalus spadiceus)*** [4].

Unlike the blaasop, the toadfish has black spots all over its head. Its head is dark brown while its surface is dark green. Part of its body is yellow, and a small part of its body has the colour similar to the colour of goldfish. This fish can grow as large as 30 cm.

DIFFERENCES OF THE POISON

To make a product, especially fish like the green rough-backed puffer attractive to tourists, certain negative stereotypes have to be removed from the mindset of the public. Because of its poison, a puffer is often being labeled as a 'killer fish', and it is widely believed that many deaths are caused by the consumption of puffer fish.

Currently there are only two species of blowfish identified as edible. The first is the toadfish or more well-known as the fugu fish among the East Asians, the second is the green rough-backed puffer of Sarawak. However, the content of poison in these two species is rather different, and this proves that the green rough-backed puffer is much more unique than the Japanese fugu. In Japan, the fugu is highly popular as a delicacy like sushi, that the Japanese government takes this delicacy seriously and trains chefs to discard the poisonous visceral leftovers. To prepare the fugu is not easy, only the well-trained and licensed chefs are permitted to handle the delicacy in Japan. For the locals who wish to enjoy the fish, they are required to obtain a life insurance. This clearly shows that the Japanese government is serious to develop this fishing source, while well aware that the poison contained in the stomach of the fish is lethal. This poison is TTX, or tetrodotoxin.

TTX can cause death in human after half an hour after consumption. A fugu would enlarge its own body and its spikes turn upright when it feels threatened (Fig. 4). Each of these spikes contains the lethal TTX and if the predator bites a fugu in such condition, the TTX poison is injected into the body of the predator through the spikes. TTX would restrict the flow of sodium in the nerve tissue causing instant muscle paralysis. This poison is able to stop respiration because the paralyzed muscles cannot aspirate which subsequently kills its predator. The symptoms of poisoning after consuming TTX start with queasiness, vomiting, feeling of numbness in the mouth cavity; and then followed by disrupted nerve functions, itchiness at lips, feet and hands. Next, the victim would have difficulty in breathing, and then followed by heart attack. These symptoms last from 10 to 30 minutes, followed by the death of the victim. The tetrodoxin is so lethal that it is 1250 times more poisonous than cyanide; tetrodoxin can cause death even with the amount as small as a match-head.

For this gravity of reason, the Japanese government, since 1958, makes it compulsory for chefs who prepare sushi made from fugu to obtain a license, so that to ensure the chefs are capable to handle the fish. Those who are interested in this field have to enroll a training course that trains them to cut, flay and cook the fugu from the beginning until the end. The peak of the training is that they are required to prove that they are capable to prepare fugu by catching, cooking and eating the fish. The difficulty and the painstaking process to prepare a fugu dish makes the delicacy one of the most expensive food in Japan, and it is not unheard of a kilogram of fugu valued at ¥ 679,792 Japanese Yen, which is equivalent to RM20.80 Ringgit Malaysia. It is not uncommon that the Haedomorari Market in Shimonoseki, also known as the Town of Fugu, to earn more than $40 million every winter from the selling of fugu alone.

Around 1869 to 1912, because of its danger, the Meiji government of Japan made it illegal to sell fugu in certain provinces in Japan. In the 18th century when Japan was ruled by the Tokugawa Shogunate, it was forbidden to eat fugu. Mitsugoro Bando VIII, a kabuki actor, died after eating fugu in 1975. Until this day, there is no known antidote that can treat the poison of TTX. This might be caused by the molecular structure of the poison, which is distinct from other organic chemical substances.

However, the poison contained in the green rough-backed puffer found in Sarawak is rather different. Although there is no available result, currently there are scientific researches being conducted by the University of Malaysia Sarawak; and based on 200 years of historical experiences in the Saribas River, there is not a single death reported caused by the poison of this fish. In fact, the locals of the Saribas River and Bahagian Betong have been enjoying the fish for generations even though they are aware of its poison. Some pointed out that the poison contained in the stomach of the green rough-backed puffer is actually neurotoxin. The neurotoxin from this type of puffer fish is not fatal and will not cause death. But it can cause the symptoms of what the locals call *mabuk buntal*, literally to be drunk with puffer. Light symptoms after consuming the poison include vomiting and fever depending on the immune system of the patient. The green rough-backed puffer does not have spikes on all of its body like the fugu when it enlarges its body; it only has spikes on the lower part of its body to protect its stomach. Although the skin and the intestines of the puffer are poisonous, cautious steps are taken to discard the poison when preparing its flesh, making it a valuable commercial product in Japan and in Sarawak [5].

PHYSICAL CHARACTERISTICS OF GREEN ROUGH-BACKED PUFFER

The general public often has the perception that a puffer fish is a hideous-looking killer fish. Many moviegoers would remember that Bloat, a character in the animated Hollywood movie *Finding Nemo*, is also a puffer that has attractive features. It is not uncommon for some people to think of a puffer as an unattractive or even an ugly creature. However, the green rough-backed puffer of Sarawak, especially the one in the Saribas River, paints a different picture. The whole body of this fish is in attractive light yellow, and adorned with some spikes, something rare among other fish found in Malaysia. It looks like as if it is an expensive ornamental fish, especially when it floats on the water surface, and a goldfish in a glimpse. Some people are surprised to see such yellow fish swimming in the Saribas River, a place still inhabited by crocodiles some time ago.

The uniqueness of this fish lies on its single air bag that can be inflated as if it is a spiked balloon. This fish attracts attentions when it starts to inflate itself and floating its body as if it is a small buoy on the river surface. This action actually proves to be fatal to itself, by exposing itself to the fishermen that look for opportunities to capture the fish. This puffer species is also rather attractive because it has shinning yellow stripes that can be seen even from afar. During the fish season, especially warm nights, the fishers would carry torch lights so that the shine can be seen as if there are swarms of fireflies flying above the river surface. However, there is certain time where the river becomes muddy; the shine cannot be seen clearly without the help of sunlight or electronic light. In this time, it is the stripe of the fish that helps the fishers to identify its position at night when they wish to catch the fish.

MEMBUTAL

The locals call the way of catching the puffer *membuntal*, and there are five methods of *membuntal* in the Saribas River area. These five methods use five different equipments such as fish net, fish trap, fish rod, scoop net (known as *tanggok* by the locals) and a kind of equipment known as *sagang* (the process of using this equipment is known as *menyagang* by the locals). Fish net is the most popular method among the locals because it can obtain a large quantity of fish within a short time. The net would be cast in the river according to the tides or dragged by a boat along the river [7].

Fish trap is a cage-shaped equipment to capture fish. Fish traps are available in different shapes, types and names. However the most common fish trap is the *bubu jantung* [8]. In the Saribas River there is a similar fish trap, known as *bulu bulat* which is made from bamboo and rattan. To capture the fish in the deep river, a long rope is tied to the trap and the trap sinks into the river. To capture the fish, shark meat is put inside the trap as baits.

Some locals and outsiders use fishing rod to capture the puffer. Shark meat and snail are used as baits. Normally the puffers caught are the young ones; because the adults have sharp teeth that can bite through a fishing line.

Scoop net is another traditional equipment used by the locals to catch the puffers. The size of the scoop net is larger than the *seledok*, and it is made of rattan. The method of using the scoop net is rather simple. It is tied at the end of a boat and thrown into the water. The boat moves slowly, against the swift river to catch the puffers. The difference between the scoop net and the fish trap is that the scoop net is larger and does not use any bait. During the peak of puffer migration season, the scoop net is able to catch three to four adult puffers at the same time.

Another popular equipment to catch the puffer is the *sagang*. The method which uses this equipment precedes the usage of fish hook in Saribas River. This is the oldest method used in the area [9]. In the Peninsular Malaysia, especially for the Aslian people in Rompin, Pahang, a *sagang* is made from sharp bamboo and measures 2 to 3 cm. It is tied like a ship anchor or a clothespin. Two sharp pieces of bamboo are tied together with a rope made from rattan. The locals of Saribas River use a piece of stone of average size which they call *batu sagang* to make a *sagang*. The stone is used as the weight to sink the *sagang* into the river.

Shark meat is used as the bait. After the bones are removed, the meat is pasted tightly on the stone in a large quantity. A few shark tails are left wiggling to attract the attention of the puffer. String or rope measuring 80 to 90 cm functions as the anchoring chain. Then, the *sagang*, pasted with shark meat, is left in the water. This way of catching puffer is known as *menglului* among the locals.

When the green rough-backed puffer starts to eat the bait, the fisher pulls the string or the rope slowly, as if pulling an anchor chain. The puffer, following the movement of the *sagang*, is pulled above. The fisher, seeing the puffer from near distance uses a *seledok* to capture the fish. The fisher knows the bait is eaten by the puffer when the string of *sagang* moves from the original position, this motion is known as *ngenjit-ngenjit* among the locals.

During the puffer season, the nights of Kampung Manggut become very lively. Other than the locals, there are other visitors and tourists coming to this village who rent boats belonging to the locals to participate in *membuntal*. Many stay in the home of their relatives or friends. For the visitors to Betong who do not have friends and relatives there, they rent a house or a room, as they do not want to miss the chance of catching the puffers and to witness the lively atmosphere.

Normally this happens on weekends and during the public holidays. To experience *membuntal* and to witness the scene where 400 to 500 boats in different sizes gather, all have light emanated from kerosene lamps which is a unique and fun experience for the visitors. There are many boats with bright light, making it look like as if it is a lively festival which lasts for the whole night until the next morning.

To catch the puffers is easy during the puffer season. This is one of the factors that attract visitors to this area. The Saribas River is shallow and narrow which causes imbalance in the number of fish migrated to the river. This also means that the fish gather in a narrow and shallow space, and a lot of puffers can be seen in the water surface. Indirectly, this makes the act of catching them a very easy process.

The ease to catch the puffers in large quantity also causes a lot of tourists come to the place in groups. The

LME Sea Surface Temperature (SST and SST Anomalies) Subsurface temperature data, albeit important, are limited in the spatial and temporal density required for reliable assessment of thermal conditions at the Large Marine Ecosystem (LME) scale worldwide. The U.K. Meteorological Office Hadley Center SST climatology was used in this analysis [13], as the Hadley data set has resolution of 1 degree latitude by 1 degree longitude globally. A detailed description of this data set has been published by Rayner *et al.* [14]. Mean annual SST values were calculated for each 1° x 1° cell and then were area-averaged by annual 1° x 1° SSTs within each LME. Since the square area of each trapezoidal cell is proportional to the cosine of the middle latitude of the given cell, all SSTs were weighted by the cosine of the cell's middle latitude. After integration over the LME area, the resulting sum of weighted SSTs was normalized by the sum of the weights, that is, by the sum of the cosines. Annual anomalies of annual LME-averaged SST were calculated. The long-term LME-averaged SST was computed for each LME by a simple long-term averaging of the annual area-weighted LME-averaged SSTs. Annual SST anomalies were calculated by subtracting the long-term mean SST from the annual SST (Figs. 11, 12).

Sea surface temperature The Earth's climate is warming. According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [15], the global mean surface air temperature increased by 0.74°C while the global mean sea surface temperature (SST) rose by 0.67°C over the last century [16].

The World Ocean's mean temperature in 0-3000 m layer increased by 0.037°C between 1955 and 1998 [17]. Global warming has already significantly affected marine ecosystems [18-20], and this impact is expected to increase in the near future owing to the current acceleration of warming [16].

Fish and Fisheries Module Indicators

Changes in biodiversity and species dominance within fish communities of LMEs have resulted from excessive exploitation, naturally occurring environmental shifts caused by climate change,

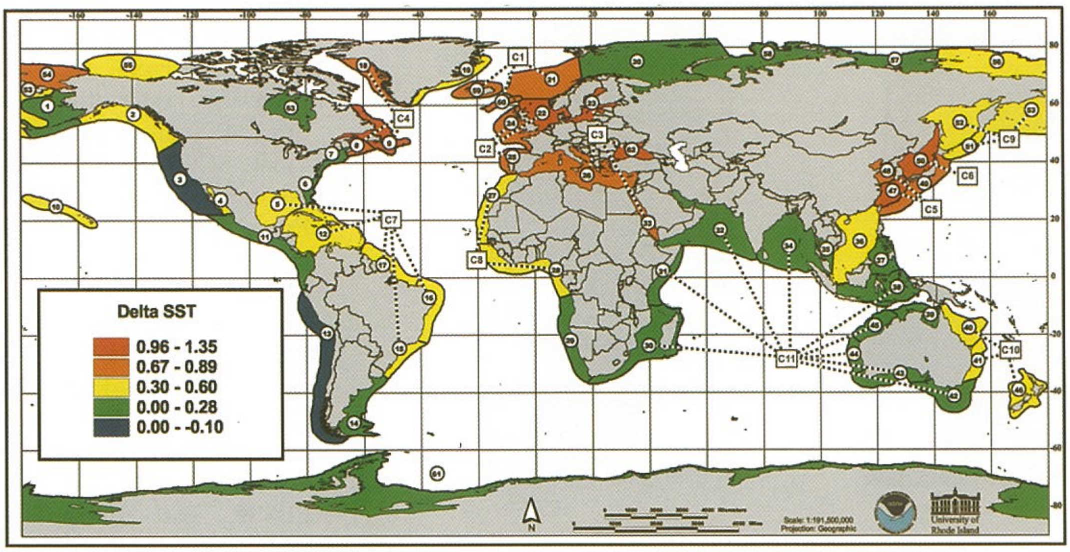

Figure 11. Warming Clusters of LMEs in Relation to SSTs, 1982-2006 [17].
FAST WARMING (0.67°C – 1.35°C): C1 Northern European Cluster; C2 Southern European; C3 Semi-Enclosed European Seas; C4 of the NW Atlantic; C5 Fast Warming East Asian LMEs; C6 Kuroshio Current and Sea of Japan/East Sea LMEs.
MODERATE WARMING (0.30°C – 0.60°C): C7 Western Atlantic LMEs; C8 Eastern Atlantic LMEs; C9 NW Pacific LMEs; C10 SW Pacific LMEs. Several Non-Clustered, Moderate Warming LMEs: NE Australia, Insular Pacific Hawaiian, Gulf of Alaska, Gulf of California; South China Sea, East Greenland Shelf;
SLOW WARMING (0.00°C – 0.28°C): C11 Indian Ocean and Adjacent Waters. Non-clustered, Slow Warming LMEs include the U.S. Northeast Shelf, the U.S. Southeast Shelf, the Barents Sea, East Bering Sea; Patagonian Shelf, Benguela Current and Pacific Central American Coastal LMEs.

locals provide boat rental to the groups; this generates extra income for them. Normally these groups will use *sagang* to catch the puffers because it is easy and fun. The catch is donated to the poor family in the Kampung Manggut, or sold to the eager visitors.

VARIETIES OF PUFFER DISHES

Edward Inskeep, a tourism planner once said, "... other than providing important services to the tourists, local cuisine can be a main tourist attraction if the place provides interesting food; in the gourmet tours in Europe, food is the main attraction" [10].

Delicious dishes made from green rough-backed puffer have successfully attracted a lot of tourists. It is undeniable that all the puffers contain poison, yet the poison of the green rough-backed puffer has been discarded in the right way that it is safe for the fish to be eaten. Usually the process of discarding the poison is conducted by the women at home, but there are also male fishers hired by visitors, especially by visitors from outside Betong, to discard the poison. Usually the cost to discard the poison from a mature puffer is RM1.00, and from a young, RM0.50. Before starting to discard the poison, the knife and scissors will be soaked in hot water for sterilization. The knife or the scissor used in ngasak buntal is used for other purposes, and kept in separate places.

The puffer is washed with clean water for at least three times. Next, its central organ needs to be identified because the removal of its stomach starts from this organ. Its central organ is round shaped, and situated in the lower middle part of its body. When the organ is identified, the fisher would start to cut from the central organ to its lower head. This is done meticulously because its stomach must be fully discarded without leaving any residue of the organ. If the organ is not discarded completely, it would cause *mabuk buntal,* the vomiting of its eater. This is caused by the neurotoxin contained in its egg membrane and in the nerve vein close to the part which is required to be discarded. The spikes found on its body are also discarded because they might contain poison as well.

However, many locals fried the puffer skin with spikes. Because it is savory and crispy, it is a favourite snack among the children. Although the puffer's stomach is discarded, its eggs and liver are still used as food. The veins and the membranes found on the eggs are meticulously removed, a time-consuming process which can take two to three hours depending on the size of the eggs. The bigger the eggs, the more time is needed to remove the veins and the membrane. At times, a kilogram of puffer eggs can cost about RM30 to RM40. After the eggs, liver, the spiked-skin and the rest of its body are separated, the last stage is washing all these parts with clean water until no black mucus-like substance can be found on its body.

The puffer can only be cooked after the poison has been discarded. Generally three types of puffer products are used for culinary purposes in Betong, Sarawak. The first is the green rough-backed puffer, called by the locals as 'live puffer'; the second is salted puffer and the third is food made from puffer eggs and liver.

There are six types of dishes made from 'live puffer' – hot and sour puffer, curry puffer, puffer relish, roasted puffer, fried puffer and grilled puffer in spicy sauce [11]. Hot and sour puffer is the most popular among the locals. The main ingredients for hot and sour puffer and curry puffer are two mature puffers, turmeric, lemongrass, hot chilies, pickled pineapples, ginger and adequately sautéed chili paste. Turmeric, salt, onions, garlic, gingers, lemongrass and hot chilies are ground together. These spices are used to expel the odour which is known as *bau lantoh* in local speech. The ground spices are to be mixed together with the puffer later. Next, the process of sauté in high temperature begins. After that, the puffer is cooked in a wok. The puffer liver can be included if desired. Flavouring powder and pickled pineapple are added after the water starts to boil.

Another popular dish made from puffer in Betong is the grilled puffer in spicy sauce. The method of preparation is: "A piece of nipa or banana leaf is cut according to the size of the puffer. The puffer, after mixing with salt, turmeric and flavouring powder, is placed on the leaf. Wooden charcoals or old coconut shells are used as fuel for grilling the fish."

Roasted puffer is prepared in the same method, but without the nipa or banana leaf. During the puffer season, there are locals selling roasted or grilled puffer along the jetty. The price for each roasted or grilled puffer ranges from RM3 to RM5, depending on its size [12]. A mature puffer, when roasted, can cost about RM5; whereas a smaller one might cost RM3. Grilled puffer costs about the same price. These puffer delicacies are one of the things that attract tourists to this place; and at the same time the locals, mostly fishers, are able to earn extra income.

Puffer relish is another delicacy that becomes a favourite among the tourists. It is popular because it can last long, up to a month. Its preparation process is rather time-consuming as well. The ingredients needed to prepare puffer relish include puffer, rice, rice porridge and salt. The rice porridge is ground with a grinder, while the puffer is mixed with salt. Next, the porridge is blended with the puffer, and sealed in a covered container like a bottle for three nights. In these three nights, yellow fried rice is prepared. The rice is fried without using cooking oil. The fried rice is then ground by using a grinder, until rice powder is obtained. After three nights, these ingredients are blended together and put inside a covered container, and left for one night before it can be eaten. This puffer relish can be fried or roasted in banana leaves as well.

Aside from „live puffer" dishes, there is also salted puffer that can last longer. There are only two puffer seasons in a year in the Saribas River, but the salted puffer can last for one to two months. Salted puffer is sold in packages, a package that contains four salted mature puffers costs RM4 to RM5, depending on the size of the puffers. For the salted young puffers, a package that costs RM4 contains
eight salted puffers.

Salted puffer is a main ingredient for fried puffer, grilled salted puffer, roasted puffer and also puffer relish. The methods of preparing these fishes are the same as preparing dishes made from „live puffers", but unlike „live puffer" dishes, the salted fish only needed to be washed and can be directly fried, roasted in banana leaves, marinated, grilled without having to be sautéed in high temperature or in other similar process. Salted puffer is washed for three times before frying. The uniqueness of the fried puffer is that the whole fish, including flesh, head, bones and spikes (if any) can be eaten. It tastes a bit salty, crispy and quite tasty. Now, under the cooperation between the villagers of Kampung Manggut and the Betong Department of Agriculture, the salted puffer is beautifully packaged as a way to promote green rough- backed puffer products to the general public, especially to the tourists.

Puffer liver can be grilled or fried. Like grilled puffer, the liver is also wrapped in nipa or banana leaf before grilling. Before grilling, the liver needs to be mixed with salt. After removing the nerve veins and membranes, puffer eggs are mixed with salt and left in a sealed container overnight. Then, it is sun dried before it can be cooked or sold. Puffer eggs can be fried without any other ingredient. The eggs can be steamed as well. The ingredients required are onions, garlic, salt, lemongrass and bamboo shoots. These ingredients are mixed together with the puffer eggs in a wok. Clean water is added three times when steaming to remove any possible remaining neurotoxin residue on the eggs. The varieties of the green rough-backed puffer dishes prove that the puffer is an exquisite delicacy, even comparable to the quality of *fugu* dishes of Japan.

PUFFER FISH FESTIVAL

Puffer Fish Festival is an important effort of the government to promote the green rough-backed puffer to the public, as well as to test its potential as a tourist attraction. The uniqueness and quality of the fish has attracted the local government to hold this program during its migration period in Saribas River. This program is the Puffer Fish Festival, and is held in every July since 2002. It is marked in the Betong tourism calendar and is one of the annual events in Sarawak. It is highly popular and anticipated by the Sarawakians, especially by the locals of Betong.

The idea of such festival is closely related to the uniqueness and the lively atmosphere during the puffer catching process. There are hundreds of boats and thousands of villagers going down to the river or stay at the river bank. In the midnight one can see the villagers carrying kerosene lamps or torches, as if having a festival. This is even livelier during the peak of the puffer migration season; it would be as if there is a 'Light Festival' taking place on the river surface.

Generally, the responsibility of the Puffer Fish Festival falls on Betong Resident's Office. The organizer divides the activities into two main sections: the first is related to promoting the puffer and the second is related to water sports, recreation and entertainment. There are three main activities managed by the first section: mini expo, exhibition, and puffer product selling. When the festival was held for the first time, there was only biological information of the puffer in the exhibition. The information was presented in details in printed pamphlets and in documentary film. The purpose of the exhibition is to inform the general public about the puffer in detail, and change their stereotypical perspective about the fish. The organizer also exhibited various tools used in catching the green rough-backed puffer, including fish trap, lift net and *sagang*.

Participating agents also sell various products made from puffer, including salted puffer in beautiful packaging. Puffer eggs and livers are packed to be sold to visitors. Locals are given opportunity to sell the puffers. A space is provided by the organizer for the locals to sell their products. Most of the sellers are local fishers, and their products are mostly salted puffers and „live puffer'. There are also those who sell puffer dishes like roasted puffer and grilled puffer.

In the second annual exhibition, the organizer prepared medium sized booths for sellers of other products like textiles, clothes, local handicrafts, souvenirs, ornaments and snacks. The sellers were from either Betong or other places.

The next activity in the first section is the Puffer Catching Contest. This activity is directly organized by the local people, without any involvement of the Betong Resident's Office. The Resident's Office gave the villagers of Kampung Manggut and nearby villages full responsibility in managing the contests and was only responsible for sponsoring the prizes. Together with the villagers, the headmen of Kampung Manggut and other villages in the Spaoh district would become the VIPs to ensure the success of the contests. This shows that the puffer is indeed quite important, that both the locals and the administrators play a role to make the Puffer Fish Festival a great success.

There are four categories of the contest: catching the puffers with fish net, *nyagang buntal, nanggok buntal* and puffer fishing. Not only men participate in the contest; a large number of contestants are actually women. Observers and media are not allowed to be close to the contest location. This is to ensure the safety of the contestants and to keep them undisturbed. The audience is only allowed to watch the contest at the river side.

Another activity organized by the locals with the cooperation of the Betong District Agriculture Office is the puffer preparation and cooking demonstration [13]. This demonstration is organized for the public near the exhibition location. The demonstration on how to discard the stomach and the poison of the green rough-backed puffer the safe and correct way is shown to the visitors. The Betong District Agriculture Office is given the responsibility to select the experienced villagers to conduct the demonstration. Cooking demonstrations of various puffer dishes, including the preparation of salted puffer are shown in detail as well.

To make the festival even more attractive, water sports, various recreational and entertainment activities are organized by the second section of the organizer. These supplementary activities function to make the festival more interesting, and at the same time attract more visitors. The most popular water sport during the festival period is the 10, 15, 20 and 30 *Sakai* Boat Racing. A Sakai boat is a boat that does not use pump engine or outboard engine. The numbers 10, 15, 20, 30 refer to the number of the paddlers. The contest is divided into two categories, male and female. If desired, contestants may use their own boat.

To make the contest even more enjoyable, there is also a contest to select the most beautiful race boat. Each year, there are more than a hundred teams from all over Sarawak to join the contest. In 2004, there were 129 teams joining the boat racing contest. This attracted thousands of racers to Kampung Manggut, making it a platform to introduce the green rough-backed puffers to the contestants. Other than the Sakai boat racing, there are also pump engine and outboard engine boat racings. For these racings, there are individual and team categories; in the team categories, there could be no more than three team members.

For the recreational activities, there are other contests to promote the spirit of cooperation. For the five years 2002 to 2006, there were contests like rope pulling, making ketupat, drawing and colouring competitions for children, VIP Football Competition, 9-a-side Footy and also fun fair.

To make the Puffer Fish Festival livelier and to make use of available time, the organizer also holds several entertainment activities. One of these activities is showcasing Sarawakian Malay culture by organizing *bermukun* (Malay drum competition). Playing Malay drum is a popular leisure and entertainment activity among the Sarawakian Malays. The rhythm of the drum beat is accompanied by verses of Pantun, a form of Malay poem, sung by the players of the drum. It is then accompanied by *tandak*, a kind of dance movement. To encourage the participation of young generation, there is a *tandak* competition for teenagers.

Malay drum and *tandak* competitions are the events long awaited by the residents of Betong, and to the lesser degree, by all the Sarawakians. RTM Sri Aman radio station also plays a role to live broadcast the competitions. There are also 60s' Oldies Singing Competition, P. Ramlee and Saloma's Songs Singing Competition, and Commercial Pop Songs Singing Competition. These activities are participated by various age groups, from adolescents to senior citizens. To participate in these competitions, contestants are required to pay a registration fee of RM10.

There are also small concerts featuring local artists from Sarawak. To make the festival even more exciting, there is Kebaya Queen Pageant. Various traditional costumes of different ethnic groups in Sarawak are showcased. These entertaining activities do not only function to discover new talents; they indirectly make the Puffer Fish Festival a platform to showcase local culture, which surely attracts more and more tourists. It is undeniable that the Puffer Fish Festival has increased the economy and income of the locals. The local villagers, especially villagers from Kampung Manggut, earn a large amount of income from renting the boats and house, and also selling raw puffer, salted puffer and puffer dishes [14].

CONCLUSION

The green rough-backed puffer once feared for its poison has now transformed into a popular food when the villagers of Kampung Manggut mastered the method of discarding its poison. After making sure that the fish is safe to be consumed, it is caught in large number by the locals and by the visitors to the district. The quantity of the puffer caught is so huge that many are made into salted puffer and puffer relish. The locals also introduced a variety of dishes made from puffer, and this has successfully attracted many tourists. The uniqueness of the green rough-backed puffer is that it is a migratory fish, and this enables the government to make the migratory season part of the Sarawak tourism agenda.

The uniqueness of puffer catching activity, which is both easy and exciting, is identified as a contributing factor to the coming of two categories of tourists, those who participate in the puffer catching process; and those who stay at the river bank, attracted by the lively atmosphere of the puffer catching process. This is as if the fishers and the visitors are having a puffer harvest festival. During the peak of the puffer season, the easiness to catch a large quantity of puffers is also identified as a factor that attracts the tourists to this place; many of these tourists, who come in groups, are not from Betong. Their involvement in puffer catching is always gratifying for them. It is also important to note that the green rough-backed puffer is a high quality food source which has high commercial value. The varieties of dishes made from puffer are of exquisite quality, and they have the potential to attract foreign tourists, especially those from East Asia that enjoy fugu in their own countries. It is clear that the uniqueness of the puffer's physical shape, the ease to catch it in large quantity during the puffer season and the lively atmosphere in puffer catching activity that make the green rough-backed puffer a product with great potential to attract tourists to Betong and Sarawak.

REFERENCES

1. Interview with Mr Romie, President of Betong Tourism Special Taskforce in Betong Resident's Office, 12th June 2007, 2:30 pm.
2. http://www.shiki-sushi.com/fugu.htm
3. Interview with Mr Sulaiman Taha, Headman of Kampung Manggut at his house, 20th June 2007, 11:00 am.
4. Abu Khair Mohammad Mohsin and Mohd Azmi Ambak (1996) *Marine Fishes and Fisheries of Malaysia and Neighbouring Countries*. Universiti Putra Malaysia Press, Selangor.
5. Siti Khalijah Daud (ed.) (1987) *Fish Biology*. Dewan Bahasa dan Pustaka, Kuala Lumpur.
6. Interview with Mr Sulaiman Taha, Headman of Kampung Manggut at his house, 20th June 2007, 11:00 am.
7. Interview with Mr Raca Mulong in Betong Resident's Office, 3rd December 2007, 11:00 am.
8. Mohammad Raduan Mohd Ariff (1988) *Fishing Industry in Malay Peninsula*. Universiti Malaya Press, Kuala Lumpur.
9. Interview with Mr Sulaiman Taha, at his house, 17th June 2007, 12:00 pm.
10. Che Elaine Che Hassan (ed.) (1996) *Tourism Planning, An Intergrated and Long-Lasting Developmental Approach*. Dewan Bahasa dan Pustaka,Kuala Lumpur.
11. Interview with Mr Sulaiman Taha, at his house, 17th June 2007, 12:00 pm
12. Interview with Mr Sulaiman Taha, at his house, 17th June 2007, 12:00 pm.
13. Betong Informational Office, Sarawak (2004) *Puffer Fish Festival, Betong*.
14. Interview with Mr Raca Mulong in Betong Resident's Office, 3rd December 2007, 9:00 am.

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The Filipino fishermen and dynamite fishing activities in the marine area of Sabah, Malaysia

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Abstract Even though the usage of dynamite in fishing is banned in Malaysia, it continues to be used in the coastal areas of Sabah. Despite of many negative consequences of dynamite fishing, it is used in fishing industry by greedy and unscrupulous individuals who aims to make short-term profit. This paper attempts to illustrate the methods of dynamite fishing, the processes involved in dynamite fishing activity and also its impact on marine lives in the waters of Sabah Even though enforcement is done continually, this phenomena is difficult to contain. The finding of this study in a way reveals that when there is a demand for dynamite fishes, there will be a supply. Dynamite fishes are made available in markets causing consumer to continue to buy these fishes. On one hand, lack of knowledge to differentiate between blasted fishes and fishes caught using ordinary methods causes the demand to prevail. On the other hand, lower prices of blasted fishes create a demand. Thus, educating the general public on the impacts of buying blasted fishes is important. At the same time, heavier punishment should be imposed and monitoring should be done persistently in order to curb this problem.

Keywords Filipino fishermen – dynamite fishing – Sabah – ecosystem

INTRODUCTION

In the early days, fishing was the way of life among the coastal communities of Southeast Asia. It was their main source of food. After the capitalist economic system was integrated into the society, fishing became a source of profit. Fish became more important than the needs of the family.

To obtain greater catch, several methods in fishing were modified. Techniques in fishing practiced in developed countries such as trawling were introduced to and accepted by fishermen in the Southeast Asian region. The introduction of modern equipment in the fishing industry enabled fishermen to catch fish in the deep sea and allowed them to work longer to catch more. However, the natural geographical character of the coastal area in Sabah, dominated by corals in some parts, limited the use of modern equipments like trawlers.

Because of the rich fish resources near the shore, independent and sponsor-dependent fishermen want to exploit it, even if the methods are dangerous and a threat to themselves as well. One of the methods identified and banned by the government is the use of explosives in fishing.

Mati ikan kerana umpan (fish dies because of the bait) is an old saying among Malay fisherman. However this saying is not true anymore, as numerous fish die because of other methods such as fish trawl, drift trawl, pull trawl, among others. This paper explains the *matinya ikan kerana ledakan* (fish dies because of explosives) currently happening in Sabah, particularly in several fishing villages such as Kudat, Kota Marudu, Semporna, Kunak, Lahat Datu and Sandakan. This is also happening in some fishing villages in the Federal Territory of Labuan.

In the areas mentioned above, one of the methods, which is easy to use and earns more profit to fishermen, is the use of explosives known as *bombing*. According to several villagers, this method has been introduced by fishermen from the Philippines in the early 1960s. These Filipino fishermen have migrated to the coastal areas of Sabah during the administration of Tun Mustapha where majority of them came from

Cagayan Island, Tawi-Tawi and other islands near the international boundary of Sabah-Philippines in the Sulu Sea. They have been using this method to catch high-value fish which can only be found in the coral areas.

Also known as dynamite fishing, its potential to give more profit to fishermen has been the major reason that it has been accepted by local fishermen mainly from Ubian and Bedadan. Filipino fishermen have used this bombing method for some time now because this method is suitable for fishing along the rocky reefs. Capital-intensified modern methods cannot be used to fish along the rocky reefs. Furthermore in the Philippines, explosives are easily obtained. With such method, dynamite fishing is popular because of its low operation cost and high yield. While in Sabah, some of the Filipino fishers relate the fishing laws in Malaysia with the laws of their country of origin. Awareness of rules and laws is not that important for them.

According to Ruppert Sievert [1], the history of this fishing method in the Philippines began before the Second World War and became more important after the end of the war. "Indeed, in many coastal villages, blast fishing is deeply rooted in tradition. The practice already existed before World War II, becoming extensive and rampant after War when the ammunition, explosives and other explosives left behind in drums and wrecks were salvaged and turned into fish explosives. Glass bottles of various sizes, weighted by sinkers made of iron or stone, serve as casing. The explosives were detonated by homemade or commercial fuses. When the ammunition was exhausted, the fishers began using miner's dynamite, and then agricultural fertilizers (ammonium nitrate, potassium nitrate and sodium nitrate) mixed with kerosene, now the most common source. Blast fishers have also learned to use battery-operated pipe explosives which explode sideways and suppress the sound of the explosion ... It may not be a major method of fishing like hook and line or the gill net, but explosive fishing is widespread in the Philippines. According to one source, about 70,000 fishers that are 12% of the total number of capture fishers in the country are suspected to engage in blast fishing. In every bay and in every gulf, there are always blast fishers; for every fishing ground, there is always a village known to be the residence of blast fishers; and every village, there is always at least one tale of misfortune, of a blast fisher or persons maimed or killed because of explosion." [1].

However, the same situation happening in Sabah is not as bad as explained above. According to a research finding by Quazi Abdul Manan, only 0.2% of the fishermen of Banggi Island and 0.6% from Semporna used explosives as a method of fishing [2].

METHODS OF EXPLOSIVE PRODUCTION AND ITS MODUS OPERANDI

Dynamite fishing is easy and does not need any sophisticated equipments. There are three methods of using explosives, one of which is the use of agricultural fertilizer. According to Yashihiro Makino "This type of fishing is illegal but it is still sometimes being practiced in Gaya Island and Banggi Island because it is the easiest method to catch fish. The explosive is usually made up of fertilizer which consists of potassium chlorate ($KC10_3$)." [3].

The said method refers to fish explosives made of several components such as a big size Guinness Stout bottle, agricultural fertilizer (ammonium nitrate), cork, kerosene, waterproof fuse, matches and fuse, known as kit and detonator. The fuse and the wick are connected together while two to four match sticks are then attached to the wick. It is covered with plastic tied by a nylon string. The fuse attached to the wick is inserted in the cork with a hole in its middle part. The fishermen put the fertilizer soaked in kerosene into the bottle until it reaches the neck part and tightly close it with the cork-fuse-wick cap. The bottle's mouth is then covered with *jilin* so that water cannot enter the bottle and compress air when the wick is lighted.

When the fishermen reach their operation site, one or two divers dive into the water to survey the types of fish and the quantity available in the said area. If the site has a very good number of fish, the diver(s) go back to the boat and begin their operation. Usually, one to three bottles are lighted and thrown into their target area. The bottle-explosives will sink into the sea and finally explode within 10-20 seconds, depending on the length of the wick. As soon as it explodes, the fishermen gather their catch and immediately leave the area to avoid being traced or caught by the Marine Police because of the loud noise created by their explosives. Normally, they make sure that there are no traces of explosive materials in their boats before hiding in one of the islands or pretend to catch fish (when in the open sea). This makes the task of the Marine Police to detain illegal fishermen more difficult for lack of evidence.

The explosive kills fishes found within the 20 metre radius from the source of the explosion. When the water clears up, two fishermen dive and collect their catch. They dive using rubber hose connected to the compressor to supply oxygen available in their boats. There are also some fishermen who are able to dive without using any equipment.

On average, a boat brings five bottles of explosives for a three-day operation. For a five-day operation, the fishermen usually bring about 25-30 bottles of explosives. The cost of producing 20 bottles of explosives is only RM40. The operation usually involves three fishermen: an engine operator and two divers. The usual catch is between seven to ten piculs each time they go to sea. The types of fish caught include *Euthynnus affinis, Epinephelus amblycephalus, Hilsa macrura, Lutianus argentimaculatus, Sphyrna* spp., *Oates calcarifer, Epinephelus sexfasciatus, Caranax* spp., *Caesio* spp., *Siganus* spp., *Mugil* spp., *Pterocaesio* spp., *Selar* spp, among others, living in reefs and rocks.

The fish are sold mainly to wholesalers waiting at the sea. Only a small portion is sold to wholesalers in the market. The total revenue after deducting the operation cost is divided equally among the fishermen.

Estimating the time when the explosive explodes is an important skill in this method. Failure to estimate the time of the explosion can cause serious or fatal accidents. Several incidents involving severed hands and shattered faces due to explosive explosion had happened in Kudat. In January 1989, eight fishermen who used explosives died in Semporna because their explosives got into contact with the matches that were kept in their boat.

Another method of explosive-use involves the use of empty cooking oil tin connected with a wire and a battery. This is used in waters with the depth of 40-70 metres. Divers use air compressors as breathing equipments. The explosives are created using empty cooking oil tins, four to eight bottles of fish explosives, agricultural fertilizer, kerosene, fuse, wire, and battery. Two long black and red wires are connected to a fuse and inserted into a fish explosive known as the main explosive. The main explosive is connected and tied with a nylon string to four to eight fish explosives. The fish explosives are then inserted into the empty cooking oil tin and compress it with sand (excluding the wires). The two black and red wires of the main explosive are connected to the battery. Once the fishermen reach their operation site, two to four divers will investigate their site. Once the area is inspected and found to have a good source of fish, the operation begins. The divers return back to their boats to take the explosives to their target site. The wires should be long enough in order to diffuse the explosive. The divers return back to their boats and start diffusing the explosives by letting electricity flow from the battery to the wires. This causes the explosive to explode and cause the water to blow up and make a loud sound. According to Ruppert Sieveret [1], "The initial wave is produced by the explosive substance under-going rapid chemical decomposition, thereby violently creating sound and releasing a large volume of gas, as a gas pocket, at high pressure and temperature. Subsequent waves are created by the rapid gas expansion in the water, causing a sequence of contractions and expansions, as the gas pocket rises to the surface." [1, 2].

The explosion does not only kill fish, but destroy other sea creatures including the reefs located at their operation site. Based on an observation done on blasted areas such as the waters of Gaya, Mengalum, and Banggi Islands, a number of small fishes with good market value also died because of the blasting. Coral reefs (leaf and branch species) that serve as breeding grounds for fishes are also destroyed and smashed because of the strong vibration and pressure due to the explosion. Studies also found that cartilaginous and non-bladder fishes such as sharks, sting-rays, crabs, etc., are likely to die because of the explosion.

According to Mr. Geriting, ".... *Dek! siapa cakap hanya ikan-ikan tulang keras saja mati. Semua ikan yang ada dakat bom mesti mati kerana semua ikan-ikan itu berisi dan bukannya besi. Cuba kau fakir, sedangkan batu (batu karang) pun hancur, inikan ikan yang berisi. Orang pun mati. Jangan main-main sama ini bom.*" [4] – (... Son! Who said that only fishes with hard bones die? All fish near the explosive die because they are made of flesh and not of iron. Know this that corals are also destroyed, and so with the fish. People die too. Don't play with explosives).

The collection and landing activities of fishes found in shallow waters are done by scooping the floating small fish such as *ikan belais or sulit* from the surface of the water or by diving into the sea bed wearing goggles and carrying fish gun for big fishes such as red fish and white fish living in the deep sea.

The landing of fish explosives in the deep sea is done with the help of an air compressor.

The third method is safer but involves higher costs and more complicated compared to the first method. This method uses a Guinness bottle filled with dynamite. A fuse is connected inside the bottle and connected with a wire to the detonator (*alat jangka peledak*) on the boat. When this operation is done, the fisherman throws the dynamite-filled bottle to the sea. The dynamite can be dropped as deep as possible until it reaches the sea bed, depending on the length of the wire used.

Fishermen identify places where there are a lot of fish available by diving and sighting the amount of fish in that area. Aside from that, they also observe the amount of catch obtained by other fishermen plying in that area. If a fisherman who uses a fishing rod catches a lot of fish, this means that the area has a lot of fish. In the case of the dynamite fishermen, they throw *bubuk* (small prawns used to make *belacan* – shrimp paste) and small fishes into the sea as bait to attract a throng of fish; the detonator is then pressed to cause the dynamite to explode. Aside from throwing baits, some dynamite-users use *unjang* made of coconut leaves or nipah to draw the attention of the fish which is normally done by fishermen in lift-net boats in Peninsular Malaysia.

Dynamite fishing is usually done by large boats, each of which houses eight to ten Filipino fishermen, mostly of Sulug origin. The total catch of a single operation can reach from four to six tonnes. The fish are placed into ice-filled containers before being sold to wholesalers.

Fishermen fishing with their own boats divide their earnings into ten portions – one-tenth for the boat used and the rest for nine fishermen. The operation cost is deducted first from the gross income before dividing it. The average income of a dynamite fisherman ranges between RM400 and RM600 per operation.

The income of fishermen working with a *tauke* (employer) is fifty-fifty, after deducting the operation costs: 50% to the *tauke* and the other 50% to the fishermen. The allocation depends as to how many fishermen are involved in the organization.

Dynamite fishing is not done every day. The number of working days depends on availability of the explosives, the sea condition, and the patrolling of the authority. On average, dynamite fishing is done four or five times in a month.

Because dynamite fishing promises huge profit, it is obvious that there are many fish *tauke* investors. At the moment, many fish *taukes* are from the city, especially Kota Kinabalu. The *taukes* supplying fish to the interior of Sabah are involved in this method. They purchase explosive materials from road construction contractors, stone-breaking contractors and also from shops selling agricultural supplies.

These explosive materials are then sent to the fishermen working in their fishing boats or to fishermen willing to sell their catch to them. These fishermen use medium sized boats and traditional fishing equipment such as fishing rod and small nets. Their boats are equipped with fish barrels filled with ice cubes. The *tauke* finances the cost of petrol and ice cubes. There are other *taukes* who give incentives such as cigarettes, money, and food.

In the early morning, the fishermen prepare their fishing equipment, normally composed of fishing rods and nets, aside from the baits needed such as *bubuk* and small fish. The explosives are hidden inside the boat. The fishermen also bring with them binoculars to check the presence of law enforcers from Sabah Department of Fisheries and Marine Police. It is used to monitor the presence of pirates.

When they reach their target location (presence of numerous fish and far from the authorities), the blasting operation begins. The operation is done by several fishing boats. As soon as the explosives are blasted, strong waves are produced and tremors can be felt, as explained by a fisherman from Kudat who said that *"masa mengebom macam perang Vietnam, di sini meletup di sana meletup, air naik sangat tinggi"* (the explosion is like the Vietnam War; blowing up here, blowing up there, the water rises so high).

If the authority arrives while they are doing their operation, the fishermen immediately speed their boats as fast as possible. They remember the place they had their operation so that when they come back after the authorities left the place, they can collect the fish. Some of them dive into the sea to collect the fish trapped in stones and reefs while the small ones normally floating on the surface are easily collected. If the authorities arrive before the operation has started, they pretend as though they are fishing using fishing rods or nets. When the authorities leave the place, it is only then that the actual operation starts. The blasted fishes are put into ice-filled barrels. These are brought to the land and will be hidden.

They usually hide in mangrove swamps.

During the night, normally around 11.00 p.m. to 1.00 a.m., the fishermen meet the *tauke*. The *tauke* bring their lorry filled with barrels and unload the fishes from the boat to the lorries. The meeting is normally arranged at the seaside connected by red-soiled road which is not in good condition.

Actually, the fish *tauke* is present when the fish are landed late between 5.00 to 7.00 p.m. They bring their lorry to the jetty and buy a few fishes from the fisherman who used this method. At this time, the dynamite fisher approaches the *tauke* and reports the amount of their catch, as well as negotiates the price and makes an appointment to unload the fish. Upon reaching agreement, cash payment is then made. They talk as if they are good friends and use a lot of signing and codes that only they can understand.

After the fishes have been unloaded, the *tauke* or his lorry driver immediately brings the fish to the city centre or other remote villages. The lorry normally reaches the city at five in the morning. The fish are then unloaded and eventually sold to wholesalers and retailers after being graded properly.

Blasted fish are much cheaper compared to fish caught using other methods. The prices are normally 25-50% cheaper. The response from the public is good even though they know that the quality is not the same as those caught using lift-net or other fishing methods. Furthermore, in this recession, the consumers prefer cheaper fish than quality ones. Blasted fish are marketed on average at about 70 *piculs* in only four hours.

MARKETING ACTIVITIES OF BLASTED FISH IN SABAH

Since the fish consumers in Sabah have little knowledge to recognize the presence of blasted fishes, the fish vendors change their tactics of deception from time to time. According to an observation conducted at the landing centres, there were some elements of fraudulent practices by the fish vendors. For instance, they mixed fishes caught legally with the ones caught by explosion in one big basket, which may mislead the consumers.

Generally, there are some tips that may be useful for consumers to detect blasted fishes. Among these tips include asking the vendors to open some parts of the fish stomach in order to see the fish's inner side whether it is destroyed or still fresh and undamaged. Blasted fishes usually have a bleeding wound in their inner sides, for their nerves are broken. Secondly, the costumers may also touch the stomach part of the fishes to check whether when being touched, it remains inwards or return back to its normal. This is in order to ensure whether its stomach remains set toward the inner side or return to its spot. They may also lift the fish up from its tail to check if the bone is damaged and its head is moving. However, these tips may only be effectively practiced on big blasted fishes and not on small ones.

Another way for vendors to mislead consumers is by cutting the blasted fishes into pieces, removing the affected inner organs, freeze it, or attach fishing hooks in its mouth and stick the fish with hook and arrow to show that it was caught legally. Other vendors sell blasted fish without removing its damaged parts at a lesser price when consumers recognize it as blasted fish.

In order to sell blasted fish to customers, the fishermen nowadays changed their tactics. They make sure that the blasted fishes do not have damaged organs. This is done by throwing the explosive from a distance of 20-30 metres from where the fish are, depending on the strength of the explosive at that time. Based on the studies done, fish caught using this method did not have too much damage such as broken stomach and bone, bleeding, and limp flesh, known to fishermen as "*mati terkejut*" (sudden death).

Moreover, blasted fish are not only sold fresh in landing centres and markets, but as salted and dried fish. This is done in order to satisfy the consumers' demands, especially those residing in remote and inner areas of Sabah. According to the study, it is not easy to identify and differentiate whether the salted fish is caught using explosives or other methods. This is because once it has been processed, all identifying marks are discarded.

Because of the high demand on salted and dried fish, which can earn bigger profit, Chinese capitalists are keen to invest in the production of salted fish, even though it transgresses the law. They participate in the production of salted fish by investing big amount of money to buy equipment used in dynamite fishing. They later on buy the blasted fish from the fishermen at the lowest price. According to Mohd Sidek bin Sheikh Osman, *"Pemasaran ikan-ikan ini dipercayai dilakukan oleh sendikit tertentu. Mereka-mereka ini yang terdiri dari "tauke ikan" dipercayai turut mendalangi aktiviti ini dengan menaja (sponsored)* *pendatang tanpa izin (PATI) untuk mengebom ikan di laut. PATI-PATI tersebut dibekalkan dengan semua komponen bom ikan termasuk dibayarkan gaji serta diberikan makanan oleh tauke-tauke tersebut. Seterusnya, ikan-ikan yang didaratkan akan dijual oleh tauke-tauke tersebut melalui dalangnya ke kawasan-kawasan yang disebut di atas khususnya di kawasan pendalaman."* [5] – (The marketing of these fish is believed to be carried out by a certain syndicate. This syndicate includes a "boss", who controls the fish products, and is believed to participate in orchestrating and sponsoring illegal immigrants (PATI) to blast fish in the sea. The PATI is equipped with all components including fish bombs. They are paid a salary, and given food by their respective employers. Finally, the fish are sold by the employers through their mastermind (people behind them) to the areas mentioned above, especially in remote areas.

NEGATIVE IMPLICATIONS OF BLAST FISHING METHOD

It is estimated that more than 30% of the world coral reef, the breeding area for ocean livings are located in the islands. Philippines, Malaysia and Indonesia play an important role in the world's biologically diverse marine ecosystem. According to L. Fredrich, "Coral reefs are some of the most valuable and spectacular places on earth. Covering less than 1% of the planet's surface, coral reefs and their associated mangrove, sea grass, and other habitats are the world's most biologically diverse marine ecosystem. Coral reefs are valuable assets providing food, jobs, protection from storms and billions of dollars in revenues each year to local communities and national economies." [6].

Coral reef is a venue for more than 25% of ocean beings for their breeding activity and for getting their protection. In the recent decades, human activities have devastated about 35 million hectares of coral reefs. According to a research conducted by Nicholas Pilcher and Steve Oakley [8] in the coastal area of the east coast of Sabah, under the "Reef Check 1997 International Project", reveals that 105 out of 110 km of coral reef researched area has been destroyed due to rigorous blasting of fisheries. The study also concludes that coral reefs along the 2500 km coastal area of the east coast of Sabah have been damaged and is in a worrying situation. "The reefs of Sabah are under great stress, primarily as a result of unsustainable fishing practices. Dynamite fishing is rampant and there are very few reefs without severe damage of the reef structure. Many reefs have less than 25% of their reef structure intact and most have an interconnecting series of bombs blast craters. Dead coral and rubble areas predominate and even recovering reefs were dominated by soft coral species. On bombed reefs, fish diversity was reduced to less than 10%. Fish size and population structure also changed as a result of the damage to the corals. Only five out of 55 reefs had breeding sized adults for the most important commercial fish species. The most valuable commercial fish, hump head wrasse and large groupers, were only found at the two reefs protected by ecotourism." [7].

Fish blasting not only threatens the ecosystem of the sea especially to the coral reef, but also the fishermen who utilize it. In reality these fishermen are aware of the risk they are taking, however they choose to ignore the fact as this technique guarantees lucrative catch. According to Rupert Sievert, "Explosives are powerful and dangerous tools to use under any circumstances and blast fishers have lost limbs or even died because of defective explosives or some miscalculation. Moreover, blast fishing has either hazard. Sometimes, the blast fisher must dive great depths for his catch and thus face the risk of getting the bends, or, when using compressor, of breathing oil-contaminated air. But, without fear of being apprehended or prosecuted, he is willing to face the risks for the promise of a big catch." [1, 2].

Local dailies also reported incidents affected by these blasting. The Daily Express (3 November, 1981), for instance, carried a report of an occurrence which took place in the Danawan Island, Semporna in November 1981. The incident involved a mother and her eight year old daughter who died of six fish blasts which was placed at the blasting house [8].

Besides that, diving activities by fishermen who do not follow the correct diving procedures while collecting fish blasts too contribute to nitrogen narcosis [9, 10] which can cause abnormality in the behaviour of the fishermen, fainting and causing disability. This happens when the divers do not perform safety stop while appearing in the surface of the water. According to the Professional Association of Diving Instructors' (PADI) scuba diving procedures, a diver who dives more than 40 metres for more than 40 minutes has to make a safety stop of five minutes at five metres of water surface before resurfacing.

and coastal pollution. Changes in biodiversity and species dominance in a fish community can move up the food web to apex predators and cascade down the food web to plankton components of the ecosystem. The fish and fisheries module includes both fisheries independent bottom-trawl surveys and pelagic-species acoustic surveys to obtain time-series information on changes in fish biodiversity and abundance levels [21-23]. Standardized sampling procedures, when employed from small calibrated trawlers, can provide important information on changes in fish species [24]. Fish catch provides biological samples for stock identification, stomach content analyses, age-growth relationships, fecundity, and coastal pollution monitoring for possibly associated pathological conditions, as well as data for preparing stock assessments and for clarifying and quantifying multispecies trophic relationships. The survey vessels can also be used as platforms for obtaining water, sediment, and benthic samples for monitoring harmful algal blooms, diseases, anoxia, and changes in benthic communities.

Sea Around Us Project Fisheries Indicators

Daniel Pauly and his colleagues from the Sea Around Us Project at the University of British Columbia have provided fisheries indicators for 63 LMEs [17], including fisheries biomass yields (catch) and dollar value, stock exploitation levels, the amount of primary productivity required to support the catch, Ecopath/Ecosim modeling results depicting mean-annual trophic levels of fish catches and fisheries in balance indices, and levels of exploitation. Graphic time-series examples of these indicators for the fish and fisheries of the southeast Asian LMEs are given for average annual fisheries landings and exploitation condition for 1950 to 2004 in Figures 13 through 16 (Sea Around Us Project (SAUP) [25]. Fisheries biomass yields are increasing in each of the four Southeast Asian LMEs where over 40% of the mean annual landings are reported as "mixed group" species since the 1980s.

The Sea Around Us Project has produced stock status plots that demonstrate the extent of overfishing in the LMEs of the world. Following are stock status plots for the South Asian Seas LMEs (Figs. 17-20). The levels of fully exploited, over exploited and collapsed stocks exceed 90 percent of the fisheries biomass yields as measured by number of stocks by status and catch by stock status for all 4 southeast Asian LMEs since 1999.

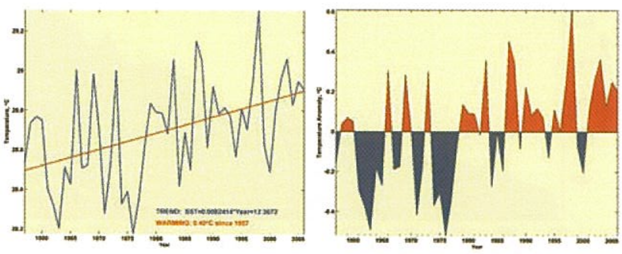

Figure 12.A. Annual mean Sea Surface Temperature (SST) and SST anomalies for the Gulf of Thailand LME (linear warming trend since 1957: 0.40°C), 1957-2006 based on Hadley climatology [13].

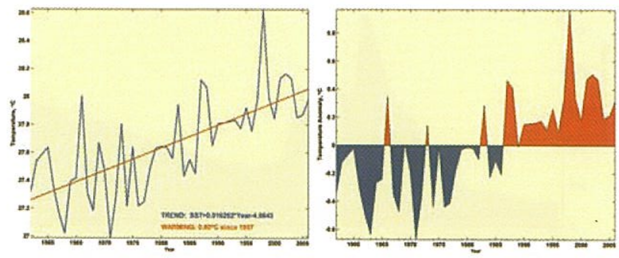

Figure 12.B. Annual mean Sea Surface Temperature (SST) and SST anomalies for the South China Sea LME (linear warming trend since 1957: 0.80°C). 1957-2006 based on Hadley climatology [13].

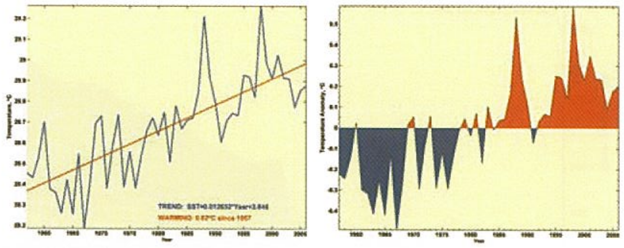

Figure 12.C. Annual mean Sea Surface Temperature (SST) and SST anomalies for Sulu-Celebes Sea LME (linear warming trend since 1957: 0.62°C), 1957-2006 based on Hadley climatology [13].

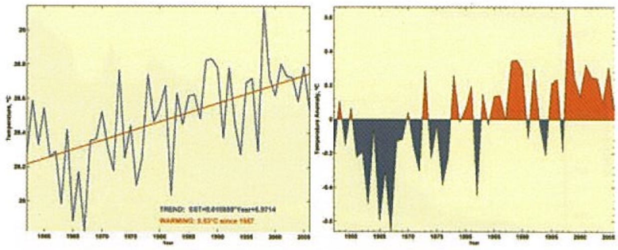

Figure 12.D. Annual mean Sea Surface Temperature (SST) and SST anomalies for Indonesian Seas LMEs (linear warming trend since 1957: 0.53°C), 1957-2006 based on Hadley climatology [13].

In Sabah fish blasting activities which take place in the Federal Territory of Labuan, not only raises concern amongst the Sabah Fishery Department, Sabah Parks, and Sabah Marine Police but also to the petroleum industry in Sabah managed by Petronas and Shell. According to Yusoff, fish bombing activities in the oil platform area has caused about 50% reduction in oil production, damaged the oil pipes which are placed at about 60 feet in the water and expose the workers towards fire.

Although the government has gazetted about 500 metres within the oil platform as a prohibited area, it seems that the fishermen turn a deaf ear towards the law. They only move temporarily when chased by security forces and return not long after. According to Sabah's Petronas Carigali Sdn. Bhd.'s statistics, in the past 18 months about 330 incidents of intruding the platform area had taken place and mostly in the month of March and June.

Meanwhile, Bill Chapman [11] is of the viewpoint that fishermen often target the platform area which is in the middle of the sea as that is where most fishes concentrate. The problems involving dynamite fishing in Sabah waters was raised in 1981 in the Sabah State Assembly by Lim Guan Sing, the then Minister of Agriculture and Fisheries. He said that the fish blasting activities not only destroyed the breeding of fishes but also destroyed the other ocean livings. He appealed to the general public to lodge report either to the police or the Sabah Fishery Department and not to buy blasted fishes [12].

Dynamite fishing method does not only destroy fishery products, the breeding area and its habitat but also threatens the income of traditional fishermen. Fishermen who use the hook and bait method and the fish-pod method reported that there has been a decline in their income as the types of fishes that they catch such as the golden band scad, one finlet scad, trevally/*Caranax* spp. and others have decreased.

The fish blasters conduct their activities at a proximate range with the fishermen's boats which means that these fishermen have to move away to a different location since it was almost sure that fishes in that area would die. This is a problem for them as they have to travel further into the ocean. For this, they would need access of oil and ice supply and this implies that they have to incur more cost than their would-be income.

These fishermen do not dare to oppose the fish blasters as they can throw explosives towards them. Furthermore, the fish blasters outnumber the fishermen. Although these fishermen do report to the Sabah Fisheries Department, in the earlier section of this paper it has already been mentioned the difficulty undergone by the Department to eradicate fish blasting activities.

Apart from fishermen using fishing rods (*nelayan pancing*), the fishermen using fishing traps (*nelayan kelong*) too face similar problems. This is because the dynamite users operate near the *kelong* or the fish housing area which affects the fishes that are actually trapped in the *kelong*. Fishermen who use traditional methods with valid licence find this unacceptable as the illegal dynamite fishermen neither possess any licence nor pay tax. While for the Sabah Department of Fisheries issuing licences to the dynamite-users implies that they endorse their activities.

Prior to the October 1987 Operation Lalang, most of the employers employed fishermen from the Philippines who were considered 'refugees' as fish blasters. This was because they were known to be braver and skilled when it comes to the details of fishing in the Sulu Sea and in the South China Sea. Under the Operation Lalang, many Filipino fishermen were caught and deported back to their country. However, they were not the only targets. The vacuum created by the Filipino fishermen was replaced by fishermen from the Ubian and Bedadan community. Most of them live in the islands of Landuyayang, Tigabu, Banggi, Mulaiangin, Tanjung Berungus and other villages in the Kudat area.

PREVENTION AND ITS PROBLEMS

Dynamite fishing is forbidden by the Malaysian government. Those who are found using such devices violate the Explosives Act 1957 (Act 207) [13] and Constitution of Malaysia Fisheries Act 317 Section 26(1) as follows:

(a) the use or attempt to use any explosive, poison or pollutant, or any apparatus using electricity or prohibited gear, for the purpose of killing, stunning, disabling or catching fish, or in any way catching fish easily.

(b) carrying or in possession or in control of any explosive, poison, or pollutant, or any apparatus using electricity, or prohibited gear, with the intention of using such explosive, poison or pollutant, or apparatus, or prohibited gear, for any of the purposes referred to in (a)-(b).

Any person who violates or fails to comply with any of the provisions of this Act is guilty of an offense and if no special penalty is provided in connection with this, the person may:

(a) if the vessel concerned is a foreign fishing vessel or the person concerned is a foreigner, a fine shall be imposed not exceeding 1 million ringgit per person in the case of master or captain, and RM100,000 in the case of every crew member;

(b) in any other case, a fine shall be imposed not exceeding RM50,000 or imprisonment of not exceeding two years or both [13].

Although the laws were made more severe, dynamite fishing is still active and incessant. Apprehension in some fishing areas has been made by the Sabah Fisheries Department and the Marine Police. However, its effects have yet to produce results that we can be proud of. As expressed by a fisherman in Kampung Air, Kudat: "dynamite fishing is not clever baa, it is similar to drugs baa, you catch more and more, it goes on from then to now." [14].

Recently, the state government of Sabah through the *Sabah State Security Committee* (SSSC) gave a mandate to the Federal Special Task Force for Sabah and Labuan to combat dynamite fishing activities on Sabah waters. According to statistics and records issued by the Sabah Fisheries Department and the Marine Police, almost all fishing centres in Sabah have recorded cases of explosives use. Between 1990 to 1999, as much as 816 cases of explosives use were reported to occur on Sabah waters where a total of 414 fishermen were caught and charged with a total of RM28,000 compound under Section 26 (1) of the Fisheries Act of 1985 [15].

From the said total, in Kota Kinabalu, higher cases were reported, i.e. 323 cases followed by Sandakan (247 cases), Tawau (124 cases), Kunak (28 cases), Kudat (28 cases), Lahad Datu (17 cases) (Table 1). These areas are the major towns on the west coast and east coast of Sabah.

In other districts of Sabah, on average, less than 10 cases were reported during that time. However, the statistics is not an accurate basis in gauging how serious dynamite fishing is in Sabah. In reality, the number of cases reported and recorded was actually much lower than the actual dynamite fishing activities in Sabah. This is because much of the series of dynamite fishing occurring in Sabah were not reported to the authorities or not directly known to exist. The situation is even worse when this fishing method is accepted by the community as one of the technologies in catching fish, together with other fishing technologies.

According to one of the residents of Kudat: *"Mimang saya selalu nampak dia orang bum ikan*

Table 1. Fish dynamite cases in Sabah, 1990-1999 [18].

District	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Total
Kota Kinabalu	5	14	47	54	51	35	15	20	25	57	323
Sandakan	3	65	39	30	23	18	17	14	32	6	247
Beluran	-	-	-	-	-	-	-	-	-	-	0
Tawau	-	1	-	22	33	11	14	21	5	17	124
Kudat	1	1	1	-	5	7	2	1	6	4	28
Kuala Penyu	3	-	4	1	3	1	-	-	3	1	13
Kota Marudu	1	-	1	2	1	-	-	-	2	-	7
Kunak	-	10	-	1	1	4	6	1	5	3	31
Sem Porna	-	-	-	-	5	-	-	-	-	2	7
Sepitang	-	-	-	1	-	-	-	-	-	-	1
Tuaran	-	-	-	-	1	-	-	-	-	-	1
Lahad Datu	-	-	-	1	7	2	-	4	3	-	17
Kota Belud	-	1	-	-	-	2	1	3	-	-	7
Beaufort	-	-	-	-	-	1	-	-	-	-	1
Pitas	-	-	-	1	-	1	-	1	-	-	3
Papar	-	-	-	-	1	-	1	1	2	1	6
Total Cases	10	92	92	113	131	82	56	66	83	91	816
No. of Catch	23	66	75	41	61	33	33	11	45	26	414
Total penalty (RM)	8900	-	500	-	4500	3000	8800	1300	1000	-	28000

dan saya orang pun tau bum ikan itu salah. Itu urusan dia orang sama pulis. Tiada kana mengana dengan saya orang. Kalu ikan born dual di pasar, kami bali jua kerana harganya murah. Kalu dibuat ikan masin, rasanya sama juga dengan ikan bukan bom. Enda jadi masalah bum ikan kerana ikan masih banyak di laut dan enda pandai habis...pasal bum ikan Jabatan Perikanan sibuk. Tapi bot pukat tunda yang menunda di pantai dia orang tidak larang." – (Really I always see people bomb fish and I also know that it is wrong. This is a police matter. I have nothing to do with it. If the blasted fish are sold in the market, we buy it because it is cheap. If it is made into salted dried fish, the taste is just the same. I don't know but the problem with blasted fish is because there are still a lot fish in the sea and so it is not going to diminish... makes the Department of Fisheries busy. But the fish-net boats along the coast do not bother them.)

Dynamite fishing seems to be no longer an unusual case because the local newspapers often cover such offence tried in court [16]. In general, the Sabah Fisheries Department and Marine Police face several problems in combating and preventing dynamite fishing activities in Sabah. Geographically, Sabah's coastal area is as long as 1448 km (900 miles) coved and clustered by approximately 154 islands and boundaries of international waters in the Sulu Sea, making it difficult for the department to monitor the entire area all the time. Because of this, dynamite fishing activities are difficult to thwart because the operation is relatively small compared to other daily activities. The Enforcement Division has a very small staff and can only operate with the help of the Marine Police, despite the fact that the Marine Police have other tasks to do.

When an operation is being carried out, the Sabah Fisheries Department staff must wear their official uniforms. This situation alerts fishermen that an operation is to be carried out. They deduce that the Department's uniformed staff will certainly conduct the operation on that day, only the time and place are not specified. Thus, they ready themselves. Apart from this, as the Department staff has no firearms, they are afraid to come near the fishing boats suspected of carrying out dynamite fishing activities. These fishermen might throw back the explosives to them and this will harm them.

The Marine Police and Fisheries Enforcement Department find it difficult to apprehend dynamite users. When the Marine Police approach, they will run for cover. They often run in the direction of the Philippine waters since they are already familiar with it and most of them were originally from there. The Marine Police cannot run after them anymore since they are already in the Philippine territory.

If the dynamite users do not have enough time to run to the Philippine waters, they run to a beach or an island where its banks cannot be accessed by big boats such as mangroves and shallow coral reefs. For those who are not able to escape, they remove all blasting tools and equipments thus no evidence is present to accuse them and prosecute them in court. This is more economical compared to the fine they must pay if convicted.

The clause lack of proof and of reasonable doubt or *"beyond reasonable doubt"* contained under the section of the Fisheries Act 1985 often fails to convict an offence in the court, and the offence is dropped against the human offender. For instance, the prosecution for offenders convicted under Section 26 of the Fisheries Act 1985 will raise reasonable doubt if the prosecution fails to submit evidences such as components in making fish explosives, or dynamites found in the fishing boats when the arrest was made.

This problem has been recognized by the Ministry of Agriculture and Food Industry of Sabah. According to them, the offenders usually remove or take away any evidence of explosives in their boats as soon as the explosives are detonated and thus making it difficult for the Fisheries Department and Marine Police to arrest them despite the fact they have already committed the crime.

But if the fishermen are caught, they are not worried because the employer bails them out. When penalty is imposed, the employer for whom the fisherman works pays the fine. Employers also pay the fine imposed on private fishermen, as long as they are willing to work or sell their catch to these employers.

Another measure taken is to arrest fish vendors selling blasted fish in the market. The Sabah Fisheries Department tries to identify blasted fish by taking several samples of fish sold and cut its abdomen. If there is blood clotting in the belly while the other parts of the fish are white, it died because of blasting. Fish caught by other means usually have defects in its other parts like a torn mouth or a scratch on its head because of trawl.

The mentioned action is only successful in arresting some fish vendors. When fish vendors become aware of the situation, they usually run away and leave behind their fish as soon as they notice officials from the Sabah Fisheries Department enter the market. The involved fish vendor disappears for three to four days until the unattended fish becomes rotten.

Another way is to hold a road block. This method is also unsuccessful because when a road block is placed, the wholesalers sense it and they temporarily stop their operations. In some cases, the wholesalers have other tricks, such as mixing the blasted fish with other fish caught using other methods (which are usually bought late in the afternoon). If they are checked and found to carry blasted fish, they deny knowledge of it. They insist that the fish are bought from a fisherman and whether the fish are blasted or not is not their business anymore. If buying blasted fish is a crime, they should also arrest all the buyers in the market. They often threaten state authorities of dealing with their lawyers and sue them and inquire in which section of the law prohibits the buying of blasted fish.

In the effort of holding road blocks, many fishermen doubt the honesty of the authorities carrying out their duties. They wonder how many of the wholesalers are able to bring blasted fish to their destination safely while the roadblock is being held. In another case, someone saw a staff of the Marine Police collecting blasted fish left behind by dynamite users on sea. In their sceptic mind, they think that this is used as evidence in court.

Apart from the efforts in arresting wholesalers and explosive users, the authorities also post notices and posters to make the people aware that fish blasting is against the law. These notices are posted at port centers and fish markets. The notice is as follows: "WARNING, CATCHING FISH USING EXPLOSIVES IS AGAINST THE FISHERIES LAW" Sabah Fisheries Department.

As one of the initial steps in controlling dynamite fishing activities, the director of the Sabah Fisheries Department has proposed to the Sabah State Government to ban the catching, selling, and buying of classified fish (*Caesio* spp.) and *anjang-anjang* (*Pterocaesio* spp.) to all fishermen, fish vendors and users [17]. This is based on a research conducted by the Sabah Department of Fisheries that these fish are usually caught using explosives only.

In an open forum organized by the Daily Express related to the dynamite fishing problems in Sabah dated 1 October 2000 entitled "Consumer Should Be Made Punishable", the director of the Department of Fisheries said that one of the reasons why dynamite fishing activities are difficult to overcome is because of the consumers buying blasted fish sold in the market. The statement brought different reactions from many people who have thought that the consumers should not be blamed. For example, a consumer who uses the name "PK Tawau" expressed his objection about the statement made by the Department of Fisheries entitled *Fisheries Department Must Not Pass The Buck To Consumers* – "kindly check with the public and see how many can easily differentiate between bombed fishes and normal fishes. My family of adults are definitely not able to and I am sure many out there have no expertise as well. Also do check with the public and see whether they would like to spend their hard earned money on bombed fishes or on fresh fishes. I totally reject bombed fishes and would not spend a sen on them. If we, the public, have no such knowledge and not willing to buy and consume bombed fishes, why should we be made punishable? Shouldn't it be the other way round that your department be made punishable for not performing its duty if bombed fishes are still commonly found in our fish markets?... wouldn't it be easier for your department to station enforcement officers at the fish market and at the fish discharging points to ensure bombed fishes are not made available to the public?" [14].

According to studies, it was found that it is not enough to just ban the capture, selling and buying of endangered fish and *anjang-anjang* whether fresh, dried or salted as a way of controlling fish blasting activities in the said state. This is because aside from the high local demand, not all endangered fish and anjang-anjang sold in the markets are caught with explosives, but caught using fishing hooks, fish trap and *selambau* by coastal fishermen. Up until now, fishermen have the tendency to use explosives in catching permitted fish such as *belais, temanong* and *belanak*, which were then caught using trawl or hook when the Department of Fisheries banned the catching of endangered fish and anjang-anjang. At the same time, a question also comes up as to why the Sabah Fisheries Department does not ban the catching, selling and buying of first class fish such as the white fish, red fish, grouper and others even though in reality, these fish are caught using explosives.

Studies also found that it is impossible for the

Sabah Fisheries Department to ban the catching, selling and buying of fish because this affects the development of fisheries in the state in general. Also, species of endangered fishes and anjang-anjang are not the main target of dynamite fishing but the cheap price, and dynamite fishing is not selective in nature. Thus, banning is not a solution to solve dynamite fishing in the long run.

As already mentioned, dynamite fishing is very profitable because the input cost is very cheap, while its return is very high. However the issue now is not how easy it is to earn profit in a short time because this method kills all types and sizes of fish. What is more important is that this method destroys coral reefs. As already known, thousands of marine life depend on coral reefs [18]. In short, this method threatens and destroys the marine ecosystem. Explosives-users are not concerned about this issue. To them, life today is for today, why think about the future when life's difficulties are felt at the moment. Humans in the future are smarter to solve their own problems. Moreover, even though dynamite fishing has been used for a long time, there are still a lot of fish in the sea. To them, "tidak pandai habis baa... (the fish will not diminish)".

If the said method of catching fish destroys small fishes, they also compare it to fish trawling which catches small fish as well. Sacks of small fish caught by trawlers are seen daily which are then made into fish fertilizers. According to them, authorities do not take any action but encourage the construction of fish fertilizers in addition to exporting these fertilizers abroad.

Fish employers on the other hand overtly share the profits they obtained. For them the opportunity of creating profits does not come often. Furthermore, if they are not doing it, someone else will. They also explained that if the fish are already gone, and they have already amassed a lot of money, they can invest in other fields.

The ease to find sources of explosives is one of the main causes why dynamite fishing occurs. Fish employers can easily get explosive from merchants from the Philippines who either barter or trade things with the local traders, particularly in Labuan. Aside from this, Filipino fishermen who travel to Sabah also supply explosives by smuggling it into the country.

One thing difficult to overcome is that some of the elements used in self-made explosives are lawfully legal. For instance, agricultural fertilizers and "dynamites" are openly sold in markets. The issue that can be raised from this is the abuse or misuse of the said material.

The dynamite fishing industry will continue as long as the people of Sabah still buy blasted fish because of cheaper price. There are opinions that blasted fish are dangerous when consumed. Nevertheless, such opinions still blur the truth. Available markets are the reason why dynamite fishing is rampant. Currently Brunei Darussalam is the reason why the prices of fish are high, thus several fish wholesalers export blasted fish into this country. According to them, the people of Brunei Darussalam are not very knowledgeable about blasted fish. Thus, this fish can be sold together with other fishes caught via other methods at the same price.

Other than the high market value, the export of blasted fish into this country is safer. This is because the investigation is only carried out on fishes transported and marketed in Sabah.

CONCLUSION

Dynamite fishing promises huge profits to entrepreneurs, particularly the capitalists. However, dynamite fishing in general, has and will continue to cause negative effects to Sabah's fishing industry. The destruction of fish resources and breeding areas in the long run is certain. Apart from this, this method has clearly threatened the traditional fishermen, who are already impoverished. Dynamite fishing activities cannot be resolved at this time because there are a lot of weaknesses in terms of law enforcement, and the public is not aware of this. Therefore it is necessary for the government, particularly the State Government of Sabah, to seriously consider this matter and take positive actions as a whole, including the improvement of arrest operation of dynamite fishing in identified areas, impose heavier punishment and fines to offenders and assign staff from the Fisheries Authority to monitor activities at fish markets.

REFERENCES

1. Sieveret R. (1999) A closer look at blast fishing in the Philippines. *One Ocean Overseas: The Online Magazine for Sustainable Seas* **2**: 5. http//www.oneocean.org/oversea/m...hal.1.
2. Abdul Manan Q. (1981) *Sabah Fisherman and Their Economy: A Socio-Economy Study.* Koperasi Kemajuan Perikanan dan Nelayan Sabah (KO-NELAYAN), Kota Kinabalu, Sabah.
3. Makino Y. (1983) *The Fishing Gears and Methods Survey in West Coast of Sabah.* Department of Fisheries, Kota Kinabalu.
4. Interview with Mr.Geriting on 24 July 2000 at the fish jetty in Kudat. He is known as "Raja Bom Kudat" (Kudat's King of Explosives) since the blasting activities in the 1980s and often caught by Kudat Marine Police.
5. Mohd Sidik b. Sheikh Osman (1997) Penguatkuasaan dan Undang-undang Pengawalan: Isu Yang Dihadapi Oleh Pelbagai Pihak Bagi Menangani Masalah Penggunaan Bahan Letupan dan Kimia Dalam Perikanan Terumbu Karang. Seminar *Mencegah Penggunaan Bahan Letupan dan Kimia Dalam Perikanan Terumbu Karang*, anjuran Kementerian Pertanian Malaysia, Kementerian Pertanian dan Perikanan Sabah, Institut Kajian Pembangunan (Sabah), Universiti Malaysia Sabah dan Taman-taman Sabah, Kota Kinabalu, 14-15 April, ha1.3.
6. Fredrich L. (2000) *Coral Reef Conservation For 21st Century.* United States Coral Reef Task Force: 1. http://coralreef.gov/.
7. Pilcher N.J. and Oakley S.G. (1998) Coral Reef\ Destruction in Sabah. *Malaysia-Japan Research Cooperation on Conservation and Sustainable Use of Tropical Bioresources Seminar, Kuala Lumpur.* http://www.unimas.my/ibec/biodiversity/html.
8. *Sabah Daily Express*, 3 November 1981.
9. Lewis J. and Shreeves K. (1990) *The Recreational Diver's Guide to Decompression Theory, Dive Tables and Dive Computers.* International PADI, Inc.
10. Lewis J. and Shreeves K. (1999) *Open Water Diver Manual.* International PADI inc.
11. *Sabah Daily Express*, 9 December 1981.
12. Akta Bahan Letupan 1957 (Akta 207), Bahagian II "Kesalahan, Penalti, Penguatkuasaan dan Prosiding" Seksyen 2, 1990, hal.95.
13. *Malaysian Law Act 317*, Fish Act Section 26 (1) page 30.
14. Wahid bin Mulatuan, a fisherman who uses the fish-hook method at Kampung Air, Kudat. Interview on 24.9.2002.
15. Sabah Fisheries Department: Bilangan kes Ikan Bom di Sabah, Sek.26 (1), Akta Perikanan 1985..
16. *Sabah Daily Express*, 19 October 2000.
17. *Sabah Daily Express*, 15 October 2000.
18. Oakley S.G., Pilcher N.J., Digges C., Enderby S., Mackey G., Clubb R., Atack K., Stapleton K., Toh S.M. and Morton E. (1997) Preliminary Results of a 1997 Survey of Coral Reef Health in Sabah, East Malaysia. *International Marine Science Conference, Terengganu, Malaysia, 25-28 August 1997.*

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The fish forecasting system – towards productivity improvement of the purse seine fishery in Malaysia

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Abstract The Fish Forecasting System is being developed for the east coast of Peninsular Malaysia. The project started in 2007, and would be completed in 2010. The project has been undertaken collaboratively between the Department of Fisheries Malaysia (DOF), Malaysian Remote Sensing Agency, Fisheries Development Authority of Malaysia (LKIM), National Fishermen's Association of Malaysia (NEKMAT) and MIMOS Berhad. The project comprises six major components, namely pelagic fish density determination from hydroacoustic surveys (using KK SENANGIN II vessel); onboard sampling by 36 enumerators on selected purse seine vessels; study on sea conditions from oceanographic surveys and satellite data acquisition and analyses (MODIS, OCM, NOAA and Radarsat); and fish forecasting modeling as well as data distribution to the fishers. It is hoped that the output of this study will help reduce 30% of the total operational cost of purse seine vessels and increase 20% of the net income for boat owners. The success of this project depends on the cooperation given by the fishers especially in providing information related to their fishing grounds.

Keywords Fish Forecasting System – South China Sea – purse seine – oceanography – pelagic fisheries – remote sensing

INTRODUCTION

The rapid development in Information and Communication Technology (ICT), data communication, data processing and data storage technology have helped us to increase the capability of remote sensing technology and its applications. One of the applications that can be developed using remote sensing technology and ICT is a Fish Forecasting System (FFS). The major challenge in this project is to develop a fish forecasting model suitable for the tropical region. In order to develop this model, there should be an integration of expertise and experience in the areas of biological oceanography, ecology, remote sensing, statistics, mathematics, and ICT which is very crucial.

The development of Fish Forecasting System (FFS) using remote sensing and related technology is a project under the 9th Malaysian Plan which started in 2007 and expected to finish in 2010. This project is a joint-venture program between five agencies – Remote Sensing Malaysia, Department of Fisheries, Fisheries Development Authority Board of Malaysia (LKIM), National Fishermen Association (NEKMAT), and MIMOS Bhd. This project is expected to cost over RM 10 million.

The main objective of this project which is also known as IKANG program, to identify potential pelagic fish location based on integration and simulation of information. This program will reduce vessel operation cost by 50%. At the moment the fuel cost has increased tremendously and thus reduces the net income of the boat operators. This project will help the fishermen to identify the potential fishing locations before they set out to the sea. Their fishing journey will be shorter thus more focused and will reduce the overall operation cost.

A similar project has been developed in Japan and also in operation in Indonesia. However, Japan has more advantage in developing the system because fishermen in Japan already have a database on fish catches 40 years ago. All information on fish catches by Japanese fishermen is kept in a systematic way and can be used easily for any simulation purpose.

The marine environment, being complex and dynamic in nature, affects the recruitment, distribution, abundance and availability of fishery resources due to any fluctuations in environmental conditions. It is not possible to measure from satellites the entire spectrum of information needed to access such changes in the marine environment. However, information about important environmental factors and processes can be retrieved by using ocean surface measurements made by satellite sensors, thereby assisting in locating marine fishery resources [1].

DATA GATHERING SURVEY

DOF is responsible for collecting fish density data and oceanography information to develop a forecasting model. This information is collected through a series of survey done by using research vessel KK Senangin II equipped with 'Scientific Echo Sounder FURUNO F80'. Oceanographic information is gathered by using 'HydroLab'.

In 2007, a survey was conducted in the waters off Kelantan to East Johor. It consisted of 144 stations. In 2008, the survey was conducted in only three predetermined areas, namely Area A, Area B and Area C (Fig. 1). The Sea Surface Temperature (SST) and chlorophyll information were gathered using satellite images. Data from satellite images were acquired twice every day.

DISTRIBUTION AND DENSITY OF PELAGIC FISH

KK Senangin II vessel was used to conduct the hydroacoustic survey which covered Kelantan, Terengganu, Pahang and East Johor. This survey was done using Echo Sounder Scientific FQ80 equipment. The verification on the echogram (produced through sampling activities) was done using hired purse seine vessel. Figure 2 shows the density and distribution of pelagic fish from April to August 2007. Pelagic fish density was higher in the coastal area as compared to the deep-sea area.

DATA PROCESSING

Data gathered through various sources will be processed to identify the Potential Fishing Area (PFA). The processing and identification of PFA will involve a model development. This model is based on sea surface temperature, chlorophyll-a, and fish density information. Mapping of sea surface temperature areas will be according to the method explained by Ku Kassim *et al.* [2].

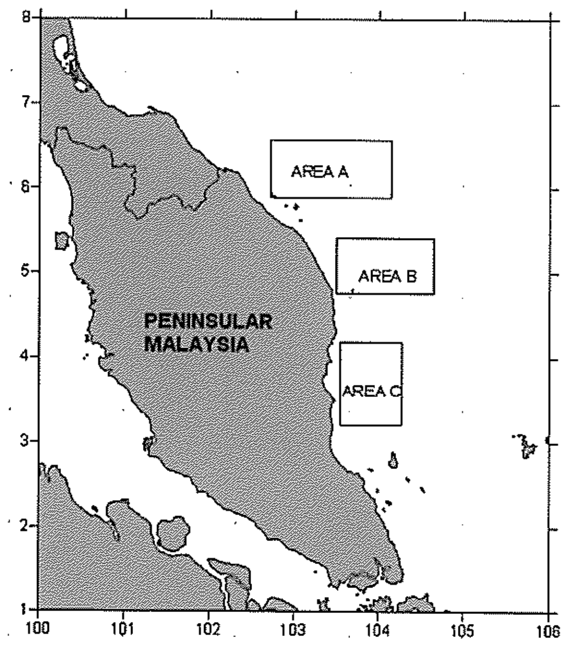

Figure 1. Predetermined Study Areas in the South China Sea.

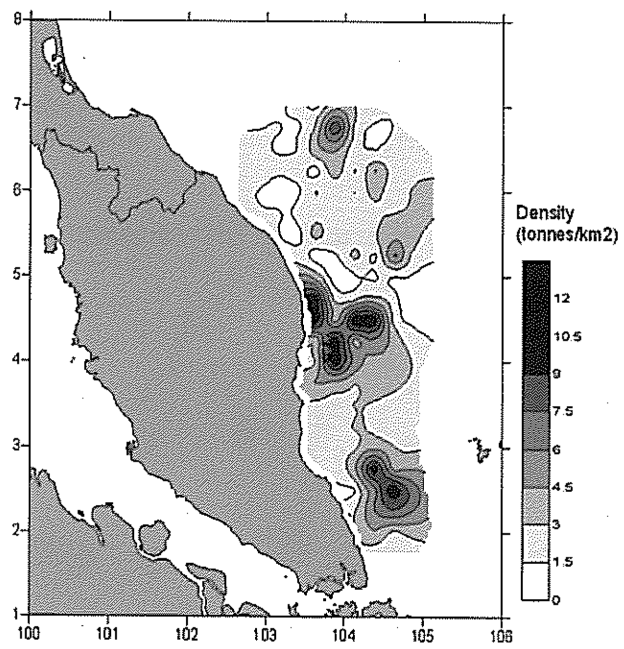

Figure 2. Pelagic fish density and distribution on the east coast of Peninsular Malaysia from April to August 2007.

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SYSTEM DEVELOPMENT

The IKANG program comprises six major components, namely, pelagic fish density determination from hydroacoustic surveys (using KK SENANGIN II vessel) and onboard sampling by 36 enumerators on selected purse seine vessels; study on sea condition from oceanographic surveys and satellite data acquisition and analyses (MODIS, OCM, NOAA and Radarsat); and fish forecasting modeling as well as data distribution to the fishers.

INFORMATION DISTRIBUTION

Potential Fishing Zone (PFZ) maps are generated after the analysis of oceanographic features such as thermal boundaries, fronts and chlorophyll-a distribution. PFZ information, consisting of latitude and longitude positions with reference to particular fishing area will be kept in the PFZ Portal. The information in this portal can be accessed by the users (including fishermen). The information can be accessed by using handphone, satellite phone, PDA, computer or fax (Fig. 3).

The output of PFZ will be displayed in various format and media, including the Global Positioning System (GPS) location of PFZ in text to multilayered thematic maps. The format and media used to display the output depend on the user type and their needs. Besides PFZ information, the users will be given sea surface temperature, chlorophyll-a, and sea current direction information periodically (daily, weekly, monthly and yearly). Figure 4 shows an example of output provided by the Fish Forecasting System (FFS). The output shows fish location and the GPS coordinates of that location.

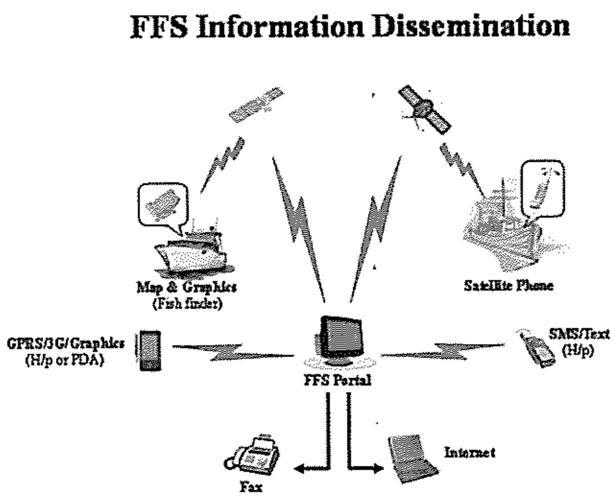

Figure 3. Information Dissemination System.

THE DEVELOPMENT OF SUPPORTING INDUSTRIES

Fishermen group

The success of IKANG program will depend very much on the cooperation given by the target group in providing fish catch area information. However, most of the fishermen consider this information as a trade secret. Thus, the fishermen are encouraged to collect the data systematically and apply these data for their benefit. These data can be marketed to other interest groups. Indirectly this program will generate fishermen entrepreneurship based on the fish catch area information.

Private and corporate

Presently, a communication system using satellite technology is the only means to communicate effectively in South China Sea. However, this involves a huge amount of operation cost and not affordable for most of the deep sea and coastal fishermen. Cellular operators like Celcom and Maxis are suggested to provide a good communication infrastructure in South China Sea by smart partnerships with companies like Petronas, Shell and Esso. The communication equipment (transmitters and repeaters) can be placed on the oil dredging platforms surrounding the Malaysia seas.

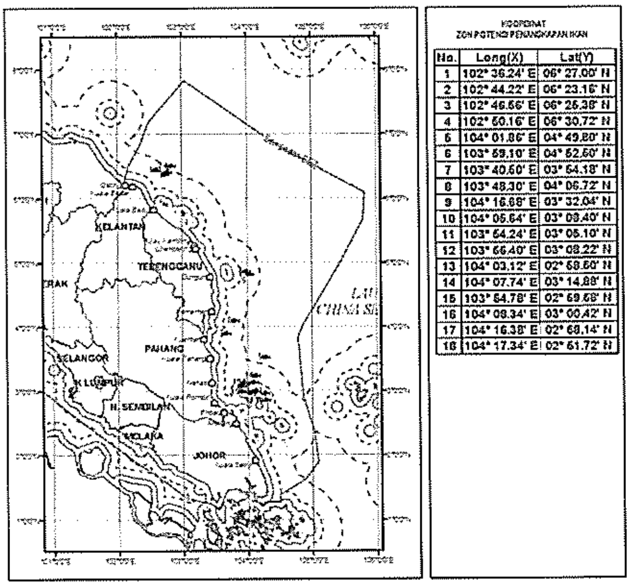

Figure 4. Screen presentation for PFZ.

By having this infrastructure, the sea communication will become cheap and affordable for most of the fishermen. Indirectly, the IKANG program will achieve its target where the potential fishing location can be transmitted directly to fishermen at the sea through handphone, fax and Internet.

CONCLUSION

Sea Surface Temperature (SST) maps showing the prevailing and changing environmental conditions are a useful indicator for various fish species especially pelagic fish. Studies have shown that information on thermal fronts derived from SST charts can be effectively used for exploiting pelagic resources especially tuna, as they are sensitive to variations in temperature. Also it has been well established that the distribution of tuna resources in different parts of the world has a close association with temperature changes.

FFS is one of the most relevant projects for the fishing community. This project will be a very significant contributor in saving fuel cost for fishermen. The anticipated overall cost saving is 30% and net income increase of 20% for fishing vessel operators. However, contribution of the project stakeholders is very important to make this project a successful one.

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REFERENCES

1. Lasker R., Palaez J. and Laurs R.M. (1981) The use of satellite infrared imagery for describing ocean processes in relation to spawning of the northern enchovy (*Engraulis mordax*). *Remote Sensing of Environ*ment **11**: 439-453
2. Ku Kassim Ku Yaacob, Ahmad Ali and Mahyam Mohd Isa (2007) *Keadaan Laut Perairan Semenanjung Malaysia Untuk Panduan Nelayan*. DPPSPM.

Biomass Yield Trends Fisheries biomass yields were examined in relation to warming trends for 63 LMEs for the period 1982 to 2004. Fisheries biomass yield trends were plotted for each LME using the LOESS smoothing method (tension = 0.5) and the emergent increasing and decreasing patterns examined in relation to LME warming data [26]. Observed trends were compared to earlier studies for emergent spatial and temporal global trends in LME fishery biomass yields [27]. Fisheries biomass yields are increasing precipitously in each of the four Southeast Asian LMEs (Fig. 21).

Pollution and Ecosystem Health Module Indicators

In several LMEs, pollution and eutrophication have been important driving forces of change in biomass yields. Assessment of the changing status of pollution and health in an entire LME requires multiple-state comparisons of ecosystem resilience and stability. To be healthy and sustainable, an ecosystem must maintain its metabolic activity level and its internal structure and organization, and it must resist external stress over time and space scales relevant to the ecosystem [28]. The pollution and ecosystem health module measures pollution effects on the ecosystem through the monitoring strategy of the US EPA; its pathobiological examination of fish and fish tissue; and estuarine and nearshore monitoring of contaminants and contaminant effects in the water column, substrate, and selected groups of organisms. Where possible, bioaccumulation and trophic transfer of contaminants are assessed, and critical life history stages and selected food web organisms are examined for indicators of exposure to and effects from contaminants, effects of impaired reproductive capacity, organ disease, and contaminant-impaired growth. Assessments are made of contaminant impacts at both species and population levels.

Implementation of protocols to assess the frequency and effect of harmful algal blooms, emergent diseases, and multiple marine ecological disturbances [29] are included in the pollution module. The US Environmental Protection Agency (EPA) has developed a suite of five coastal condition indices: water quality, sediment quality, benthic communities, coastal habitat, and fish tissue contaminants, as part of an ongoing collaborative effort with NOAA, the

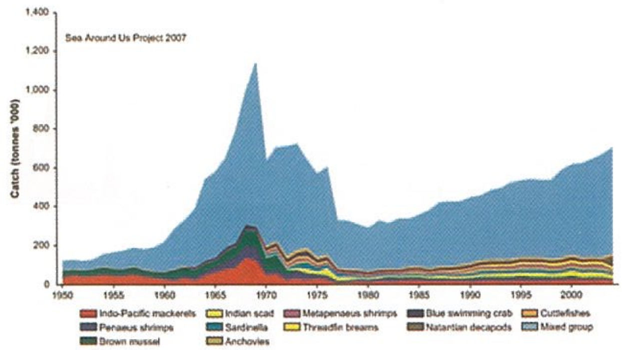

Figure 13. Total reported landings in the Gulf of Thailand LME by species (Sea Around Us 2007).

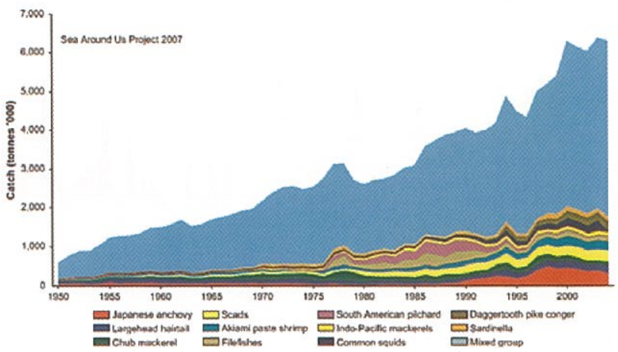

Figure 14. Total reported landings in the South China Sea LME by species (Sea Around Us 2007).

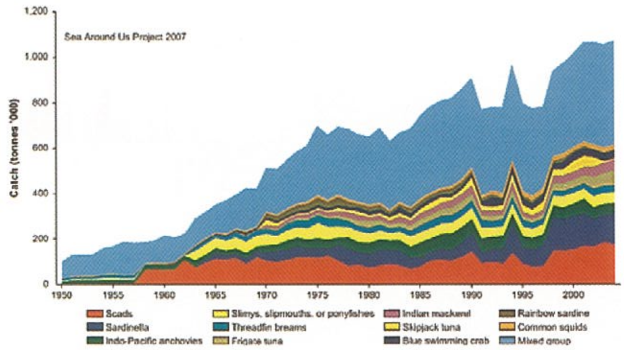

Figure 15. Total reported landings in the Sulu-Celebes Sea LME by species (Sea Around Us 2007).

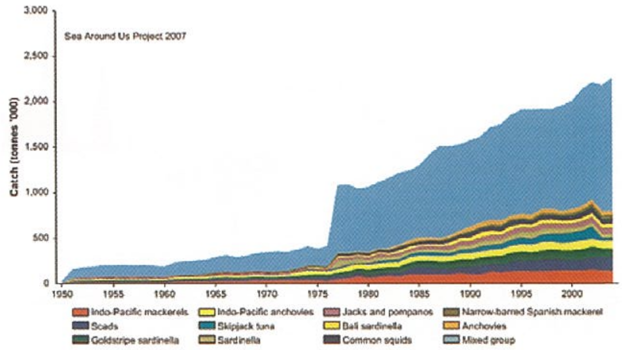

Figure 16. Total reported landings in the Indonesian Sea LME by species (Sea Around Us 2007).

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Role of education and awareness in empowering coastal communities for the conservation and sustainable use of fishery, natural and marine resources

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Abstract It is important to communicate the values and functions of coastal ecosystems to the public at large and target groups so that with this basic understanding, conservation and sound-use of coastal ecosystems can be maintained. This paper deliberates on how the role of education and awareness can instill the values of stewardship of natural resources to become embedded in fishing communities by exemplifying the work of the Penang Inshore Fishermen Welfare Association (PIFWA). The education and training component seeks to develop environmental awareness among fishing communities that eventually translates into remedial actions to problems faced in sustaining their livelihood. Promoting conservation and sustainable use of fishery and mangrove resources brings about positive impacts to support the sustainable livelihood of inshore fishing communities. PIFWA's experience has shown that rehabilitating degraded mangroves is beneficial in the long run as the improved wetland ecosystem revives its biodiversity and thus sustains the livelihood of fishers. The development of a self-help mechanism and empowerment of local communities to take action to ensure sustenance of their livelihood through conservation efforts and wise use of natural resources has contributed to the sustainability of this initiative. The fisher community has also realized their potential to enhance their surrounding natural habitats and livelihoods.

Keywords education – awareness – empowerment – coastal communities – conservation – sustainable livelihood

INTRODUCTION

Environmental issues affect the most fundamental of people's concerns, among them, their livelihood and economy, safety, food and nutrition. Environmental awareness, most often comes about when communities become victims of environmental degradation or threatened by development projects in their backyard.

Education is central to achieving environmental and ethical awareness, changing values and behaviours consistent with sustainable development and improving skills, as well as for informed public participation in decision-making [1]. Environmental education is basically an environmental management tool for the long term as it allows the values of sustainable development and of stewardship of natural resources to become embedded in individuals and communities.

The processes of education and awareness-raising vary and also take a considerable time before they truly become effective. It is anticipated that the understanding of the ecosystem would eventually translate into actions and attitudes which bring about environmental protection and conservation.

Development of environmentally responsible behaviour among the general public can be enhanced through active participation in environmental related activities such as participation in nature-related clubs, environmental seminars, engaging in outdoor activities and environmental campaigns. However, there is a need for sustained education and awareness-raising if we want to bring about positive changes in attitude and behaviour.

The education and training component of the Consumers' Association of Penang (CAP) and Sahabat Alam Malaysia (SAM) seeks to develop environmental awareness among communities. Our work with communities is a long process with an aim to promote the conversion of awareness into actions. Advocacy and networking which is closely linked to education and training, subsequently ensues. All activities for advocacy and networking involve an education component. This is the ingredient that makes effective engagement of communities to propel them to act and not merely to know.

This paper addresses the role of education and awareness in empowering coastal communities, showcasing CAP and SAM's work with the Penang Inshore Fishermen's Welfare Association (PIFWA) and subsequently the formation of a network of coastal communities whose aim is to advance conservation and wise use of coastal ecosystems and resources.

From our experience, education and awareness-raising amidst active community involvement in local issues is sustainable. This case study shows how with increased awareness, a group of fishers facing threats to their livelihood, were able to take charge and take actions to defend their livelihood and protect the environment.

CASE STUDY: THE INITIATION AND ACTIVITIES OF THE PENANG INSHORE FISHERMEN WELFARE ASSOCIATION (PIFWA)

Fishery resources are treated as a common good. Based on Malaysian fisheries law, trawling within five nautical miles of the shoreline is forbidden but due to lack of enforcement, some fertile inshore areas became focal points for trawler activities.

The idea of an association among inshore fishermen in Penang was born out of discontent with these trawler encroachments, destruction of natural resources and dwindling fish catch. The inshore fishermen decided to set up an association which would truly defend their rights for livelihood as the government sponsored fishermen's associations were not effective in looking after the welfare of the smaller fisher folk [2]. They garnered support for this idea without much difficulty from like-minded individual fishermen who were very concerned over the future of fisheries in Penang.

Consequently the grouping was named as Penang Inshore Fishermen Welfare Association (PIFWA). In 1990, the pro-tem office bearers attempted to register the organization as an association because authorities and agencies remarked that PIFWA was not registered, thus illegal and that they should not be representing fishermen in the state.

The pro-tem committee went through vetting procedures by the Registrar of Societies and interviews were conducted on why they needed to form another organization when one already existed. The fishermen had to reason out that they were actually trying to save the remaining fisheries in the sea and convinced the Registrar that they were working towards sustainable fishery. After almost four years later, in November 1994, PIFWA was registered with the Registrar of Societies.

In PIFWA's earlier years, CAP took a leadership role in facilitating and collaborating in PIFWA's activities. CAP played an important role by supporting and guiding PIFWA until it became independent and self-reliant. CAP also facilitated and provided assistance when needed and thus, was actively involved in ensuring the smooth implementation of PIFWA's various projects.

It was not enough to have only the fishers involved in PIFWA to be aware of their livelihood and environmental issues. We needed the whole community to be involved and this can only be done through awareness raising and education. In designing and implementing the awareness raising programme we considered the sustainability and longevity of the programme beyond its development phase and implementation.

After gaining knowledge, the fisher communities acquired new attitudes in caring for the environment, working for its defence and protecting its richness. The fisher communities recognize that ecological and environmental protection is an integral part of the stewardship of God's creations.

CAP and SAM play a key role in discussing new ideas and mobilizing coastal communities. We assist PIFWA leaders to communicate, exchange information and to learn from other fisher communities, local and foreign, by networking. Activities conducted with the fisher communities were valuable lessons for both the communities and also our field and programme staff.

We also assist PIFWA in securing funding to conduct their activities. These funds include Global Environment Facility Small Grants Programme Malaysia (GEF SGP) coordinated by the UNDP Office in Malaysia. Coastal management is an integral part of coastal fishing community in order to sustain their livelihood. They are committed to protect and sustain the coastal ecosystem and needed funds to carry out activities to further advance their commitments.

PIFWA also embarked on a campaign to raise awareness on the importance of wetlands, popularize coastal resources such as mangroves and promote ecological concerns in their respective communities. By generating awareness, we have found that public support can be mobilized and this increases pressure for change and policy reforms. Some of the activities that we have conducted are exhibitions, campaigns to save mangroves from degradation, implement environmental projects such as mangroves replanting and engage in social activities such as helping those in need.

In addition to books, a variety of material such as streamers, pamphlets and videos on coastal resources and traditional fishing that is educational, practical and communicative have been developed, courtesy of funders including GEF SGP Malaysia and Danish International Development Agency (DANIDA).

PIFWA also conducts educational programmes to promote environmental awareness among young children, aiming to lay the foundation to generate a society which will have the knowledge and capability to act responsibly and care for the environment. Local experiences enrich what is learned in school. Caring for the environment is inculcated through their experience in taking part in community programmes such as mangroves planting.

Many of PIFWA's activities are done voluntarily and have always been a grassroots initiative, participatory and people-centred. Some of the activities undertaken are elaborated further, as follows.

Adopting and replanting of mangroves

In 1997, PIFWA adopted the mangroves in Balik Pulau, Penang as a vital resource to be protected. PIFWA members planted nearly 1000 mangrove saplings in a controversial mangrove belt which was earmarked for development of shrimp aquaculture. Planting of mangrove saplings which started as an expression of discontent has now evolved into a movement to rehabilitate degraded mangroves. Besides the coastal communities, others are also invited to take part which itself is an awareness-raising and education element.

PIFWA members replanted mangroves because they recognized the importance of mangroves as spawning grounds for fish, crabs and prawns. It is also common knowledge that, in the absence of mangroves, their boats moored at jetties would have little protection against strong winds and waves. The mangrove replanting projects were carried out in collaboration with other organizations or on their own and thus far more than 100,000 saplings have been planted in the coastal belts of Penang Island and Seberang Perai.

Over the years, PIFWA's experience has shown that rehabilitating once degraded mangroves is beneficial in the long run as the improved wetland ecosystem has revived its biodiversity and thus sustains the livelihood of fisher communities. As a result of these replanting initiatives, fishermen reported that there are now more crabs, shellfish and mollusks in the regenerated mangroves. Many people, besides the local communities, are now sourcing for these crabs and shellfish to supplement their income. Fish catch in the neighbouring waterways have been reported to have improved too.

PIFWA manages a mangrove nursery in a wetland area in Sungai Chenaam whereby mature mangrove seeds are sown in polybags. The mangrove replanting project has been a success with a high survival rate of the planted saplings at 80-90%. The high success rate came about through years of experience.

Establishing river monitors

Using traditional fishing methods, the fishing communities around Seberang Perai sustained themselves by catching and selling river lobster from the Sungai Kerian, netting crabs in the mangrove forests and fishing in the seas. Their livelihoods face many challenges due to pollution, mangrove destruction and trawling.

In order to address these threats, the fisher community decided to 'adopt' Sungai Kerian. They designed a monitoring system. River surveillance was carried out by a number of fishermen who go in a boat up and down the river daily to monitor any discharge of waste into the river system. They documented the fish living in the river, the sources of pollution and collected water samples to test for pollutants. Information was sent to the relevant government authorities who could then act against polluters.

As the implementation of the project was designed by the core group of fishers themselves, their concerns, experiences, and local knowledge were taken into account, and hence were the keys to the success of this project. The fishers who undertook surveillance activities, both river and sea, indirectly became 'watchdogs', 'eco-rangers' and 'whistle blowers'.

As a result, the water quality of the Sungai Kerian has improved as indicated by the return of river lobsters, several types of freshwater fishes, and better fish catches by the fishermen. Fireflies are also thriving as the *berembang* trees by the riverbank are healthier. Enforcement agencies have also been proactive in taking action against polluters.

Sea surveillance

Over the years, the nature of fishing in Malaysia and the condition of marine and freshwater resources has changed most radically. From sampans, *bubus*, and drift nets, we have now new technology like high-powered diesel engine vessels. The shift from artisanal fishing to commercially orientated fishing has rendered the fish resources in inshore waters fully exploited up to the maximum sustainable yield and now there is a tendency for over exploitation [2].

Since the 1960s, Malaysia's traditional inshore fishermen have been complaining about the illegal activities of trawlers. The trawlers encroach within one to five nautical miles from the shoreline, which has been designated for traditional fishing. Due to the encroachment of trawlers, sea-beds have been polluted and become muddy, breeding ground of marine life threatened and extinction of various marine species have been reported.

To conserve and sustainably use the sea, the fishermen have to watch out for illegal trawlers. While the Fisheries Department has the manpower to keep watch during the day, at night the seas used to be unprotected. The fishermen set up a nightly watch by patrolling the sea, taking photographs, filming using video cameras and jotting down boat numbers of the encroaching trawlers. These are then reported to the Department of Fisheries.

As a result of the nightly sea surveillance, generally there have been fewer encroachments by trawlers. The fishermen still reported trawler sightings within the five nautical miles zone designated for inshore fishing.

Engaging enforcement agencies and the media

Initially in the 1990s, PIFWA was not well received by the government, especially from the State and relevant implementing agencies. This was because PIFWA frequently complained of lackadaisical attitude of the enforcement authorities. PIFWA was not perceived as a constructive force but a negative element.

With our support and guidance and participation from the fishers, PIFWA successfully brought back fish resources through mangrove replanting activities, sea cleaning and tipping off the authorities regarding lawbreakers. Over the years, after recognizing that PIFWA's objectives and attempts were beneficial for local communities, the authorities are now more open when the fishermen approach them.

A lesson learnt here is that with perseverance PIFWA which was once threatened of deregistration, is now sitting at meetings with the authorities to discuss their problems. The improvement in the rapport between PIFWA and government departments also shows that the authorities are now more open to community-based projects, supporting novel actions undertaken by the fishermen to protect the ecosystem they rely on for their livelihood. Through this relationship, future and sustained collaboration with the government authorities can be maintained.

The media played a big role in highlighting issues brought up by PIFWA and at the same time raising awareness and educating the public on these issues. The coverage given by the local media and international media with technical support from groups such as CAP, SAM and Mangrove Action Project has made PIFWA known internationally for its role in safeguarding coastal biodiversity especially mangrove ecosystem.

Networking

The development of a network of community organizations involved in similar issues was next in our agenda. This network of coastal communities, called Jaringan Bertindak Nelayan Pantai Semenanjung (JARING) was able to compare strategies, approaches, solutions and share lessons learned from the various activities that were implemented. The networking also helps solve larger issues and strengthens the voice of coastal communities.

The establishment of this network was a long process. First we had to raise the awareness of the various coastal communities. This was done by carrying out workshops, dialogues, road-shows at venues where fisher communities converge. Then interested coastal community groups from Penang, Kedah, Perlis, Perak, Melaka and Johor formed the network called JARING which is facilitated by SAM.

Some of the activities carried out by the network include participation in study tours, attendance in regional conferences and regular meetings to learn from the experience of each others. There are now five community mangroves and mangrove nursery project implemented by the JARING network. PIFWA members with support of SAM staff were the main resource persons in building the capacity of the JARING network.

JARING members also network with regional and international groups such as YADFON from Thailand, WALHI in Indonesia, World Forum of Fisher People, Asia Solidarity Against Industrial Aquaculture and the Mangrove Action Project.

With the spirit, perseverance and willpower to further their cause, this grassroots network now tackles a broad range of problems faced by the fishing community including shrimp aquaculture, overfishing, trawling, toxic dumping, poverty and coastal development that would be detrimental to coastal resources and fisheries.

CONCLUSION

The PIFWA experience is indeed exemplary in illustrating a truly grassroots initiative borne out of awareness and realizing the value of environmental stewardship, which has subsequently brought about effective results in protecting the environment and sustaining their livelihood. PIFWA's initiative and determination to protect coastal natural resources and livelihood of coastal communities has inspired many other communities to assert their rights and safeguard the environment. With their collective actions and dedication towards environmental stewardship they have rehabilitated many degraded coasts and continue to do so for the benefit of the environment, the present and the future generations.

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REFERENCES

1. United Nations (1996) *Promoting education, public awareness and training. E/CN.17/1996/14/Add.1.* United Nations Department of Economic and Social Affairs.
2. Balan P. and Saidin H. (2005) Case study: Fishing resources – empowering the fishing community in Penang. In MENGO (Ed.) *Proceedings of National Conference and Exhibition on Sustainability, Malaysia 2005* pp. 511-512. Malaysian Environmental NGOs, Kuala Lumpur.

Making a case for legal protection for the survival of the Malaysian marine fishing industry

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Abstract This paper argues that there are several lacunae in the current Malaysian laws dealing with the marine fishing industry giving rise to several challenges for the industry which ought to be addressed. The Malaysian marine fishing industry should comprise the industrial fishing community and the artisanal, small-scale fishers. Today, these fishers face a variety of challenges, some of their own and some cascading from the international level and consequently deserve special legal protection to prevent the total collapse of this industry. The challenges faced include unsustainable fishing practices and threats stemming from illegal, unreported and unregulated fishing, depletion of fishery resources, unhealthy grants of foreign subsidies, and non-compliance with international fishery instruments. The drafting of national legislation in accordance with international standards and effective interpretation by the courts would assist in countering these challenges and would be in consonance with Malaysia's international law obligations in the context of sustainable international fisheries law and policy and would contribute to a level playing field for the Malaysian fishing community. It is argued that Malaysia can overcome these challenges and if she does not, then there is a high probability that the sun will set on an already endangered industry.

Keywords International unsustainable fishing practices – Malaysia – collapse of marine fishing industry– present regime – future protection

INTRODUCTION

The global fisheries crisis according to the analyses of the Food and Agriculture Organisation (FAO) shows a trend towards worldwide depletion of fisheries resources for decades [1]. Fully exploited or overexploited fisheries stand at 74% worldwide. Developing countries continue to demand for fish protein while climate change, toxic pollutants, alien species and other environmental threats are adding unprecedented stress to marine ecosystems. The fisheries crisis is one of the defining environmental challenges of our time [1] because of intertwined issues of inadequate management and harmful subsidies [1]. The marine fishing industry in Malaysia should comprise the artisanal, small-scale and industrial fishing community. They face a variety of challenges, some of their own and others cascading from the international level which include unsustainable fishing practices, illegal, unregulated and unreported fishing (IUU), depletion of fishery resources, unhealthy grants of foreign subsidies, and non-compliance with international fishery instruments. Consequently, they deserve special legal protection to prevent the total collapse of this industry.

The special legal protection envisaged in this paper comprises the adoption of national legislation in accordance with international standards and effective interpretation by the courts that would counter these challenges. Such actions are in consonance with Malaysia's international law obligations in the context of international fisheries law and policy and will hopefully contribute to a level playing field for the Malaysian fishing community. The oft asked policy question is whether a fisheries protection regime should be based on science, that is a science based command and control theory or in an economics based theory focused on maximizing employment and fulfilling basic human rights of fishers rather than on the biomass of fisheries or the aggregate income of fleets [1] or perhaps on the best indigenous approaches.

This paper recognizes the importance of a fused policy approach of science and economics. It has not considered best indigenous approaches as none were available for comparison. This paper argues that standards established by international organizations in specialized international fishery treaty obligations, decisions of judicial bodies and international environmental law principles need to be included for a protective legal regime in Malaysia.

The paper is divided into two broad parts: the international scenario and the Malaysian experience. The part on international scenario discusses the theory of New Institutionalism in economics, global subsidies, the standards laid down in conventions of the International Maritime Organisation (IMO) and of the FAO. These aspects are the significant building blocks for the new legal protection regime for the marine fishing industry of Malaysia. For instance, the excessive European Union (EU) subsidy experience and the administrative and regulatory failure of the governance structure of the sector are significant as they were the Achilles heel of the EU fishing industry and the accompanying reforms that have enabled the industry to bounce back in the EU. The Malaysian section discusses Malaysian statutes and case law and evaluates these standards from the international legal perspective and highlights the lacunae. Finally, the paper discusses the way forward for an effective legal regime that will ensure a level playing field for the Malaysian marine fishing industry in the absence of which the industry will collapse.

INTERNATIONAL SCENARIO

In the theory of New Institutionalism or new institutional economics and natural resource management ideas, institutions refer to humanly devised rules and market conditions not financial institutions. Internal institutions consist of constraints such as taboos and customs. New institutional economics focuses on a field of study that encompasses institutional structures that govern economic behaviour and the economic exchange and allocation of resources and consumer goods and services in the protection of the fisheries regime. It deals with the consequences of institutions for the governance of ocean fisheries, climate change and biodiversity and property rights in the fish, processes of contracting and the enforcement of contracts for fisheries. The three main types of institutions that govern natural resources are defined as property rights, entitlement systems, and mechanisms for allocating and adjusting entitlements. Fish is considered as an open-ended or open access natural resource. It means that no one in particular can claim the benefit of the stream. This theory addresses entitlement systems whereby a resource owner may consider the fish as private property, the community as its common property, and the government as its state property over which it can assert control in two ways by imposition of direct controls through input or output restrictions, or by operating controls which indirectly affect the resource (fiscal controls, subsidies, taxes, or price and marketing strategies). From a new institutional perspective, the best method is chosen by comparing transaction costs, or the costs of "doing business" [1]. Output controls are generally effective in limiting fishing effort, and do not suffer the inefficient costs of fishing arising from input controls. However, output controls have other shortcomings, such as the risk of over-capitalisation, large enforcement costs and the encouragement of exploitative behaviour [2]. In short, there is no perfect entitlement system. The optimal system depends on the characteristics of the resource being controlled. In the case of fisheries, these characteristics include those of the fishery, the fishers, and the broader institutions of social and economic governance.

The issue of fisheries subsidies has been the subject of negotiations at the Doha Round of the World Trade Organisation (WTO) talks in November 2001 and this was followed by the World Summit on Sustainable Development (WSSD) in Johannesburg [3] where States were called upon to eliminate the subsidies that contributed to IUU fishing and over-capacity, while efforts were underway at the WTO to improve the issue of fisheries subsidies [4]. The WSSD in 2002 stressed the need to eliminate environmentally harmful subsidies. The UNEP informs the WTO negotiations on new disciplines for fisheries subsidies in the interface of fishery policy, the environment and trade. The Icelandic proposal on Fisheries Subsidies and elimination of environmentally damaging and trade distorting practices recalls the joint condemnation expressed against this subsidisation by Australia, Iceland, New Zealand, the Philippines and the United States of America [5]. In a report prepared by David K. Schorr and John F. Caddy "Sustainability Criteria For Fisheries Subsidies: Options for the WTO and Beyond" which was jointly commissioned by UNEP and WWF, it was highlighted that in the

WTO, governments are moving towards adopting binding new limits on fisheries subsidies, including an outright ban on certain classes of them. Beyond the WTO, domestic policymakers in many countries have begun reviewing – and some even reforming their own fisheries subsidies policies. The most fundamental question facing governments reconsidering fisheries subsidies is the scope of the WTO ban they have agreed to adopt – whether, for example, the ban will cover subsidies to land-based fisheries infrastructure or post-harvest processing and marketing, and how far the ban should be relaxed in accordance with the principal of "special and differential treatment" for developing countries" [5].

The Korean Fisheries Industries, comprising the National Federation of Fisheries Cooperatives, Korea Fisheries Association, Korea Deep Sea Fisheries Association, Korea Federation of Advanced Fishermen, and The Civil Federation for the Sea Preservation have strongly opposed the stance adopted at the WTO where fisheries subsidies are banned but fisheries products are exempted from tariffs. In their resolution they have passed the following:

- Discussion on the tariff elimination that is in contravention to the Doha Ministerial Declaration must be stopped immediately;
- The recommendation …to eliminate the tariffs on fisheries products must be abolished;
- Flexibilities must be embodied in the reduction of tariffs on fisheries products;
- Norms on fisheries subsidies must be established in a manner to assure the continual survival of the fisheries industries in each of the countries, in order to assure and support the continued growth in fisheries industries and fisheries communities, and to appropriately manage and preserve fisheries resources; and
- An objection to the separate regulations on fisheries subsidies at the WTO level. Environment in which each country is situated must be thoroughly recognized in categorizing fisheries subsidies [6].

In the EU, fisheries gained from a variety of subsidies such as new market outlets, fleet modernization and capacity reduction. Fisheries are administered by the European Fisheries Fund (EFF) established for the period 2007-2013 with a budget of 3.8 billion Euros for the said period. Based on their excessive fishery subsidies which have led to loss of fish stocks and an unsustainable fisheries sector, their present commitment is to reduce overcapacity and to introduce sustainable fishing practices [7]. The EFF budget stands at €4304 million for the period 2007-2013. During the period 2007-2013 the Commission will allocate on average €615 million per year to the Member States who have decided to benefit from EFF aid (all the Member States except for Luxembourg) depending upon their fisheries sector size, the number of workers and taking into account any "adjustments considered necessary for the fishing industry and continuity of the measures in hand." The EFF is distributed in proportion to the "total sum of all public expenditure". Higher payments are made to the most disadvantaged regions and for the new Member States covered by the new "convergence" objective under theStructural Funds. The Regulation besides setting "the rules on governing eligibility of expenditure (Article 55), financial management, financial corrections, budgetary appropriations and reimbursement also establishes a Committee of the European Fisheries Fund to assist the Commission in managing the EFF. In summary, the EFF contributes to the realization of the Common Fisheries Policy (CFP) objectives of ensuring the long-term future of fishing activities and the sustainable use of fishery resources; the reduction of pressure on stocks by matching EU fleet capacity to that available; promotion of sustainable development of inland fishing; helping boost economically viable enterprises in the fisheries sector and making operating structures more competitive; fostering the protection of the environment and the conservation of marine resources; encouraging sustainable development and improving the quality of life in areas with an active fishing industry; and promoting the equality between women and men active in the fisheries sector. The five priority areas are focused on measures to adapt the EU fishing fleet, on aquaculture, inland fishing, processing and marketing, collective action, sustainable development of fishing areas, and technical assistance [7].

Markus Knigge in his article "Putting an end to harmful fisheries subsidies" points out that according to the European Commission estimates, the European fleets operated at approximately 40% overcapacity which because of European subsidies saw too many vessels chasing too few fish which in turn has led to the up-building of this overcapacity. In Europe's case, it is clear that subsidy reforms are needed to reduce fleets capacity which includes fleet modernization, replacement of engines and under declaration of engine power to enable fish stock recovery and promote a sustainable fisheries sector [8].

The WWF Study on Spanish Fleets Operating in the Mediterranean 2003 said that "80% of the engines supported by EU aid exceeded the legal engine power limit. On average, real engine power was over 2.5 times higher than declared" [9]. The harmful effects of the subsidies also included target aid to adapting EU fleet's capacity to existing resources, aid to IUU fishing vessels and operators or those engaged in breach of environmental laws and abolition of fuel tax exceptions [9].

Coffey argues that if the EU Fisheries Fund had been managed well, the EU Fisheries Fund could have helped to regenerate the severely depleted fish stocks, implemented properly the EU habitats Directive and the so-called "Natura 2000" network of protected areas, and certified fish products caught using environmentally friendly methods [9]. Coffey points out that none of the measures in the EFF was compulsory and each country could determine its national priorities and measures. However, limited funds were allocated to environmental measures [9]. In January 2008, the EFF beneficiaries and their allocated financial amounts were disclosed which allowed for a more effective financial instrument to be prepared for the future. EU governments broadly acknowledge that the EU fisheries crisis was contributed to by EU subsidies. Coffey stresses that it is crucial for the EU to transit to "a well-managed, socially and environmentally sustainable fisheries sector." Coffey warns that the next financing instrument should avoid repeating the mistakes of the past and instead focus on areas of common concern, such as monitoring and enforcement and involvement of environmental organizations in the programming process for the sustainable management of the EU fish resources or fear total collapse of fish stocks and ecosystems as predicted by scientists by 2050 [9].

The Economics and Trade Branch of UNEP placed new fisheries subsidies disciplines based on distinct sustainability criteria on the international agenda and called for an elimination of environmentally harmful subsidies that destroy sustainable fisheries. UNEP does not believe that the WTO must sit as a judge of fisheries management policies. Based on the FAO Expert Consultation Report 2000, the term "subsidy" can mean anything from government financial transfers to any government intervention to any short-term benefit given to producers, and finally includes all government action.

In the EU, based on the recent changes made to the use of the EFF, the EU fishing industry should now be a sustainable venture.

The FAO refers to the wider community of fishers and explains the difficulties in characterizing the small scale fishers as this is a relative term, for small scale fisheries in one country may be classified as industrialized fishery in another. Some have defined this term by default in opposition to the larger-scale fisheries based on sophisticated technologies which involve heavy investment outlays which makes them inaccessible except to a new class of capitalists arising from outside the fishermen communities [10,11]. In the past, small scale fisheries have been characterised as an activity that yields low productivity and low yield rates [10, 11]. As a result of the diverse nature of small scale fisheries, the FAO Working Group on Small Scale Fisheries Meeting in Bangkok 2003 agreed that they would adopt a working definition of the subject that encompassed a range of characteristics that are likely to be found in any particular small scale fishery – "Small scale fisheries can be broadly characterized as a dynamic and evolving sector employing labour intensive harvesting, processing and distribution technologies to exploit marine and inland water fishery resources. The activities of this sub-sector, conducted full time or part-time, or just seasonally, are often targeted on supplying fish and fishery products to local and domestic markets, and for subsistence consumption. Other ancillary activities such as net-making, boat building, engine repair and maintenance, etc… can provide additional fishery-related employment and income opportunities in marine and inland fishing communities. Small scale fisheries operate at widely differing organizational levels ranging from self-employed single operators through informal micro-enterprises to formal sector businesses. This sub-sector, therefore, is not homogenous within and across countries and regions and attention to this fact is warranted when formulating strategies and policies for enhancing its contribution to food security and poverty alleviation" [12].

The main elements of small scale fisheries are that they are labour intensive, poor and supply fish to local markets. By their very nature, they are confined to coastal waters. The Organisation for Economic Co-operation and Development, (the OECD) states that, "Poverty encompasses different dimensions of deprivation that relate to human capabilities including consumption and food security, health, education, rights, voice, security, dignity and decent work" [13].

Volume 4 of the FAO Ethics Series points out that aggressive fishing has yielded some economic benefit but conservative estimates indicate that the fisheries as a system is not operating in a sustainable and efficient manner [14]. Developing countries have about 95% of the world's fishers of which 85% are found in Asia alone. Artisanal fishing families in Asia represent the most socially, economically and politically disadvantaged segments of the population and are akin to landless labourers or marginal farmers. Compared to artisanal fishers, small scale fishers might be considered better off even if their average income levels are often below the national poverty lines. There are about 5.8 million small scale fishers alone representing 20% of the world's 29 million fishers and they earn less than USD1 per day. This figure does not include the 23 million upstream or downstream income-poor people who rely on the small scale fishers for their livelihoods. They also face competition from the industrial fishers who have taken over the business in South and Southeast Asia resulting in a feeling of hopelessness and despair or feelings of anger among the small scale fishers [14].

Industrial foreign fishermen in foreign waters are required to furnish proof of certification or licence when coastal State enforcement agencies board their fishing vessel. The international policy for fishing, protection of fishery resources and compliance with the laws and regulations is based on the principle of sustainable development of the coastal waters. The term "coastal waters" is technical and is defined with reference to the 1982 Law of the Sea Convention (1982 LOSC), which is a constitution for the oceans, as waters falling within the territorial sea, straits, archipelagic waters, contiguous zone and the exclusive economic zone (EEZ). The 1998 Permanent Court of Arbitration (PCA) Award of *the Eriteria Yemen Arbitration* Tribunal over the Zuqar-Hanish and Zubayr groups of islands in the Red Sea upheld the territorial sovereignty claim of Yemen over these island groups, and affirmed that "sovereignty entails the perpetuation of the traditional fishing regime in the region, including free foreign access and enjoyment for the fisheries of both Eriteria and Yemen" [15]. But small scale fishers in the contiguous zone fall within the regime of the EEZ as Article 55 of the 1982 LOSC provides that the waters of the EEZ incorporate the area beyond and adjacent to the territorial sea, under which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of the 1982 LOSC. In a legal regime for the protection of the fishing industry, artisanal, small scale and industrial fishers need to have an educated, protected and well-managed access to the seas.

Before the adoption of the 1982 LOSC, the ICJ had occasion in the *Fisheries Jurisdiction Case* (*United Kingdom v Iceland*) [16], to consider the issue of preservation of fish stocks in the reconciliation of traditional fishing rights and preferential fishing rights of the States concerned. The concept of preferential fishing rights had originated in proposals submitted by Iceland at the Geneva Conference of 1958 which recommended that for the purpose of conservation, it was necessary to limit the total catch of a stock or stocks of fish in an area of the high seas adjacent to the territorial sea of a coastal State, any other State fishing in that area should be required to "collaborate with the coastal State to secure just treatment of such situation, by establishing agreed measures which shall recognize any preferential requirements of the coastal State resulting from its dependence upon the fishery concerned while having regard to the interests of the other States". The ICJ endorsed that the coastal State's 12 mile exclusive fisheries zone had crystallized as a rule of customary international law: this was a 12 nms fishery zone between the territorial sea and the high seas. These States could claim another zone adjacent to the exclusive fishing rights, namely, the Zone of Preferential Fishing Rights in a situation of special dependence on its fisheries. The ICJ held that in order to reach an equitable solution of the dispute it was necessary to balance the preferential fishing rights of Iceland with the traditional fishing rights of the UK while taking into account the rights of third States and conservation needs. So Iceland could not exclude British vessels or unilaterally impose restrictions on them.

In the *Gulf of Maine Case* [17], the ICJ disregarded

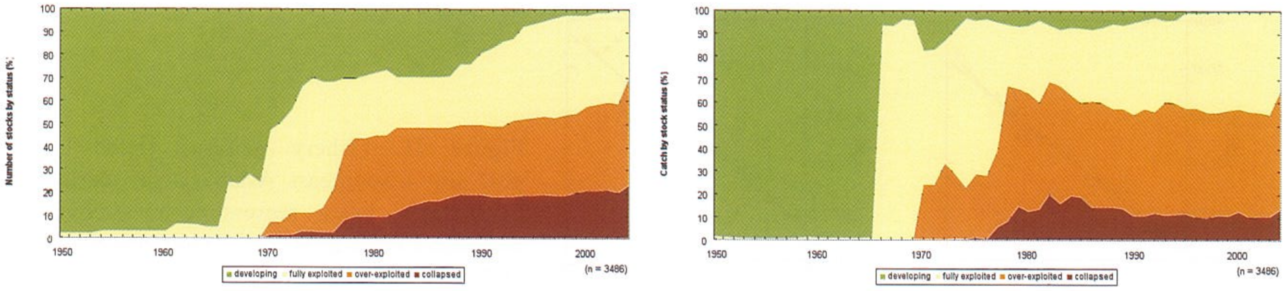

Figure 17. Stock-Catch Status Plots for the Gulf of Thailand LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (left) and by catch biomass (right) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level.

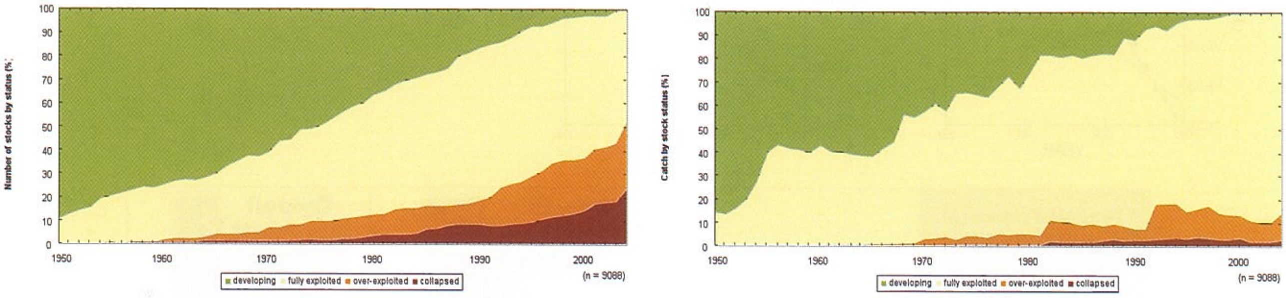

Figure 18. Stock-Catch Status Plots for the South China Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (left) and by catch biomass (right) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level.

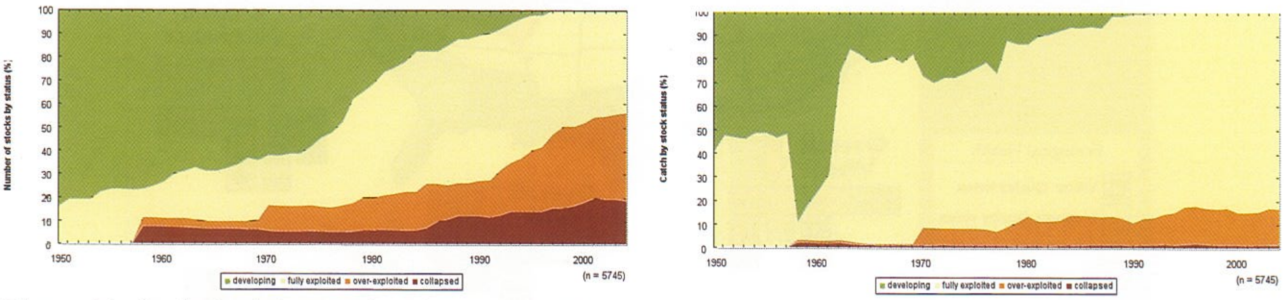

Figure 19. Stock-Catch Status Plots for the Sulu-Celebes Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (left) and by catch biomass (right) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level.

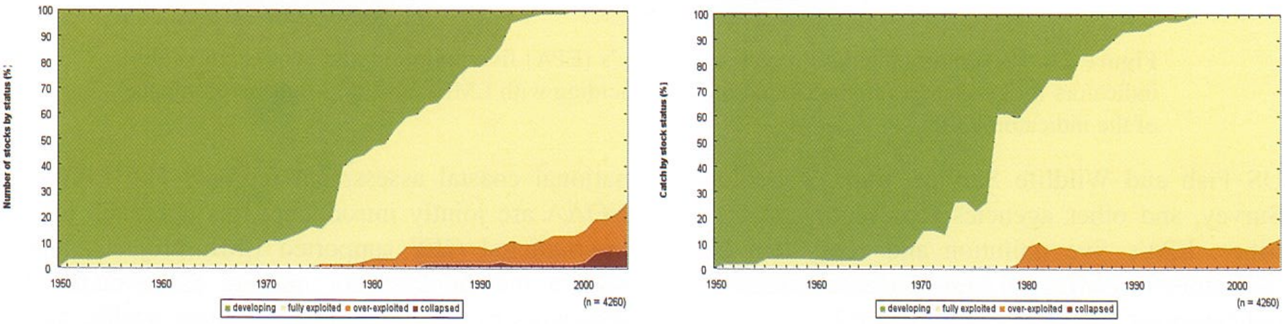

Figure 20. Stock-Catch Status Plots for the Indonesian Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (left) and by catch biomass (right) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level.

the arguments of the USA and Canada on their fishing practices when the Court used geodetic lines to draw the single maritime boundary delimitation of the continental shelf and the EFZ in the Gulf of Maine [17].

In the *Pulau Sipadan and Pulau Ligitan Cases* [18], a case between Malaysia and Indonesia, the ICJ observed that activities by private persons such as Indonesian fishermen cannot be seen as effectivités if they did not take place on the basis of official regulation or under governmental authority.

In the *Kasikili/Sedudu Island Case* [19], the ICJ held that even though the Kasikili/Sedudu Island formed part of the territory of Botswana, the Kasane Communique of 24 May 1992 between the Presidents of Namibia and Botswana continued to be in force, *inter alia*, for economic activities such as fishing to continue on the understanding that fishing nets should not be laid across the river. Judge Ranjeva also declared that that the Kasane Communique created legal obligations for the two States parties to the dispute with regard to the enjoyment and exercise of rights by their nationals in the relevant area such as fishing rights in the channels. The Declaration of Judge Higgins stated that the ICJ, contrary to what is stated in the judgment, was not engaged in an exercise of treaty interpretation of words in their ordinary meaning [19].

In the *Fisheries Jurisdiction Case* (*Spain v Canada*) [20] one of the issues that came up for consideration in the jurisdictional issue was the meaning of the term "conservation and management measures" as found in the Canadian legislation covering that part of the high seas outside Canadian EEZ [21]. Spain's main argument, on which it relied throughout the proceedings, was that the term "conservation and management measures" had to be interpreted in accordance with international law and that consequently it must exclude any unilateral measure by a State which adversely affected the rights of other States outside that State's own area of jurisdiction. Having regard to the legal characterization placed by the ICJ upon the facts in this case, it concluded that the dispute submitted to it by Spain constitutes a dispute "arising out of and concerning" conservation and management measures taken by Canada with respect to vessels fishing in the NAFO Regulatory Area and the enforcement of such measures. It follows that this dispute came within the terms of the reservation contained in paragraph 2(d) of the Canadian Declaration of 10 May 1994. The ICJ found by 12 votes to 5 that consequently it had no jurisdiction to adjudicate upon the present dispute.

In the *Jan Mayen* Case (Iceland v Norway), [22] the separate opinion by Vice President Judge Oda deserves special mention as the judge distinguished between the fisheries zone and the EEZ regime. Judge Oda emphasized that the ICJ was competent to delimit a maritime boundary only by specific agreement of both parties concerned. Denmark's unilateral application ought, consequently, to have been dismissed. Denmark's submissions furthermore supposed, wrongly, that the EEZ could co-exist with a fishery zone of the kind eliminated from the 1982 LOSC. Its request for a single-line boundary also overlooked the separate background and evolution of the continental shelf régime. In that respect Judge Oda considered that the ICJ wrongly followed the Parties in applying Article 6 of the 1958 Geneva Convention on the Continental Shelf [23] which related to a superseded concept of the continental shelf. What applied today to the delimitation of either the continental shelf or the EEZ was the customary law reflected in the 1982 LOSC, which left the Parties free to reach agreement on any line they chose, since the reference to an "equitable solution" was not expressive of a rule of law. A third party called upon to settle a disagreement over delimitation could either suggest guidelines to the parties or itself choose a line providing an equitable solution. In Judge Oda's view the ICJ, as a judicial body applying international law, was however precluded from taking the second course unless mandated by both parties to do so. It should not have so proceeded on an application which relied on declarations under Article 36(2) of the Statute of the ICJ [24] since such declarations conferred jurisdiction only for strictly legal disputes, whereas an act of delimitation requires an assessment *ex aequo et bono*. Judge Oda further criticized the ICJ's concentration on the area of overlap between claims, to the neglect of the whole relevant area, as well as its failure to give any good reason why access to fishing resources should have been taken into account in relation to a boundary applying to the continental shelf.

With reference to the adoption of a special legal regime for the protection of the Malaysian fishing industry, these ICJ decisions suggest that the drawing of Malaysian baselines ought to follow the general direction of the coast, the preservation of fisheries stocks in waters beyond the national waters requires the cooperation of neighbours and distant fishing fleets, preservation of traditional fishing rights of the Malaysian fishing community and provisions on gears and nets have to be determined by official communication and the demarcation of the continental shelf boundary and the EEZ boundary have to be settled on the basis of equitable means on a line of the States parties choice.

MALAYSIAN EXPERIENCE

Flewwelling and Hosch point to a strong commitment of the Government of Malaysia to develop the fisheries sector where the Government of Malaysia adheres to the objectives of the National Agricultural Plan of 1992-2010 to achieve total fish production of 2.9 million metric tonnes in 2010 with an annual growth rate set at 5.5 percent per annum which in turn serves to ensure sustainable exploitation [25].

Four agencies are involved in fisheries management, namely, the Department of Fisheries within the Ministry of Agriculture which is responsible for the overall management, planning and implementation; the Ministry of Science, Technology and Innovation (MOSTI) which lays down the scientific foundation for fisheries management; the Fisheries Development Authority (FDAM) or *Lembaga Kemajuan Ikan* which is responsible for enhancing the livelihood of fishers, for ensuring value-added processing and marketing to maximize benefits to the industry; and the law enforcement officers from the Malaysian Maritime Enforcement Agency, the Navy, and Marine Police all of which are coordinated by the Maritime Enforcement Coordinating Centre (MECC) chaired in rotation by the Navy and Maritime Police [25].

The policies and strategies of the Department of Fisheries for the proper management of the national fisheries sector are to:

- enforce the Fisheries Act 1985 amended in 1993, and the Exclusive Economic Act 1984;
- manage, conserve, and rehabilitate fisheries resources to ensure their sustainability;
- conduct fisheries research;
- provide training to personnel and fisheries extension services for fishermen, farmers and downstream industry entrepreneurs;
- develop and manage inland fisheries and aquaculture;
- develop and manage marine parks and recreational fisheries;
- control fish diseases and provide quarantine services; monitor pollution affecting the fisheries resources; provide basic fishery data; and
- establish standards, inspect fisheries products, and control imports and exports of fish products with the co-operation of other related agencies [25].

These policies and strategies (FAO, 2001) include those focused on:

- direct limitation of fishing effort through the licensing of fishing gear and fishing vessels through the Fisheries Licensing Policy;
- identification of nursery areas that should be protected and managed as a nursing area to ensure survival of juveniles of commercially important fish species through use of closed areas, establishment of seasons and of marine park areas (MPAs) and reserves, and zoning by vessel size;
- facilitation of cooperative research effort between government and academic institutions to provide data essential for the formulation of area management plans through transparent management planning involving the stakeholders - fishers and their associations, universities, government at all levels, processors and marketing agents;
- establishment of a strict Monitoring, Control and Surveillance (MCS) scheme to enforce fisheries laws and regulations and address illegal fishing;
- rehabilitation of resources through the establishment of artificial reefs and coral replanting programmes; and
- conservation of endangered species and biodiversity of marine ecosystems [25].

The direct limitation on effort includes a policy for conservation with a moratorium on coastal fishing to limit overexploitation. There are policies to control the size and power of fishing vessels with permission for increases only provided by the Director-General of Fisheries. Similarly, voluntary resettlement to reduce fishing pressures in areas of heavy exploitation and closing off areas to protect spawning grounds, establishment of nurseries and marine parks have also been utilized. Further, the establishment of fishery management zones plays a key role:

- Zone A which comprises less than 5 nms from shore, reserved solely for small-scale fishers using traditional fishing gear,
- Zone B beyond 5 nms and 11nms, where owner-operated commercial fishing vessels of less than 40 GRT using trawl nets and purse seine nets are allowed to operate,
- Zone C beyond 12 nms and 29 nms where commercial fishing vessels of more than 40 GRT using trawl nets and purse seine nets are allowed to operate, and
- Zone C 2 beyond 30 nms up to 200nms of the EEZ where deep sea fishing vessels of 70 GRT and above are allowed to operate [25].

In addition there are policies related to the conservation of resources, rehabilitation of resources using artificial reefs made from tires, confiscated fishing vessels, and reefs using PVC piping and prohibition of destructive fishing gear and methods. A strict Monitoring Control and Surveillance (MCS) system is part of the fisheries laws and regulations. The Fisheries Development Authority's mandate is to upgrade the socio-economic status of the fishermen community, and as such has policies to:

- promote and develop efficient and effective management of fishery enterprises and fish marketing;
- create and provide credit facilities for fish production;
- engage in fishery enterprise through boat construction, and the production and supply of fishing gears and equipment;
- promote, facilitate and undertake economic and social development of the fishermen's associations;
- register, control and supervise fishermen's associations and fisheries cooperatives and to make provisions for matters related thereto; and
- control and co-ordinate the implementation of the aforesaid activities [25].

The Annual Reports on Fishery Statistics for the years 2005 [26] and 2008 [27], presented here for comparative purposes, are chosen for the state of fisheries in the year of the South China Sea Conference and for the latest available statistics which give the current fisheries scenario in Malaysia. For instance, in 2005 unlike in 2008 there were no statistics on ornamental fish and aquatic plants [26, 27]. The Federal Government places a great deal of emphasis upon aquaculture which is made up of freshwater culture, brackish water systems (production of cockles, mussel and oyster culture), ornamental fish and freshwater fingerling production from government hatcheries. There is also general consensus that these fisheries have reached their maximum level of exploitation.

Quite the opposite of the EU subsidy experience, the strict management measures that have been implemented through legislative means include direct limitation of fishing effort by placing a moratorium on licences in coastal waters, controls on tonnage size and engine power of fishing vessels, registration of fishermen through a fisherman registration card, and voluntary resettlement of excess fishermen into other sectors such as aquaculture and post-harvest fish harvesting. Another stringent measure includes demarcation of a 5nms zone from shore which is a closed fishing area for commercial fishing vessels being nursery grounds for juveniles of prawns and fish. Equally strict are the establishment of four different types of management zones for local fishermen, prohibition of fishing in more than forty marine parks unless licensed to do so, rehabilitation of resources through the establishment of artificial reefs, amongst others, experiments using boats and PVC pipes, and the monitoring, control and compliance programme for fisheries management through the acquisition of scientific data and monitoring of authorized fishing vessels. Other strict management measures focus on licensing of both fishing vessels and fishing gear. Many types of gear are banned such as fish pair trawling, explosive electric fishing and poison fishing. Fishing gear such as push nets and gill nets are prohibited. The Malaysian Maritime Enforcement Agency also conducts surveillance of the fishing activities. There is a public water restocking programme whereby fish and prawn fries are released into estuaries of rivers [25].

In 2005, the Malaysian fisheries sector comprised three main subsectors, namely, marine capture fisheries, aquaculture and inland fisheries. Marine capture fisheries were further divided into inshore coastal fisheries and deep-sea fisheries. Inshore fisheries take place within the first 30 nms from the coastline where boats less than 70 GRT are used and deep sea fisheries constitute those beyond 30 nms where boats heavier than 70 GRT are used. Deep-sea fisheries use trawl nets, purse seines, drift nets and hook and line. In 2005, the fisheries sector produced 1,421,402.83 tonnes of fish valued at RM5245.68 million. Statistics showed that the fisheries sector recorded an overall decrease in production by 7.58% and value by 4.23% contributing about 1.08% to the GDP. However, the results from the aquaculture sector were more encouraging for this sector recorded a production of 207,219.66 tonnes which constituted about 14.58% of the total fish production and an increase by 2.47% from the production of 2004. Correspondingly, the value from the aquaculture sector also increased by 3.24% from RM1158.5 million in 2004 to RM1196 million in 2005. The inland fisheries sector continued to be insignificant producing only 4582.17 tonnes or 0.33% of the total fish production with a value of RM 32.16 million. No information was available on deep sea fisheries. In 2005, in marine fisheries, a total of 90,702 fishermen worked on licensed fishing vessels. A decrease in the number of licensed fishing vessels registered in Malaysia was recorded in 2005: it decreased by 0.33% from 36, 136 units in 2004 to 36,016 units in 2005. A decrease in fishing gear was recorded in 2005. A decrease in inshore fishery tonnage was also recorded in 2005 where the total marine landings stood at 1,209,601 tonnes out of which 988,313 tonnes came from inshore fisheries and deep-sea fishery contributed 221, 288 tonnes. The decrease in inshore fishery was attributed to the tsunami of 26th December 2004 which phenomenon saw fewer fishermen go out to sea. In addition, they also had to contend with the increase in diesel prices. In 2005, data collection from landings of tuna vessels operating in the Indian Ocean began. A total of 2400 tonnes was recorded for the year 2005.

By comparison in 2008, the picture is less gloomy for the marine fisheries if we look at the overall policy goal of producing more fish but still reported as poor for the Malaysian marine fishing industry and the artisanal, small-scale fishing community. In 2008, the fisheries sector excluded the inland fisheries and comprised only the marine capture fisheries and aquaculture sectors which produced 1,753,311.33 tonnes of food fish valued at RM7406.29 million. There were 590,139,150 pieces of ornamental fish valued at RM734.02 million and 143,659,220 bundles of aquatic plants valued at RM14.48 million. There was an increase in food fish production by 5.99% and in value by 14.52% as compared to the year 2007. The report stated that in the year 2008 the fisheries sector contributed 1.2% to the GDP. The marine capture fisheries sub-sector, made up of inshore and deep-sea fisheries, produced 1,394,531 tonnes, contributing 79.54% to the total national fish production valued at RM5627.14 million, representing an increase of 0.95% from the year before. Under this fisheries sub-sector, the inshore fisheries remained the major contributor with a production of 1,078,752 tonnes valued at RM4,494.79 million or 77.36% of the nation's fish production. Meanwhile, the deep-sea fisheries contributed 315,779 tonnes valued at RM1132.35 million. For 2008, the aquaculture sub-sector recorded a production of 354,427.55 tonnes, constituting about 20.21% of the total fish production valued at RM1740.05 million. This sub-sector showed an increase in production by 32.0% and in value by 24.88% as compared to the year before. Ornamental fish production was 590,139,150 pieces, an increase of 32.39% to the previous year. Aquatic plants production increased by 27.78% to 143,659,220 bundles. The total value of the ornamental fish and aquatic plants increased by 15.68% to RM748.50 million.

In 2008, production from the inland fisheries sub-sector continued to be insignificant with only 4352.78 tonnes valued at RM39.10 million or 0.25% of the total fish production. There were 109,771 fishermen working on licensed fishing vessels compared to 99,617 in 2007, an increase of 10.19% and 30,634 fish culturists were involved in various aquaculture systems.

A total of 40,959 fishing vessels were licensed in 2008 with the majority operating traditional gears. The report stated that out of this total, 33,052 were foreign (non-Malaysian citizens) fishermen from Thailand, Indonesia and China. A total of 52,257 fishermen (47.61%) worked on fishing vessels operating commercial gears namely trawlers, fish and anchovy purse seiners and the remainder 57,514 (52.39%) fishermen worked on fishing vessels operating traditional gears. On the whole, the number of licensed fishing vessels increased by 4.43% from 39,221 units in 2007 to 40,959 units in 2008 due principally to the additional number of renewed licensed fishing vessels during 2008. The number of deep-sea fishing vessels remained small when compared to those operating in the inshore waters. Deep-sea fishing vessels are fishing vessels of sizes

70 GRT and above and are licensed to fish in waters 30 nms from shore until the Exclusive Economic Zone boundary.

In 2008, there were 39,960 fishing vessels licensed to operate in inshore areas. There were 999 deep- sea fishing vessels licensed in 2008, an increase by 24.72% from 801 units in 2007. The said deep-sea fishing vessels did not include vessels of sizes 70 GRT and above licensed to catch tuna, anchovy purse seiners, anchovy processing vessels as well as vessels of 70 GRT and above operating lift nets, tuna long line and fish traps. The number of fishing gear licences issued increased by 3.65% to 39,961 units from 38,554 units in 2007.

As in 2005, the Report stated that the number of fishing vessels licensed did not match equally the number of licensed fishing gears. This was because each fishing vessel which was licensed to operate only one fishing gear was at times licensed to operate more than one fishing gear throughout the year or for certain seasons only. The report stated that such licenses were given to vessels operating traditional gears which were fisheries resource friendly. Dual or multiple traditional gear licences were also issued for the purpose of increasing the income of the traditional fishermen. Another reason for the inconsistency was that sometimes some licensed vessels such as anchovy processing vessels and vessels used for fish aggregating devices surveillance did not have any licence to operate any gears or where licences were issued to two vessels to operate only one gear as in the case of the vessels operating the gear known as *kenka two boats* gear.

On marine fish landings, the 2008 Report showed that it went up moderately to 1,394,531 tonnes which is an increase by 0.95% as compared to 1,381,424 tonnes in 2007. However, the inshore landings decreased by 3.43% from 1,117,056 tonnes in 2007 to 1,078,752 tonnes in 2008. Meanwhile, landings from the deep-sea fisheries sector increased by 19.45% from 264,367 tonnes in 2007 to 315,779 tonnes in 2008. The total marine landings consisted of 38.25% pelagic fish amounting to 533,404 tonnes, 19.65% of demersal fish amounting to 274,049 tonnes and 42.10% of molluscs, crustaceans and others which was 587,078 tonnes. This was due to an increase in the number of vessels operating fish purse seine.

The year 2008 saw a total of 3437 tonnes of oceanic tunas valued at RM29.84 million, an increase of 28.53% compared to 2674 tonnes in 2007 which was attributable to the seasonal migration of tuna closer to Malaysia and fish being landed at the Malaysian International Tuna Port (MITP) in Penang. The species landed were Yellow Fin Tuna, Big Eye Tuna and Albacore. In Peninsular Malaysia, the inshore fisheries contributed to 76.55% of marine landings. However, the total landings decreased by 0.49% from 811,767 tonnes in 2007 to 807,818 tonnes in the year 2008. This was due in large measure, 75.76%, to commercial fishing vessels of below 70 GRT operating trawl nets and fish purse seines. In these vessels, landings had decreased by 1.53% from 621,472 tonnes in 2007 to 611,992 tonnes in 2008. Deep-sea fisheries landings, from trawlers and purse seines, in Peninsular Malaysia increased by 13.88% from 217,316 tonnes in 2007 to 247,470 tonnes in 2008. Earnings increased from RM724.96 million in 2007 to RM890.75 million in 2008. In Sabah, Sarawak and Labuan, inshore fisheries landings decreased by 11.25% from 305,289 tonnes in 2007 to 270,934 tonnes in 2008. But deep-sea fisheries landings of Longtail Tuna, Frigate Tuna and Kawakawa went up by 45.18% from 47,051 tonnes in 2007 to 68,309 tonnes in 2008. In Labuan, this was contributed to by the fish purse seiners of 70 GRT and above [28].

An analysis of the above statistics for marine fisheries shows that for the year 2008, non-Malaysian fishermen from Thailand, Indonesia and China benefited from Malaysian marine waters as out of a total of 40,959 fishing vessels that were licensed, a total of 33,052 were foreigners. It is also clear that artisanal and small-scale fishers working in inland fisheries are unable to compete with the returns of the industrial fishers for the marine fisheries sector in our seas and have turned to aquaculture leaving behind their traditional fishing occupation. The returns of the industrial fishers have only improved marginally when compared to the 2005 statistics. The policy goal, as mentioned above, was to produce 2.9 million tonnes of fish overall.

With regard to international fishery rules and standards for sustainable development, Malaysia has ratified the 1973 Convention on International Trade in Endangered Species (CITES) [29], 1982 Law of the Sea Convention (LOSC) [30], the 1992 Convention on Biological Diversity (CBD) [31] and non-binding instruments such as the 1995 FAO Code of Conduct for Responsible Fisheries (CCRF) [32].

It is incumbent on Malaysia to implement these international treaty obligations into municipal laws. She has not ratified the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks 1995 necessary for the protection of species such as tuna [33].

The decisions of the international judicial bodies, namely the International Court of Justice (ICJ) [34] and the International Tribunal for the Law of the Sea (ITLOS, for example *Monte Confurco Case and the Tomimaru Case*) are binding to the extent that the principles in the cases represent customary international law or have some policy bearing on the protection of the fisheries regime in Malaysia. Malaysia is also a party to regional instruments such as the 1967 Agreement on the Association of South-East Asian Nations [35], and certain non- binding instruments namely, the Code of Conduct in The Manual of ASEAN Good Shrimp Farm Management Practices, ASEAN Ministerial Understanding on Fisheries Cooperation 1983, and Manual on Practical Guidelines for the Development of High Health *Penaeus Monodon Broodstock* and Harmonisation of Hatchery Production of *Penaeus Monodon* in ASEAN Countries and the Agreement on the Network of Aquaculture Centres in Asia and the Pacific (1988). The latter Agreement came into force on 11 January 1990. The member states are Australia, Bangladesh, Cambodia, China, Republic of Korea, India, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Viet Nam, and China. Malaysia is a member of the Southeast Asian Fisheries Development Centre (SEAFDEC).

Referring to the legislations in place to steer the fishing industry in Malaysia, Flewwelling and Hosch point out that, in 1990s, Malaysia made attempts to gain her fishing grounds back from "over fishing; illegal fishing; the lack of timely submission of fisheries data for planning and the enhancement of its fisheries management regime"[25]. They also point out that joint fishing ventures were approved but no international agreements permitting foreign fishing vessels access into Malaysian waters were concluded.

The principal legislations are the Fisheries Act 1985 Act (Act 317), the Exclusive Economic Zone Act 1984 (Act 311), the Fishermen's Associations Act 1971 (Act 44) and the *Lembaga Kemajuan Ikan Malaysia* Act 1971(Act 49) (Malaysian Fisheries Development Board Act 1971) and numerous subsidiary regulations made thereunder and state legislation. These are the Fisheries (Marine Culture System) Regulations 1990 which allows one to engage in marine aquaculture which is subject to a double authorisation system and the Fisheries (Cockles Conservation and Culture) Regulations 2002 which regulates licences for the capture of cockles with no provisions on sea ranching. Other regulations include the Establishment of Marine Parks and Marine Reserves Order 1994, Fisheries (Licensing of Local Fishing Vessels) Regulations 1985, Fisheries (Closed Seasons for the Catching of Grouper Fries) Regulations 1996, Fisheries (Prohibited Fishing Methods for the Catching of Grouper Fries) Regulations 1996, Fisheries (Prohibited Areas) Rantau Abang Regulations 1991, Fisheries (Prohibited Areas) Regulations 1994 (Sarawak), Fisheries (Prohibition of Import etc... of Fish) Regulations 1990 (piranhas), Fisheries (Control of Endangered Species of Fish) Regulations 1999 (protected and endangered species of fish and mammals under CITES like dugong, whale, dolphin, whale shark and giant clam). It is an offence to kill or trade in these aforementioned species. Other legislations include the Waters Act No. 418 of 1920 as amended which applies to freshwater and coastal waters but does not make a reference to aquaculture and the Guidelines on Erosion Control for Development Projects in the Coastal Zone (1997), EIA – Environmental Quality Act 1974 No. 127, Malaysia National Biodiversity Policy 1998 and Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987, the Environmental Quality (Sewage and Industrial Effluents) Regulations 1979 as amended which could also be applied to industrial aquaculture facilities. Fish health may be regulated by the Animals Ordinance No. 17 of 1953 as there is no other Act to regulate this matter. However, the term "fish" is also included in the definition of an animal. Some of the 1982 LOS Convention's broad concepts on the EEZ are found in the EEZ Act 1984 and the 1985 Fisheries Act.

The Fisheries Development Board Act 1971 deals with the marketing of fish through an appointed board called the Fisheries Development Board. Various aspects of marketing such as the sale, purchase, assembling, storage, transport, processing, grading, packaging, advertising and promotion of fish fall within the Board's mandate. By virtue of sections 4(2) and 23 of the Fisheries Development Board Act 1971,

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the Board with Ministerial approval has passed the Fish Marketing Regulations 1973 and the *Lembaga Kemajuan Ikan* Malaysia (Fisheries Complexes and Harbours) Rules 1986. The Act does not refer to any international intergovernmental access agreement between Malaysia and the rest of the global fishing communities probably because no such access agreements were concluded.

The priority areas under the Fisheries Act 1985 for the protection and regulation of the fisheries industry in Malaysia are adoption of fisheries plans, general licensing provisions, regulation of foreign vessels through permits, stipulation of offences and enforcement provisions, provisions on aquaculture, turtles and inland fisheries and marine parks and reserves. Malaysia is reported as having the best licensing system. Penalties as heavy as a million dollars can be imposed for violations. The Fisheries Act 1985 regulates inland fisheries and aquaculture which are state matters whilst marine fisheries and aquaculture are federal responsibilities under the Federal Constitution. The Preamble to the Act states that the Parliament *vide* Article 74 Clause (I) is empowered to make laws with regard to "fisheries, including maritime and estuarine fishing and fisheries (excluding turtles)." This is a matter enumerated in the Federal List under Item 9 of List I of the Ninth Schedule to the Federal Constitution. Maritime and estuarine fishing and fisheries are also matters enumerated in the Concurrent List under Item 12 of List IIIA of the said Ninth Schedule in respect of the States of Sabah and Sarawak. Parliament may also make laws for any matter under the State List for promoting uniformity of the laws of two or more States. Turtles and riverine fishing are matters enumerated in the State List under Item 12 of List II of the Ninth Schedule of the Federal Constitution. The short title of the Fisheries Act 1985 indicates that it includes provisions on the "conservation, management and development of maritime and estuarine fishing and fisheries in Malaysian fisheries waters, to turtles and riverine fishing in Malaysia and for matters connected therewith. This Act strives to arrive at a balance between conservation of inland and marine resources and exploitation of these resources through a system of licences, permits and enforcement measures.

In terms of definition of fish, there are two competing definitions of which one is stated in the Fisheries Act 1985 which defines fish as "any aquatic animal or plant life, sedentary or not, and includes all species of finfish, crustacean, mollusca, aquatic mammals, or their eggs or spawn, fry, fingerling, spat or young, but does not include any species of otters, turtles or their eggs." The second definition of the term "fish" is any variety of marine, brackish water or fresh water fishes, crustacean, aquatic mollusca, marine sponges, trepan and other aquatic life and the products therefrom but does not include turtles or their egg as in the 1971 Act and the 1973 Marketing Regulations. The basic difference between the two definitions is that the latter includes fish products as it involves marketing regulations. The definition under the Fisheries Act 1985 does not include "fish seed" which is further defined under the Act as "fish egg or larva or post-larva of fish, or the spawn, fry or fingerling of fish." Fisheries include "aquaculture." Section 2 defines "aquaculture" as "the propagation of fish seed or the raising of fish through husbandry during the whole or part of its life cycle." Conservation of turtles and aquaculture are also within the scope of the Act. The Fisheries Act 1985 does not define the terms "fisher, fisherman" or "fishermen's association." Neither does it define the term "artisanal fishers" or "coastal fishers." The Fisheries Act 1985 refers to several maritime zones for fishery purposes as follows: 1. Estuarine waters; 2. Internal waters of Malaysia; 3. Malaysian fisheries waters; 4. Marine parks and marine reserves; 5. Maritime waters; 6. Riverine waters; 7. Territorial sea of Malaysia; 8. Exclusive economic zone. In Malaysia, these eight zones are re-classified into the four zones mentioned above.

An occasion to consider the overlap of Malaysian fisheries waters and the Exclusive Economic Zone arose in *Pai San v Public Prosecutor* [36], where an offence arose for illegal fishing in Malaysian EEZ waters without a valid permit under sections 2, 15(1), 19, 24(1) and 25(a) of the Fisheries Act 1985. Section 2 deals with Interpretations under the Act. Section 15(1) refers to regulation of fishing by foreign fishing vessels under international fishery agreements in Malaysian fisheries waters and section 19 states the provisions with respect to permits in respect of foreign fishing vessels. Section 24(1) addresses liability of persons in respect of foreign fishing vessels and section 25(a) states a one million ringgit penalty for foreign vessels or nationals who do not comply with the Act and imposition of a fine not exceeding RM 50,000/- or a term of imprisonment not exceeding two years or both. The present case turned on the powers of the Prosecutor, in this case a Fisheries Officer, who, it was argued, could not prosecute under the Fisheries Act 1985 as the Act lacked such provisions. The Court of Appeal at Kuala Lumpur held that the Fisheries Act 1985 should be read together with section 38 of the EEZ Act 1984 as the latter contained the necessary powers of the Public Prosecutor to prosecute under Article 145 (3) of the Federal Constitution. The Public Prosecutor could give his consent to prosecute to a Fisheries Officer under the Fisheries Act 1985 for an offence in the Exclusive Economic Zone.

The Court reasoned as follows: "The Preamble of the Fisheries Act, *inter alia*, reads: An Act relating to fisheries ... in *Malaysian fisheries waters*... Section 2 of the Fisheries Act defines "Malaysian fisheries waters" thus: "Malaysian fisheries waters means maritime waters under the jurisdiction of Malaysia over which exclusive fishing rights or fisheries management rights are claimed by law and includes the internal waters of Malaysia, the territorial sea of Malaysia and the maritime waters comprised in the exclusive economic zone of Malaysia." Section 2 of the Fisheries Act also defines the "exclusive economic zone": Exclusive economic zone means the exclusive economic zone of Malaysia as determined in accordance with the Exclusive Economic Zone Act 1984. Section 2 of the EEZ Act 1984 defines "Malaysian Fisheries Waters" as: Malaysian fisheries waters means all waters comprising the internal waters, the territorial sea and the exclusive economic zone of Malaysia in which Malaysia exercises sovereign and exclusive rights over fisheries.

The question of foreign fishers arose for determination in several cases discussed below and in none of the cases was an Application for Prompt Release pending at ITLOS. In *Irwan bin Abdullah & Ors v Public Prosecutor* [37] 39 Indonesian fishermen were arrested and charged under sections 15(1) (a) and 53 of the Fisheries Act 1985 for illegal fishing without a permit under section 19 in Malaysian fisheries waters. The charge was made out under section 25(a) of the 1985 Fisheries Act read together with section 34 of the Penal Code

Section 25 of the Fisheries Act states that when "Any person who contravenes or fails to comply with any provision of this Act shall be guilty of an offence and where no special penalty is provided in relation thereto, such person shall be liable –

a) Where the vessel concerned is a foreign fishing vessel or the person concerned is a foreign national, to a fine not exceeding one million ringgit in each case of the owner or master, and one hundred thousand ringgit in the case of every member of the crew.
b) In all other offences, to a fine not exceeding fifty thousand ringgit or a term of imprisonment not exceeding two years or both.

Section 53 states that "Any person who resists or wilfully obstructs any other officer or fails to comply with any requirement made by any authorised officer in the exercise of his powers and duties under this Act shall be guilty of an offence and liable to a fine not exceeding fifty thousand ringgit." As the 39 fishermen were not given bail initially and subsequently when given bail could not meet bail requirements and being guilty of the offence of illegal fishing, they were imprisoned for a period of up to 13 months and nine days. The issue was whether the sentencing was valid under the law. The High Court at Alor Setar agreed with the Deputy Public Prosecutor that from the point of view of public interest and national resource protection, the sentence imposed on the fishermen was a fair one.

In *Aone and Ors v Public Prosecutor* [38], the High Court at Penang had to deal with the conviction of eight (8) Thai nationals who were charged with an offence falling under sections 15(1) (a), 25 (a), 34 and 52 of the Fisheries Act 1985 to which they pleaded guilty. On the strength of the applicant's word that he was the owner of the boat, the magistrate allowed the boat to be released on a bond of RM 75,000/- on condition that the boat be produced to the court or the Fisheries Department when required. To the contrary, the impugned boat could not be produced before the High Court as the appellant had instructed the boat to sail away to a destination in Thailand beyond the Penang High Court's jurisdiction. Eventually, the boat became a wreck. The appellant lied to the Court saying he was the boat owner when he was in reality a shipping agent. The fishing boat was owned by a Thai national and evidence to this effect was produced before the Court. As a result of this appalling conduct, the appellant forfeited the surety that he stood for.

In *Tan Khing Hung v Public Prosecutor* [39], the High Court at Kuching held, *obiter*, that under section 34 of the Fisheries Act 1985, the Court may order the forfeiture of a seized vessel under certain circumstances. Section 34 of the Act provides that

"Where it is proved to the satisfaction of a court that any vessel, vehicle, article or thing seized under this Act was the subject matter of, or was used in the commission of an offence under this Act, the court may order the forfeiture of such vessel, vehicle, article or thing notwithstanding that no person may have been found guilty of such offence."

In *Ment & Ors v Public Prosecutor*[40], the High Court at Penang had to deal with a case where nine (9) Thai nationals were found guilty of violating the provisions of section 15(1) of the Fisheries Act 1985 for fishing in Malaysian fisheries waters without a permit. They were acquitted by the magistrate but a successful conviction followed upon appeal. This decision casts some light on how to interpret a penal statute. The Court held: "Acts imposing criminal or other penalties should be clear and unambigious and should be construed narrowly in favour of the person proceeded against...." In *Tan Kheng Teong & Anor v Public Prosecutor* [41] and *Chu Beow Hin v PP* [42], it was held that the strict construction of penal statutes seems to manifest itself in four ways: in the requirement of express language for the creation of an offence; in interpreting strictly words setting out the elements of an offence; in requiring the fulfillment of statutory conditions precedent to the infliction of punishment; and in insisting on the strict observance of technical provisions concerning criminal procedure and jurisdiction."

The issue of fishing without permits on foreign fishing vessels also arose for determination in *Public Prosecutor v Kwok Tai Seng & Ors* [43] where the defendants were charged with the offence of fishing on a registered foreign fishing vessel without a permit from the Director-General of Fisheries, an offence under section 15(1)(a) of the Fisheries Act punishable under section 25(a) of the same Act. The magistrate acquitted them. The Prosecution appealed to reverse the sentence. The High Court at Sandakan framed two main issues of the case: first, whether it was established beyond reasonable doubt that the boat was in Malaysian fisheries waters at the relevant time, and second, whether the respondents were diving or fishing while not in possession of a valid permit at the relevant time. To prove both counts, the Court went through much of the evidence on the location of the boat and the activity of the respondents and dismissed the appeal by the prosecution and affirmed the order of the trial magistrate. While the prosecution could rely on Section 56 of the Act in so far as it was established that it was a foreign fishing boat, it could not be established beyond reasonable doubt that the activity was a diving or a fishing activity.

In *Pendakwa Raya v Nasrun Effendi* [44], an offence was committed under the Fisheries Act 1985, section 15(1) read together with Section 127 Customs Act 1967 whereby the fishing boat of the accused was ordered to be forfeited as it was used in the commission of an offence under the law. The High Court at Johor Baru agreed with the decision of the magistrate as the accused had pleaded guilty to the charge.

In *Public Prosecutor v Hon Jin Bong & Anor* [45], the issue of machinery used for the commission of the crime arose under section 32(2) of the Trade Descriptions Act 1972. Defence counsel argued that it was imperative for the Prosecutor to prove that the goods they wanted to forfeit were used in the commission of the offence or were the subject-matter of the offence. Defence counsel then cited a similar example of section 15(1) (b) of the Fisheries Act 1985 before the Court as where a crime could be committed using machinery. If the machines were used in the commission of the crime, then it had to be proven to the satisfaction of the Court for the offenders to be found guilty. If not, they were not guilty.

ANALYSIS

Overall, an analysis of the 2005 and 2008 Malaysian fishery statistics are gloomy for marine fisheries and for inland fisheries generally engaged in by artisanal, small-scale fishers. It is important for Malaysians to engage in marine fisheries in Malaysian waters because if we do not have the capacity to harvest the entire allowable catch of the living resources of the exclusive economic zone, then under the provisions of Article 62(2) and (3) of the 1982 Law of the Sea Convention to which Malaysia is a party, other States have access to the surplus of the allowable catch.

In terms of the case-law, an analysis of the *Pai San* decision shows that from these provisions, the Court established the inter-connection between the Fisheries Act and the EEZ Act. The EEZ Act does not provide for offences relating to fisheries. It makes the minister charged with responsibility for fisheries responsible for fisheries in the EEZ, and for that purpose, the "Authorised officer" is defined as including the fisheries officer. The law applicable to fisheries in the EEZ is the 1985 Fisheries Act. So, the phrase "A prosecution for an offence under any applicable written law clearly refers, *inter alia*, to a prosecution for offences under the Fisheries Act. ...there can be no other reasonable interpretation." The case did not explore the law on international sustainable fisheries mentioned above and so missed the opportunity to consider the elements of IUU fishing in the national context.

An analysis of the rest of the decisions shows that many of the case-law relating to the prosecution of fishermen were related to the arrest of fishermen for fishing without a stipulated licence or permit, sometimes on a registered boat, in the concerned maritime zone. The Court in the above cases generally did not examine the perspective of the 1982 LOSC on the setting and payment of reasonable bonds, issue of imprisonment of fishermen, and/or even consider the possibility of IUU fishing. Generally, the issues relating to imprisonment and compensation were settled under municipal law by the Court.

For prevention and deterrence of unlawful fishing, two articles of the 1982 LOSC are relevant, namely, Articles 73 and 292. Under Article 73 to vindicate the coastal State's legitimate efforts at fishery resource protection, the bond or other security for release of arrested foreign vessels and their crew should be reasonable [46]. Article 292(1) deals with the detaining State's failure to post a reasonable bond for the prompt release of the fishing vessel and its master and crew which entitles the State of the detained vessel to, within 10 days from the time of detention, to submit the matter to a court or tribunal. Under Article 292(2) an application for release of the fishing vessel may be made only by or on behalf of the flag State of the vessel. Article 292(3) provides that the ITLOS has jurisdiction only to hear the question of release without prejudice to the merits of the case before the appropriate domestic forum against the vessel, its owner or its crew without delay. Article 293(4) states that once the Applicant has posted the bond or other financial security as determined by the court or tribunal, the authorities of the detaining State shall comply promptly with the decision of the court or tribunal concerning the release of the vessel or its crew.

The adoption of a good fisheries protection regime is a challenging task for it should ensure that affected stocks are well below sustainable levels of exploitation; affected fleets are well below sustainable levels of capacity; and affected fisheries are subject to effective management [1]. New challenges for the proper protection and management of the fisheries sector stem from policies that involve the application of the eco-system management expounded in the 1992 CBD Convention, the application of the precautionary principle of international environmental law, addressing effects of land-based pollution on the productivity of coastal habitats and resources [47], the adoption of an Integrated Coastal Zone Management (ICZM) plan, the provision for exploitation at optimal levels of fisheries according to the principle of the "maximum sustainable yield" or MSY as stated in the 1982 LOSC and consideration of the new economic rent associated with a fishery before reaching the MSY point referred to as maximum economic yield or MEY.

The FAO defines MSY as: "The highest theoretical equilibrium yield that can be continuously taken (on average) from a stock under existing (average) environmental conditions without affecting significantly the reproduction process" [1]. The theory of new institutionalism and the law takes into account gear restrictions that will affect selectivity and affect fishing power, closed seasons, closed areas and limits on fishing entry on the limitation on the number of vessels by licensing and on wasteful practices where in the shortest time possible, the maximum amount of fish is caught. Other questions are centered on the success or otherwise of limiting entry through the licensing of vessels by using the geographic information system of mapping (GIS) and the ability to impose sanctions for reducing the effectiveness of reducing fishing effort. The latter requires a control on the number of fishing vessels as efforts are made to control a single species of fish in a multi-species fishery when all species are not subject to the same control. Finally, the regulation of output quota which is an allocation of a total allowable catch between individual units of effort is also relevant. This right may be given for a specified time, quantity of fish or percentage of total catch. This method of control may be biologically and economically efficient, where there is knowledge of the year to year allowable catch which requires expansive monitoring and quotas are distributed in a way that ensures the most efficient fishers are allowed the right to resource use [48]. The FAO explains "underexploited fishery" as referring to a significant potential for expansion in total production; "moderately exploited fishery" as those exploited with a low level of fishing effort and it is

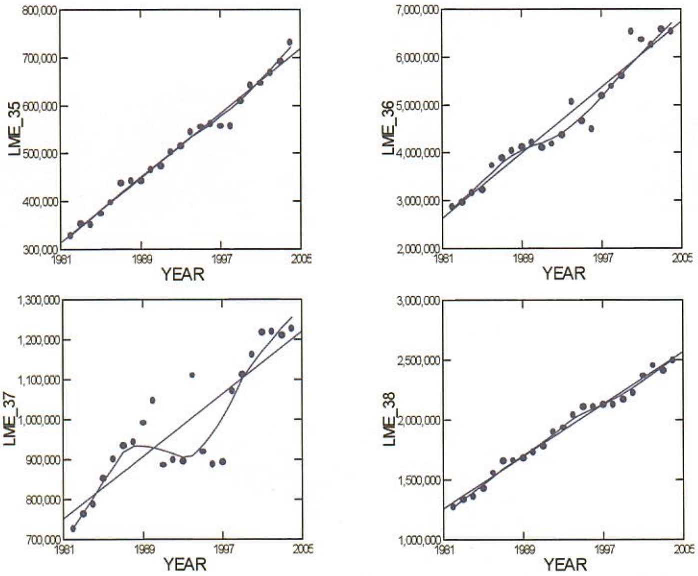

Figure 21. Fishery biomass yields by year for 4 southeast Asian Large Marine Ecosystems, linear regression lines cover the period 1982-2004, smoothing curves are LOWESS smoothers at tension=0.5. LME numbers correspond to the LME numbers in Figure 1. Upper left: Gulf of Thailand LME; Upper right: South China Sea LME; Lower left: Sulu-Celebes Seas LME; Lower right: Indonesian Sea LME.

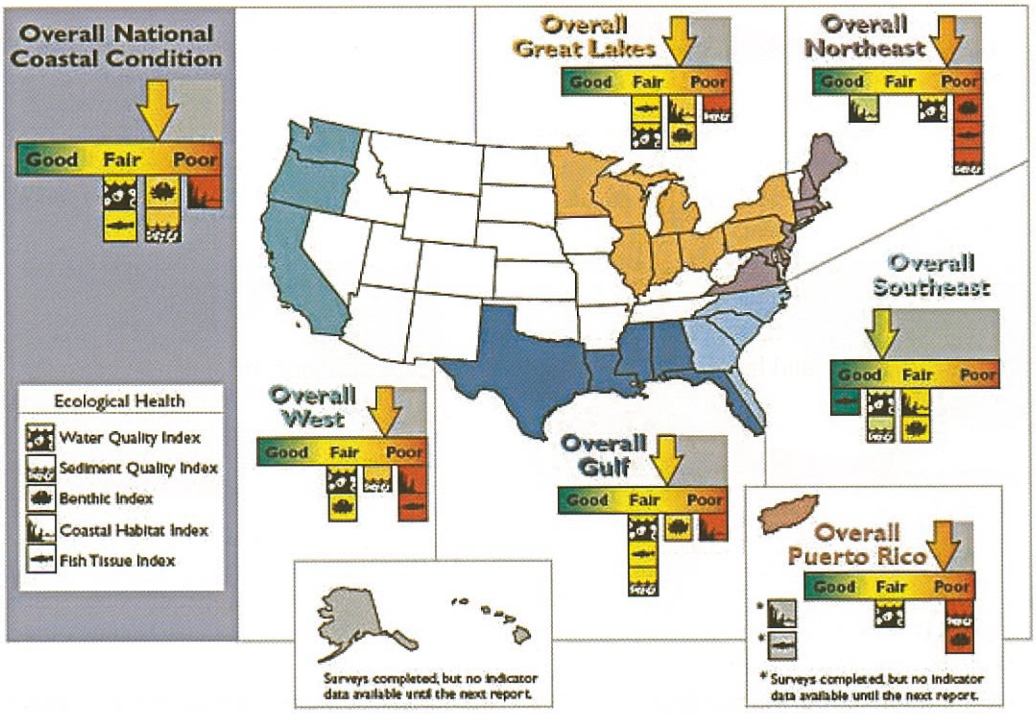

Figure 22. The Environmental Protection Agency's (EPA) five pollution and ecosystem health indicators for seven areas in the United States coinciding with LMEs, and stop-light assessments of the indicators [30].

US Fish and Wildlife Service, the US Geological Survey, and other agencies representing states and tribes. EPA's five pollution and ecosystem health indicators for LMEs and stop-light assessments of the indicators are shown in Figure 22 [30].

The 2004 *National Coastal Condition Report II* [30] includes results from the EPA's analyses of coastal condition indicators and NOAA's fish stock assessments by LMEs aligned with the EPA's national coastal assessment regions. The EPA and NOAA are jointly introducing this approach to the international GEF supported LME projects, along with a methodology for nutrient assessment. The indicators of pollution and ecosystem health, based on the NOAA and EPA model used for monitoring changes in condition of US coastal waters, include contaminant effects, trophic transfer of contaminants, frequency and effect of harmful algal blooms, believed to have some limited potential for expansion in total production; "fully exploited fishery" refers to those operating at or close to an optimal yield, with no expected room for further expansion; "overexploited fishery" as those exploited above a level which is believed to be sustainable in the long term with no potential room for further expansion and a higher risk of stock depletion/collapse; "depleted stocks" as those catches that are well below historical levels, irrespective of the amount of fishing effort exerted; and "recovering stocks" as those catches which are again increasing after having been depleted or a collapse from a previous high." Another method of output control is to place "limits on fish landed." This is effective when fish is landed at regulated ports and is not appropriate when fish is trans-shipped or sold at sea.

Mechanisms for allocating and adjusting entitlements are divided into administrative or market-based mechanisms [48]. In an administrative mechanism, the objective of the managing authority is the socio-economic consideration which could favour poorer small-scale fishing units which rely on fishing as a source of income of equity rather than efficiency [48]. On the other hand, market-based systems allow the trading of entitlements between the governing body and the users, or between users. It usually gives the managing authority the most economic rent, that is, the most return for a trip to the sea.

A good fisheries protection regime will also keep the parameters and perimeters of permitted subsidies well-demarcated with legal rules keeping in mind the three questions that WTO fisheries subsidies negotiators face. In the case of artisanal fisheries, it is "broadly agreed that fisheries subsidies are least dangerous where fisheries are underexploited, under-capitalised and well-managed. Legal rules on subsidies need to be drafted: such a measure not only "assists governments in the identification of criteria for the use of fisheries subsidies" but also assists the "WTO negotiators craft new international law and provide domestic governments with useful advice as they pursue responsible fisheries subsidies policies. WTO rules can set a few simplified (but important) legal constraints on the "policy space" that governments enjoy for fisheries subsidies" [1]. The three questions faced by the WTO fisheries subsidies negotiators are:

1. "What legal effects could be given to criteria for fisheries subsidies that are incorporated into WTO legal texts? At least three possibilities should be considered:
   - A criterion can serve as an element of a dispositive legal test. For example, the right to subsidies could be conditioned (among other requirements) on the registration of all vessels to be subsidized in an open international registry.
   - A criterion can have less than a dispositive legal effect, such as shifting or changing the level of a burden of proof. For example, a finding by the FAO that a fishery is overexploited could be presumed true unless proved false by clear and convincing evidence.
   - A criterion may have no automatic legal effect, but can serve as a factor to be considered in reaching a dispositive judgment. For example, evidence that fishing quotas have been exhausted prior to season closure for several consecutive years may be considered evidence tending to prove that a fishery is in a condition of overcapacity.
2. What standards and burdens of proof could be associated with minimum criteria? If WTO fisheries subsidies rules are to emphasise the sustainability, the basic burden to prove conditions justifying the use of capacity – or effort enhancing subsidies should fall initially on the subsidizing member. But, burdens of proof can be manipulated within legal tests to give greater or lesser emphasis to particular fisheries-related criteria.
3. Who could adjudicate whether minimum WTO criteria for fisheries subsidies have been met? To what extent should new institutional mechanisms be devised for involving expert intergovernmental bodies such as the FAO in the administration of fisheries subsidies rules?" [1]

These questions will affect the minimum criteria in WTO rules and the choice of the criteria to be incorporated. It is advisable to adopt a flexible approach to legal rules. Following from the study of the UNEP-WWF abovementioned, the new subsidies for fisheries must be based on stock-related, capacity-related and management-related criteria. In this regard, access agreements are also a form of subsidy as the fishing fleets do not repay the government this money. Hence, this aspect of the trade has to be looked into deeply as access agreements are management agreements in so far as fisheries are concerned. Eco- labelling and market access for fish is also considered a new approach to promoting the sustainability of small-scale fisheries. The environmental aspects of fisheries call for renewed studies in the implementation of new WTO rules on fisheries, lesson learned from UNEP's work and next steps for sustainable fisheries and extending the work to other sectors [49].

WAY FORWARD

Besides, the adoption of a good economic and administrative management regime, for the protection of the Malaysian marine fishing industry, Malaysia would be required to implement the main provisions under the 1982 LOSC on fishing gear, total allowable catch, harvesting capacity, maximum sustainable yield, rule on disclosure, evidentiary rule on proof of fish, rules on anadromous and catadromous fish catch, allocation of surpluses, conservation and management, rules on fishing vessels and international labour law criteria which set the standards that the crew are to enjoy. Malaysia should determine the elements of the law in IUU fishing and should punish IUU fishing as it is illegal according to the *Camouco Case* [50] and the *Hoshinmaru Case* [51] being carried out in violation of the 1982 LOSC or in violation of a multilateral or bilateral fishing agreement or in violation of domestic laws of the coastal state and can take place in any maritime zone including the high seas [52].

Malaysian fisheries laws should reflect the scope of fisheries jurisdiction under the 1982 LOSC such as in Article 19(2)(i), Art 21(1)(e), Art 21(1)(f), Article 42(1)(c), Article 56(1) (a), Articles 60 and 61, and Articles 62-70. Article 56(1)(a) endorses the sovereign right of the coastal State to explore and exploit fish in the EEZ. This is immediately followed by Article 56(2) wherein the coastal State in exercising this right, shall have due regard to the rights and duties of other States and are required to act in a manner that is compatible with the provisions of the 1982 LOSC. Article 60(3) provides that when installations are decommissioned and removed, such removal must pay due regard to fishing, the protection of the marine environment and the rights and duties of other States. The nationals of other States are allowed to fish in the coastal State's EEZ as found in Article 61(5). According to Article 61(1) the coastal State shall determine the allowable catch of the living resources in its EEZ. Article 61(2) provides that the coastal State, taking into account the best scientific evidence available to it, shall ensure, through proper conservation and management measures, that the maintenance of the living resources in the EEZ is not endangered by over-exploitation.

As appropriate, Malaysia as the coastal State together with a competent international organization, whether subregional, regional, or global, shall co-operate to this end. Article 61(3) states that such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield, as qualified by relevant environmental and economic factors, *including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns*, the interdependence of stocks and any generally recommended international minimum standards, whether sub-regional, regional or global.

Article 61(4) further provides that in taking such measures the coastal State shall take into consideration the effects on species associated with or dependent upon harvested species with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened.

Finally, Article 61(5) refers to available scientific information, catch and fishing effort statistics, and other data relevant to the conservation of fish stocks which shall be contributed and exchanged on a regular basis through competent international organizations, whether sub-regional, regional or global, where appropriate and with participation by all States concerned, including States whose nationals are allowed to fish in the EEZ.

Article 62 states that the coastal State shall promote the objective of optimum utilization of the living resources in the EEZ. Article 62(3) recognizes a need to minimize the economic dislocation in States whose nationals have habitually fished in the zone. Article 62(4) provides that there are 11 areas where the coastal State may legislate upon to regulate these foreign fishers. These 11 areas relate to:

- licensing and payment of fees;
- quotas of catch;
- regulating seasons and areas of fishing;
- fixing age and size of fish;
- specifying information required;
- specified fisheries research programme;

- placing of observers on these vessels;
- the landing of catch;
- joint ventures;
- training of personnel; and
- enforcement procedures.

Straddling stocks and conservation measures and grant of fishing rights to land-locked States as provided in Articles 63 to 70 should also be regulated. A comparison of the EEZ provisions of Article 62 in the 1982 LOSC with the coastal waters provisions in the 1985 Fisheries Act 1985 shows that the latter make no express reference to the principle of optimum utilization of living resources and there is no requirement to take into account the significance of the living resources of the area to the economy of the coastal State, and to its other national interests, or to minimize economic dislocation in States whose nationals have habitually fished in the seas.

Similarly, there is no express provision stipulating the species that may be caught or fixing quotas of catch, whether in relation to particular stocks or groups of stocks or catch per vessel over a period of time or to the catch by nationals of any State during a specified period. There are also no express provisions regulating the seasons and areas of fishing, the types, sizes and kind of gear, sizes and number of fishing vessels that may be used; fixing the age and size of fish and other species that may be caught; and specifying information required of fishing vessels [53, 54, 55]. These regulations may also be applied in Malaysian territorial seas.

As between States which have not ratified the 1982 LOSC but the 1958 Geneva Convention on Fishing and Conservation of the Living Resources of the High Seas [56], the latter applies in Malaysia's bilateral relations and this should be reflected in the 1985 Fisheries Act. Article 6 of the 1958 Geneva Convention on Fishing and Conservation provides that a coastal State has a special interest in the maintenance of the productivity of the living resources in any area of the high seas adjacent to its territorial sea. Article 6(2) provides that the coastal State is entitled to take part on an equal footing in any system of research and regulation for purposes of conservation of the living resources of the high seas in that area, even though its nationals do not carry on fishing there. More importantly Article 7(1) provides that having regard to the provisions of Article 6(1), any coastal State may, with a view to the maintenance of the productivity of the living resources of the sea, adopt unilateral measures of conservation appropriate to any stock of fish or other marine resources in any area of the high seas adjacent to its territorial sea, provided that negotiations to that effect with the other States concerned have not led to an agreement within six months. From these provisions, it is apparent that coastal States do have an interest in controlling their contiguous zones for fishery purposes [57]. As Malaysia was a party to this Convention, municipal laws may reflect these provisions necessary for conservation of fish stocks.

The IMO Conventions, namely the 1995 International Convention on the Standards of Training, Certification and Watch-keeping for Fishing Vessel Personnel and the 1993 Torremolinos Protocol to the 1977 Torremolinos Convention on fishing vessel safety have not entered into force internationally. Malaysia is not a party to either of them. However, it would be the administrative responsibility of the government to engage in consultations with the fishing industry and government stakeholders to assist in developing a government position on the implementation of these Conventions.

Other measures that need to be considered for a case of legal protection regime are the adoption of pro-poor fisheries legislation, and the doctrine of fish *refugia* and an update of the Fisheries Act 1985 according to the 1995 CCRF. Currently, concepts of "sources of fisheries and sinks of fisheries," and doctrine of *refugia* in fisheries are all absent in municipal legislation. For a healthy and vibrant fish population, there has to be a healthy reproductive source and sink of fisheries. This has to be followed by a sound analysis of the doctrine of fish *refugia* based on a scientific study of the various species and related depths, reefs, biomass, electronic tagging, and the depth at which they can be safe. The latter includes recuperation from the powerful fishing vessels and ability to outrun the fishing net and gear such that environment friendly and sustainable fishing is promoted.

The Ministry of Agriculture should consider providing responsible and sustainable subsidy to the Malaysian fisheries sector not only in terms of fuel but also of boats, engines and other equipment assistance even though the discipline of new institutional economics says that subsidies should be banned.

However, the WTO grants some concession in so far as a marginal groups of fishers are concerned.

In Malaysia, it would be necessary to have some protective subsidies not only for poverty alleviation, food security, community/social development, improving sustainable fisheries management but also for the preservation of fishing cultures and lifestyles as they have traditionally practiced, but which they are unable to practice now [58].

Subsidy could also be given for vessel/gear modernization, landing and processing infrastructure, port facilities, refrigeration, roads/ transport, export, fuel, and other inputs such as ice, training and capital [58]. Other areas include engagement with conservation subsidies for the construction of artificial reefs, aid for restocking of fish resources, and fisheries enhancement expenditure, regional development programmes, fisheries-related social insurance programmes such as on-the-job training to assist those fishermen who wish for transition out of the industry. For the deep sea fisheries, the areas of focus would be fisheries infrastructure, management, research, enforcement and enhancement, access agreements with third States if necessary, decommissioning of vessels and licence retirement, investment and modernization, income support and unemployment insurance, and taxation exemptions. The government should also assist the deep sea group of fishers to venture out into fish products marketing and diversify the bases and positions from which they draw their strengths. The stance to be adopted at the WTO for fishing, subsidies and fish products will depend on these factors. The new EU regulation discussed above could also serve as a guide in this matter.

Next, scientists would have to be given top priority in conserving and managing natural resource protection based on an ecosystem approach using the precautionary principle particularly for the marine ecosystem as was endorsed in the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem. Some worrying trends were observed by scientists in the South China Sea: "Very few larvae of any important fish species were observed along the east coast of Peninsular Malaysia. ... larvae of less important fish were found in States of Sabah and Sarawak. The linking of an oceanographic circulation model for the South China Sea to the distribution and abundance of fish larvae would assist the Working Group in developing a better understanding of sources and sinks of fish larvae for economically important species" [59]. Scientists could identify and describe the structure, components and functioning of relevant marine ecosystems, diet composition and food webs, species interactions, and predator-prey relationships, the role of habitat, and the biological, physical, and oceanographic factors affecting ecosystem stability and resilience [60]. They should work in tandem with the economists and the lawyers.

Finally, Malaysia should consider ratifying conventions such as the FAO 1995 Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (the 1995 UN Fish Stocks Agreement), which entered into force on 11 December 2001, [61] where Articles 10 and 11 deal with the functions of regional and sub-regional fisheries management organizations and arrangements and the participatory rights of new members. On the conservation of high seas stocks this Agreement builds on Article 117-120 of the 1982 LOSC which states that, "All States have the duty to take or cooperate with other States in taking measures, for their nationals as may be necessary to conserve living resources on the high seas" and for flag State jurisdiction as it builds on the strength of the provisions of Articles 90-98 of the 1982 LOSC. The 1995 UN Fish Stocks Agreement requires the harmonization of relevant legislation by States parties and implementation of relevant provisions in regional organizations and arrangements. There are high seas boarding and inspection provisions under Articles 21 and 22 of the Agreement. The UN has, through several General Assembly Resolutions made a call for the implementation of Article 21(4) of the Agreement, for the conservation and management of discrete high seas fish stocks.

The implementation of the outcome of the Review Conference on the 1995 UN Fish Stocks Agreement was held in New York in May 2006. States active in this Review Outcome were Canada, Latvia, New Zealand, Norway, the United States, Qatar and Yemen. Based on another review conference in 2010 the top ten fisheries producer countries in 2006 were identified as China, Peru, the United States, Indonesia, Japan, Chile, India, the Russian Federation, Thailand and Philippines [62].

Other international instruments that Malaysia should ratify include the 1993 FAO Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas (1993 FAO Compliance Agreement) (Resolution 15/93) [63]; the 2008 FAO Guidelines for the Management of Deep-Sea Fisheries, FAO, Rome 2008 and the 2009 Agreement on Port State Measures following the development of the FAO Model Scheme on Port State measures to Combat Illegal, Unreported, and Unregulated Fishing in 2004 [64] and transformation of soft law instruments such as the 1999 International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries, FAO, Rome 1999 and International Plan of Action for the Conservation and Management of Sharks, FAO, Rome 1999 into municipal law.

CONCLUSION

In conclusion, this paper argued for the protection and survival of the Malaysian marine fishing industry through the rule of international fisheries law. The marine fishing community should comprise not only the industrial fishing community but also the artisanal, small-scale fishers who should be encouraged to engage in marine inshore fishery as inland fisheries in the 2005 and 2008 statistics do poorly. The law and policy structure is based on the rules of science, economics and international fishery laws and policy. Well-managed and well-administered subsidies based on WTO recommendations are an important feature of this regime bearing in mind that the dangers of the earlier EU subsidies should not be repeated regarding the tragedy of the commons whereby 75% of the world's fish resources were depleted by European fishermen based on the subsidies that they had received. Malaysian fishermen need not lose out to foreign industrial fishermen. Malaysia has to adopt a new fishing policy by undertaking an iterative review of the old. All thorough analytical reviews start from an analysis of the international legal obligations entered into and by a forecast of new obligations that should be entered into. Malaysia has the ability to take her rightful place in marine fishing including inshore marine fisheries in Malaysian national waters as she has the manpower, the fish stocks and enforcement machinery to ensure compliance. Above all, the necessary political will may be found in the government. If this is not done, then surely the sun will set on this industry in Malaysia.

REFERENCES

1. UNEP and WWF (2007) *Sustainability Criteria for Fisheries Subsidies: Options for the WTO and Beyond* online at http://www.unep.ch/etb/publications/fishierSubsidiesEnvironment/UNEPWWF_FinalRevi09102007.pdf
2. Schorr David K. and Caddy John F. *Sustainability Criteria For Fisheries Subsidies: Options for the WTO and Beyond* online at http://www.earthtrack.net/documents/sustainability-criteria-fisheries-subsidies-options-wto-andbeyond.
3. World Summit on Sustainable Development (WSSD) Johannesburg UN Doc A/Conf 199/20 (2002).
4. United Nations (2002) para 30 (f) cited in Cox Anthony and Schmidt Carl-Christain, *Subsidies in the OECD Fisheries Sector: A Review of Recent Analysis and Future Directions* online at http://www.oecd.org/dataoecd/43/402507604.pdf
5. World Trade Organisation (2000) *Fisheries Subsidies and the Environment* WT/CTE/W/132 dated 18 February 2000.
6. *Resolution of Korean Fisheries Industries in Correspondence to the WTO-DDA Negotiation on the Fisheries Products Centre*, 27th November 2003, online at http://webcache.googleusercontent.com/search?q=cache:SJTnrHIFoigJ:www.wto.org/english/forums_e/ngo_e/p_
7. European Fisheries Fund, *Council Regulation (EC) No 1198/2006 of 27 July 2006* online at http://europa.eu/legislation_summaries/maritime_affairs_and_fisheries/fisheries_sector organisation and financing/166004_en.htm
8. Knigge Markus, *Putting an end to harmful fisheries subsidies* online at http://www.sbilanciamoci.org/does/sbileu/17.pdf
9. Coffey Clare, *WWF Fisheries Subsidies, Will the EU turn its back on the 2002 reforms?* Online at http://assets.panda.org/downloads/eu_fisheries_subsidies_2006.pdf
10. Bene C., Macfadyen G. and Allison EH (2007) *Increasing the contribution of Small Scale fisheries to Poverty Alleviation and Food Security* (FAO Fisheries Technical Paper).
11. Platteau J-P., *The Dynamics of Fisheries Development in Developing Countries: a general overview: Development and Change* (20)(4), (1989) at p 568.
12. Bene C., Macfadyen G., and Allison E.H., *Increasing the Contribution of Small Scale Fisheries to Poverty Alleviation and Food security* (FAO Fisheries Technical Paper, 2007) at p 8.
13. OECD Development Action Committee's *Guidelines*

on Poverty Reduction, Conceptualisation of Poverty (2001), online at http://www.oecd.org/dataoecd/47/14/267235.pdf.
14. FAO *Ethics Series* Vol 4 (2005), (1982) 21 *ILM* 1261.
15. *Award of the Arbitral Tribunal in the First Stage - Territorial Sovereignty and Scope of the Dispute, October 1998* (The Government of the State of Eriteria and the Government of the Republic of Yemen), online at http://www.pca-cap.org. (2001) 40 *ILM* 900.
16. 1974 *ICJ Reports* 3.
17. *Delimitation of the Maritime Boundary in the Gulf of Maine Area* 1984 *ICJ Reports* 246
18. *Sovereignty over Pulau Ligitan and Pulau Sipadan* (Indonesia/Malaysia) 2001 *ICJ Reports* 575.
19. (Botswana/Namibia) 1999 *ICJ Reports* 1045.
20. (1998) *ICJ Reports* 432.
21. (1998) *ICJ Reports* 431 at paras 64-73.
22. (1981) 20 *ILM* 797.
23. 499 *UNTS* 311.
24. 1 *UNTS xvi.*
25. Information on Fisheries Management in Malaysia (2004) *Country review: Malaysia* by Peter Flewwelling and Gilles Hosch, FAO Consultants, Fishery Policy and Planning Division, Fisheries Department September., online at http://www.fao.org/docrep/009/a0477e/a0477e0c.htm.
26. Malaysian fisheries statistics (2005) online at http://www.dof.gov.my/278
27. Malaysian fisheries statistics (2008) online at http://www.dof.gov.my/buku_perangkaan_tahunan_perikanan.
28. Source of 2008 Report online at: http://www.dof.gov.my/html/themes/moa_dof/documents/WRITE_UP_BI.pdf.
29. (1973) 12 *ILM* 1085.
30. Malaysia acceded to the 1982 LOSC on 14 October 1996.
31. (1992) 31 *ILM* 818.
32. FAO, Rome 1995.
33. (1995) 34 *ILM* 1542.
34. *Anglo–Norwegian Fisheries Case* 1951 *ICJ Reports* 116.
35. (1967) 6 *ILM* 1233.
36. (2002) 4 *MLJ* 538.
37. (2002) 2 *MLJ* 577.
38. (2002) 3 *MLJ* 614.
39. (1996) 4 *MLJ* 316.
40. (1994) 1 *MLJ* 201.
41. (1992) 2 *CLJ* 1273.
42. (1981) 2 *MLJ* 85.
43. (1996) 1 *LNS* 316.
44. (2008) 4 *MLJ* 272.
45. (1999) 5 *MLJ* 366.
46. Serdy A., and Bliss M. (2004) "Prompt Release of Fishing Vessels: State Practice in the Light of the Cases before the International Tribunal for the Law of the Sea" in Elferink Alex G. Oude and Rothwell Donald R. (Eds.) *Oceans Management in the 21st Century: Institutional Frameworks and Responses* at pp 272–294, 294.
47. UNEP/GEF SCS Project (2006) *Reversing Environmental Degradation Trends in the South China Sea and Gulf of Thailand* Report Fourth Meeting of the Regional Task Force on Economic Valuation Xuan Thuy, Nam Dinh Province, Viet Nam, 27- 30 March 2006.
48. Petersen E.H. (2006) *Institutional Economics and Fisheries Management: The Case of Pacific Tuna.* Edward Elgar, Cheltenham, UK.
49. UNEP (2008) *Update on DTIE/ETB' s ongoing work on fisheries subsidies* UNEP, January 2008.
50. *The Camouco Case* Case No 5, (Panama v France) Prompt Release, *ITLOS* 2000.
51. *Hoshinmaru Case,* Case No 14, (Japan v Russian Federation), Prompt Release, *ITLOS* 2007.
52. Haward M. (2004) "IUU Fishing: Contemporary Practice" in Elferink Alex G. Oude and Rothwell Donald R., (Eds.) *Oceans Management in the 21st Century: Institutional Frameworks and Responses* at p 86.
53. Barnes R. "The Convention on the Law of the Sea: An Effective Framework for Domestic Fisheries Conservation?" in *The Law of the Sea: Progress and Prospects*, Freestone D., *et al* (Eds.), (Oxford University Press: Oxford: 2006) at pp 233- 260.
54. Birnie P. W. "Marine Mammals: Exploiting the Ambiguities of Article 65 of the Convention on the Law of the Sea and related Provisions: Practice under the International Convention for the Regulation of Whaling," in *The Law of the Sea: Progress and Prospects*, Freestone D., *et al* (Eds.), (Oxford University Press: Oxford: 2006) at pp 261- 280.
55. Gjerde K. M. "High sea Fisheries Management under the Convention on the Law of the Sea" in *The Law of the Sea: Progress and Prospects*, Freestone D., *et al* (Eds.),(Oxford University Press: Oxford: 2006) at pp. 281-307.
56. 559 *UNTS* 285.
57. *Bering Sea (Fur Seals) Arbitration* (1999) *International Environmental Law Reports*, Vol 1, 43.
58. Schorr D. (2005) *Artisanal Fishing: Promoting Poverty Reduction and Community Development Through the New WTO Rules on Fisheries Subsidies*, Commissioned by UNEP, ETB, at pp 19 and 20.
59. Fisheries *Refugia* Science Programme (2009) *Distribution and Abundance of Fish Larvae in the Gulf*

of Thailand and the South China Sea online at http://refugia.unepscs.org/Fisheries_Refugia_Information/About Fisheries.

60. Article 5(b) of the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem as adopted at the Conference on Responsible Fisheries in the Marine Ecosystem, Reykjavik, Iceland, 1- 4 October 2001.
61. (1995) 34 *ILM* 1542.
62. UN (2010), *Resumed Review Conference on the Agreement Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks* New York, 24th-28th May 2010, online at http://www.un.org/Depts/los/convention_agreements/reviewconf/FishStocks_EN_A.pdf.
63. (1994) 33 *ILM* 1144.
64. UNGA Resolution 2009 at p. 21.

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emergent diseases, and multiple marine ecological disturbances (MMEDs) [29]. The number and frequency of MMEDs in an LME can be used as indicators of a decline in ecosystem health and loss of essential services. Indicators for the Pollution and Ecosystem Health Module also include habitats such as coral, seagrass and mangroves.

In several LMEs, excessive nutrient loadings of coastal waters have been related to harmful algal blooms implicated in mass mortalities of living resources, emergence of pathogens (e.g. cholera, vibrios, red tides, and paralytic shellfish toxins), and explosive growth of non indigenous species [31]. Excessive nitrogen loadings and oxygen depletion events are causing significant mortalities among marine resource species. In European LMEs, recent nitrogen flux increases have been recorded to range from 3-fold in Spain to 4-fold in the Baltic Sea to 11-fold in the Rhine River basin draining to the North Sea LME [32, 33]. This disruption of the nitrogen cycle has been ascribed to the Green Revolution of the 1970s, as the world community converted wetlands to agriculture, utilized more chemical inputs, and expanded irrigation to feed the world. For the Gulf of Mexico LME, much of the large increase in nitrogen export is from agricultural inputs, both from the increased delivery of fertilizer nitrogen as wetlands were converted to agriculture and from concentrations of livestock. Industrialized livestock production during the last two decades increased the flux, the eutrophication, and the oxygen depletion even more, as reported by the National Research Council [34]. Significant contributors to eutrophication are sewage from drainages of large cities and atmospheric deposition from automobiles and agricultural activities, with the amounts depending on proximity of sources.

The GEF is frequently asked by countries to help support the agreed-upon incremental cost of actions to reduce such nitrogen flux. Actions range from assisting in: (1) development of joint institutions for ecosystem-based approaches for adaptive management; (2) on-the-ground implementation of nitrogen abatement measures in the agricultural, industrial, and municipal sectors; and (3) breaching of floodplain dikes so that wetlands recently converted to agriculture may be reconverted to promote nitrogen assimilation. The excessive levels of nitrogen contributing to coastal eutrophication constitute a new global environment problem that is cross-sectoral in nature.

Preliminary global estimates of nitrogen export from freshwater basins to coastal waters have been determined by Seitzinger and Kroeze [35]. A GEF/LME global project, "Promoting Ecosystem-based Approaches to Fisheries Conservation and Large Marine Ecosystems", has filled gaps relating to LME Nitrogen loadings and provided forecasts for 63 LMEs [36]. The project has used GIS-based models relating land use and human activities in watersheds to nutrient transport by rivers to coastal systems.

Watershed DIN export to rivers as predicted by Seitzinger *et al.* [36] above was compiled for 63 LMEs (Fig. 23). The Antarctic LME data base was excluded as information was limited. Total DIN load and yield to each LME was aggregated from all

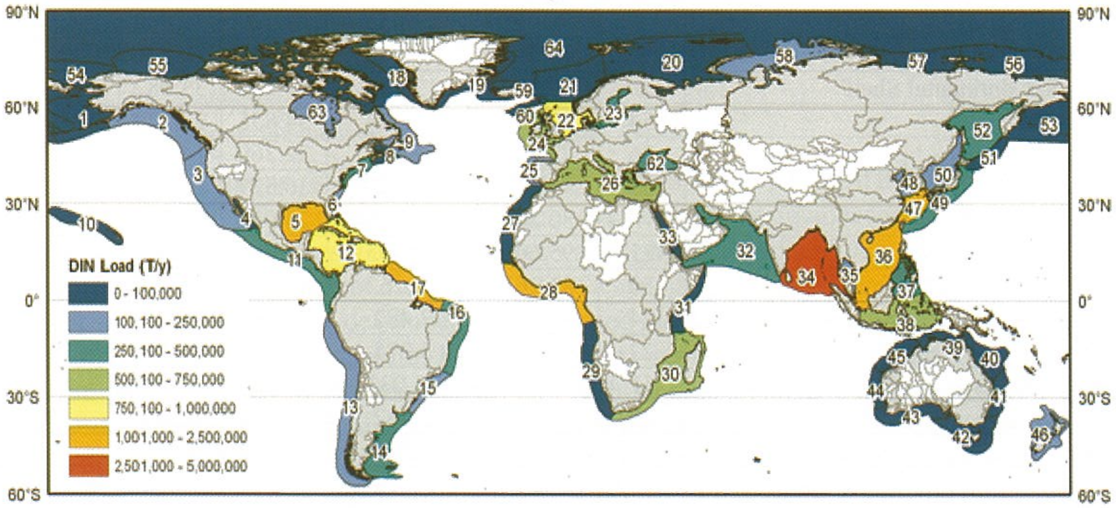

Figure 23. DIN load from land-based sources to LMEs predicted by the NEWS DIN model. See Figure 1 for LME identification [33].

CONTENTS

fishing and aquaculture, tourism and shipping and oil activities.

From a comparison of ranked socioeconomic and marine industry activity indices for southeast Asian LMEs (Table 1), countries bordering the South China Sea are the most economically active (MIA >20) followed by the countries bordering the Indonesian Sea, Gulf of Thailand and Sulu-Celebes LMEs in marine industrial index ranking. High levels of marine industry activity often are associated with significant levels of environmental degradation.

Governance Module Indicators

In GEF supported LME projects, the countries bordering an LME jointly prepare documents based on consensus that rank coastal resource issues, identify and prioritize transboundary problems, analyze socioeconomic impacts, outline root causes and advance possible remedies and actions for sustaining LME goods and services. The process of planning and implementing a program to recover depleted fisheries, reduce coastal pollution and restore damaged habitats in an LME is provided financial support by the GEF for two 5 year phases. Following consensus reached on priority transboundary issues to be addressed based on a12-month period of Transboundary Diagnostic Analysis (TDA) and agreement on a Strategic Action Program (SAP), the partners are prepared to implement the ecosystem based management (EBM) approach [3]. As conflict and negative environmental consequences arise from the use of LME goods and services, governance issues arise. Governance arrangements for the use of marine goods and services already exist in areas encompassed by LMEs. They have not, however, been developed around the operationalized governance structure of an LME and its multiple economic sectors including fish and fisheries, marine transportation, tourism, offshore oil and gas production, mining and other sectors. A system of indicators for measuring the changing conditions of those human activities in relation to gains or losses of benefits to the coastal communities is essential input to ecosystem sustainability accounting. LME

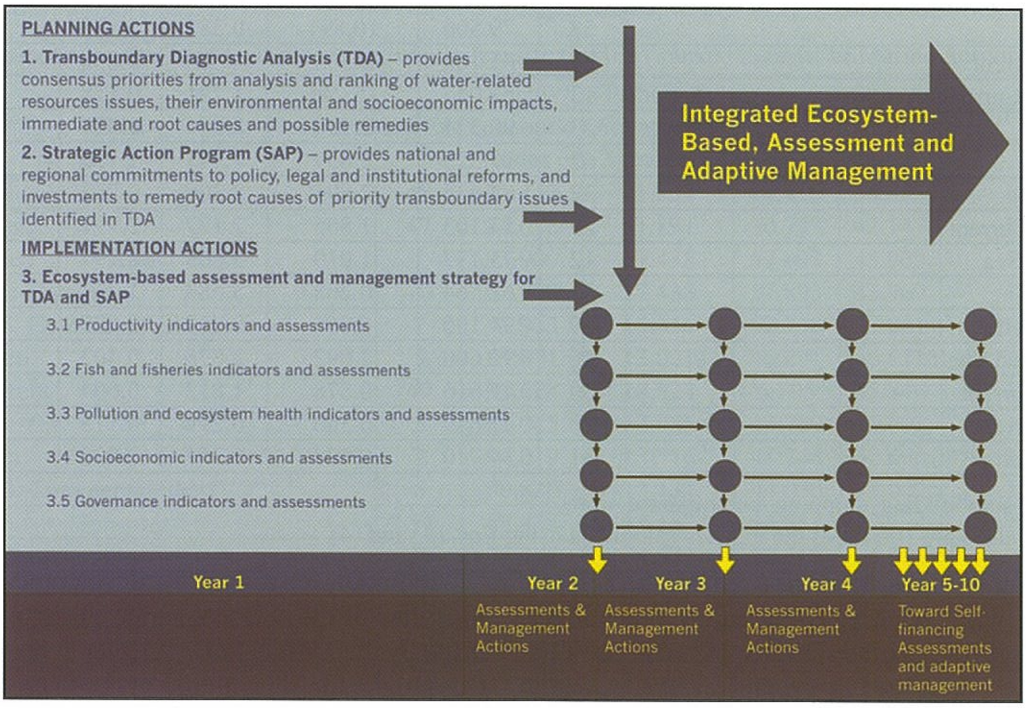

Figure 24. Large Marine Ecosystems Program planning and implementation process and schedule. The countries bordering an LME jointly prepare documents based on consensus that rank coastal resource issues, identify and prioritize transboundary problems, analyze socioeconomic impacts, outline root causes and advance possible remedies and actions for sustaining LME resources. The process to recover depleted fisheries, reduce coastal pollution and restore damaged habitats in an LME is funded by the Global Environment Facility and donor contributions over a period of 10 years. The Project is subsequently expected to be supported through self-financing [1].

monitoring and assessment indicators of changing economic and ecological conditions are examined annually and included as input added and integrated into adaptive management decisions. A 10-year timeline of annualized adaptive management actions is depicted in Figure 24.

SUSTAINABILITY OF LMES

The Southeast Asian LMEs – Gulf of Thailand, South China Sea, Sulu-Celebes Sea and Indonesian Sea – are under stress from overfishing and nutrient over enrichment, coastal pollution and habitat loss. The relatively steep increases in fisheries biomass yields of the past two decades (Figs. 10-13) and the high percentage of fisheries stocks in a fully exploited and overexploited condition (Figs. 14-16, 25), is cause for concern considering the dependence of the combined 350 million people of Indonesia, Malaysia, Philippines, and Thailand on fish as a critically important protein source. The per capita consumption of fish in Southeast Asia is among the highest in the world.

Examination of the socioeconomic indicators provides evidence of potential for expansion of marine industrial activity (Table 1) that would add stress to already degraded coastal habitats and fisheries. The ministries of environment, fisheries, tourism, energy and finance of the coastal countries bordering the Southeast Asian LMEs have been informed of the problems during the preparatory TDA and SAP phases of GEF supported projects for the Gulf of Thailand, South China Sea, Sulu-Celebes Sea and Indonesian Sea LMEs. In all four Southeast Asian LME cases, participating countries are aware of the need to improve management and governance policies for ensuring security of socioeconomic benefits from ecosystem goods and services.

The environmental ministers of Southeast Asian countries should consider seeking ways and means to invest in environmentally sound practices for fertilizing agricultural lands and limiting drainage basin effluent to reduce the excessive nitrogen inputs responsible in large part for the increased frequency and extent of nutrient over enrichment condition leading to harmful algal blooms, anoxic induced mortality events, and increasing incidence of dead zones.

It would be prudent for fisheries managers in the region to (1) exercise the precautionary approach and honor the Code of Conduct for Responsible Fisheries [42, 43] and (2) protect marine fisheries by authorizing a cap and sustain process for limiting catch levels [44-46].

Given enactment of precautionary measures for capping and sustaining fishery yields and controlling nutrient flux, the countries of the region can hold to the expectation that rates of global warming in the LMEs of Southeast Asia are lower than in other more northerly LMEs [27] and levels of average annual primary productivity are relatively stable (Fig. 6), contributing to robust and resilient ecological conditions at the base of the food web, thereby enhancing recovery and sustainability, given reductions in fishing effort, of important fishery resources of the Gulf of Thailand, South China Sea, Sulu-Celebes Sea, and Indonesian Sea LMEs.

REFERENCES

1. Sherman K., Celone P. and Adams S. (2004) NOAA Fisheries Service's Large Marine Ecosystems Program: *Status Report*, NOAA Technical Memorandum NMFS-NE-183. NOAA, NEFSC.
2. Pikitch E.K., Santora C., Babcock E.A. *et al.* (2004) Ecosystem-based fishery management. *Science* **305**(No. 5682): 346-347.
3. Duda A.M. and Sherman K. (2002) A new imperative for improving management of large marine ecosystems. *Ocean and Coastal Management* **45**: 797-833.
4. Sherman K., Aquarone M-C. and Adams S. (2007) *Global Applications of the Large Marine Ecosystem Approach, Technical Memorandum NMFS-NE 208.* National Oceanic and Atmospheric Administration, NEFSC.
5. Sherman K., Sissenwine M., Christensen V. and others. (2005) *A global movement toward an ecosystem approach to marine resources management.* Marine Ecology Progress Series 300 (Theme Section: Politics and socio-economics of ecosystem-based management of marine resources) pp. 275-279.
6. Pauly D. and Christensen V. (1995) Primary production required to sustain global fisheries. *Nature* **374**: 255-257
7. Beddington J.R. (1995) The primary requirements. *Nature* **374**: 213-214.

8. Epstein P.R. (1993) Algal blooms and public health. *World Resource Review* **5**(2): 190-206.
9. Seitzinger S., Sherman K. and Lee R. (2008) *Filling Gaps in LME Nitrogen Loadings Forecast for 64 LMEs, Intergovernmental Oceanographic Commission Technical Series 79*. UNESCO, Paris, France.
10. SAHFOS (2008) Annual Report (2007). The Sir Alister Hardy Foundation for Ocean Science, *Plymouth*, UK.
11. Aiken J., Pollard R., Williams R., Griffiths G. and Bellan I. (1999) Measurements of the upper ocean structure using towed profiling systems. In Sherman K and Tang Q. (Eds) *Large marine ecosystems of the Pacific Rim: Assessment, sustainability, and management* pp. 346-362. Blackwell Science, Inc., Malden, MA.
12. Berman M.S. and Sherman K. (2001) A towed body sampler for monitoring marine ecosystems. *Sea Technology* **42**(9): 48-52.
13. Belkin I. (2009) Rapid warming of Large Marine Ecosystems. *Progress in Oceanography* **81**(1-4): 207-213.
14. Rayner N.A., Parker D.E., Horton E.B., Folland C.K., Alexander L.V., Rowell D.P., Kent E.C. and Kaplan A. (2003) Global analyses of SST, sea ice and night marine air temperature since the late nineteenth century. *Journal of Geophysical Research, Atmospheres* **108**(D14); pages: **ACL 2**, 1-29 with illustrations in color following; 4407, doi:10.1029/2002JD002670.
15. IPCC (2007) *Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. WMO, UNEP, Geneva, Switzerland.
16. Trenberth K.E., Jones P.D., Ambenje P. and others (2007) Observations: Surface and Atmospheric Climate Change. In Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (Eds) *Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* pp. 235-336. Cambridge University Press, Cambridge, UK and NY.
17. Levitus S., Antonov J. et al. (2005) Warming of the world ocean, 1955-2003. *Geophysical Research Letters* **32**(2): L02604 doi: 02610.01029/02004GL021592.
18. Behrenfeld M.J. and Falkowski P.G. (1997) Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography* **42**(1): 1-20.
19. Halpern B.S., Walbridge S. et al. (2008) A global map of human impact on marine ecosystems. *Science* **319**: 948-949.
20. Richardson A. J. and Schoeman D.S. (2004) Climate impact on plankton ecosystems in the Northeast Atlantic. *Science* **305**(10): 1609-1612.
21. AFSC (2006) *Cooperative Acoustic Surveys, year index available for all* years. online at <http://www.afsc.noaa.gov/quarterly/amj2006/divrptsREFM7.htm>. NOAA, NMFS, Alaska Fisheries Science Center.
22. NEFSC (2002) Assessment of 20 Northeast groundfish stocks through 2001: A *Report of the Groundfish Assessment Review Meeting (GARM), 8-11 October 2002*. Northeast Fisheries Science Center, Woods Hole, MA.
23. NEFSC (2006) Northeast Fisheries Science Center research vessel groundfish surveys overviews. www.nefsc.noaa.gov/sos/vesurv/vesurv.html, A description of the Alaskan Fisheries Science Center 2006 Aleutian Islands.
24. Sherman K. (1993) Monitoring, mitigation, and sustainability of biomass yields in large marine ecosystems. In Della Croce N.F.R. (ed.) *Symposium Mediterranean Seas 2000. Istituto Scienze Ambientali Marine, Saint Margherita Ligure, 23-27 September 1991.: Universita di Genova* pp. 257-288.
25. Sherman K. and Hempel G. (Eds) (2008) *The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas*. UNEP Regional Seas Report and Studies.
26. Cleveland W.S. and Devlin S.J. (1988) Locally weighted regression: An approach to regression analysis by local fitting. *Journal of the American Statistical Association* **83**: 596-610.
27. Sherman K., Belkin I., Friedland K.D., O'Reilly J. and Hyde K. (2009) Accelerated warming and emergent trends in fisheries biomass yields of the world's large marine ecosystems. *Ambio* 38(4): 215-224.
28. Costanza R. (1992) Toward an operational definition of ecosystem health. In Costanza R., Norton B.G. and Haskell B.D. (Eds) *Ecosystem health: New goals for environmental management* pp. 239-256. Island Press, Washington, DC.
29. Sherman B. (2000) Marine ecosystem health as an expression of morbidity, mortality, and disease events. *Marine Pollution Bulletin* **41**(1-6): 232-254.
30. USEPA (2004) *National Coastal Condition Report*. United States Environmental Protection Agency, Washington, DC.
31. Epstein P.R. (1993) Algal blooms and public health. *World Resource Review* **5**(2): 190-206.
32. Howarth R., Anderson D., Cloern J. and others. (2000). *ESA Issues in Ecology* 7: 1-15.
33. Duda A.M. and El-Ashry M.T. (2000) Addressing the global water and environmental crises through integrated approaches to the management of land,

water, and ecological resources. *Water International* **25**: 115-126.
34. NRC (2000) *Clean coastal waters: Understanding and reducing the effects of nutrient pollution.* National Research Council, National Academy Press, Washington, DC.
35. Seitzinger S.P. and Kroeze C. (1998) Global distribution of nitrous oxide production and N inputs to freshwater and coastal marine ecosystems. *Global Biogeochemical Cycles* **12**: 93-113.
36. Seitzinger S., Sherman K. and Lee R. (2008) *Filling Gaps in LME Nitrogen Loadings Forecast for 64 LMEs. Intergovernmental Oceanographic Commission Technical Series 79.* UNESCO, Paris, France.
37. Seitzinger S. and Lee R. (2008) Land-based sources of nutrients to Large Marine Ecosystems. In Sherman K. and G. Hempel G. (Eds) *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas* pp. 81-98. UNEP, Nairobi.
38. Costanza R., d'Arge R., de Groot R. and others. (1997). The value of the world's ecosystem services and natural capital. *Nature* **387**: 253-260.
39. Hennessey T.M. and Sutinen J.G. (Eds) (2005) Sustaining large marine ecosystems: *The human dimension.* Elsevier Science, Amsterdam.
40. Sutinen J. (ed.) (2000) *A framework for monitoring and assessing socioeconomics and governance of large marine ecosystems.* NOAA Technical Memorandum NMFS-NE-158.
41. Hoagland P. and Jin D. (2006) *Accounting for economic activities in Large Marine Ecosystems and Regional Seas. UNEP Regional Seas Reports and Studies 181.* UNEP Regional Seas Programme, Nairobi, Kenya.
42. FAO (1995) Code of Conduct for Responsible Fisheries; Precautionary Principle. FAO, FAO Document Repository at www.fao.org/DOCREP/005/v9878e/v9878e00.htm.
43. Pitcher T., Pramod G., Kalikoski D. and Short K. (2009) Not honouring the code. *Nature* **457**: 658-659.
44. NPFMC (2002) *Responsible Fisheries Management into the 21st Century.* North Pacific Fishery Management Council.
45. Witherell D. (2005). Managing our Nation's Fisheries II: Focus on the Future. *Proceedings of a Conference on Fisheries Management in the United States, held in Washington, D.C. USA, March 2005* [at http://www.managingfisheries.org/managingfisheries05.pdf]. Fisheries Management in the United States II, Washington, D.C., USA, Eight Regional Fishery Management Councils and NOAA Fisheries.
46. Witherell D., Pautzke C. and Fluharty D. (2000) An ecosystem-based approach for Alaska groundfish fisheries. *ICES Journal of Marine Science* **57**: 771-777.

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Climate change in Southeast Asia

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Abstract Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air temperatures, including over Southeast Asian region. As reported by the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gases (GHGs) concentrations. Changes in the large-scale atmospheric circulation are also apparent and the changes have influenced regional atmospheric circulation including over Southeast Asia region. In relation to the warming and atmospheric circulation changes, precipitation patterns have generally changed globally with highly variable trends occurring over the tropical region including Southeast Asia. Widespread melting of polar ice has also caused rising in global average sea level.

There is high agreement that continued GHG emissions would cause further warming and induce many changes in the global climate system during the 21st century which would very likely be larger than those observed during the 20th century. As projected by the global general circulation models (GCMs) and regional climate model (RCMs), the warming in Southeast Asia is likely to be similar to the global mean. The GCMs and RCMs simulations project highly variable changes in precipitation over Southeast Asia, with the projected seasonal changes varying strongly within the region.

This paper discusses major findings from the AR4 of the IPCC, with particular attention to the changing climate of Southeast Asian region, and its associated impact, vulnerability and adaptation responses. Some projected regional impacts of global warming in Southeast Asia are decrease in freshwater availability, greater risk due to flooding from the sea over coastal areas, and an increase in extreme weather events. This will result in increase pressures on natural resources, the environment and economic development.

Keywords climate change – surface temperature – rainfall – sea level

INTRODUCTION

Global atmospheric concentration of the major greenhouse gases, namely, CO_2, CH_4 and N_2O, have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm over the last 650,000 years (180-300 ppm). The consequences of this change for the planetary atmosphere are beginning to be felt and as reported by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [1, 2] there is now convincing evidence for a growing human influence on global climate. Evidence is also emerging that these changes in climate are altering some of the physical and biological systems of the planet.

Given the inertia in our energy systems and the long memory exhibited by the climate system, the human-induced climate change will become increasingly important relative to natural climate variability during the next 50 to 100 years to come. Efforts to reduce greenhouse gas emissions in the future may well slow the rate of future warming, but during the coming century these efforts will not arrest it completely. There is therefore also a pressing need to adapt to climate change.

There are however some uncertainties on how the climate may change during the 21st century for two main reasons. We do not know what will happen to future global emissions of greenhouse gases and aerosol precursors, nor do we know for sure what effects such future emissions will have on our climate. The first of these uncertainties can be thought of as a consequence of the many possible paths that future society may follow, or emissions uncertainty; the second can be thought of as uncertainty about our understanding of how the climate system works, or scientific uncertainty.

OBSERVED GLOBAL WARMING

According to the recent IPCC Fourth Assessment Report (AR4) [1], the updated 100-year linear trend from 1906-2005 shows that the global temperature has risen by 0.74±0.18°C. This observed trend is larger than the corresponding trend of 0.6°C for 1901-2000 given in the Third IPCC Assessment Report (TAR) [3]. Figure 1 shows the anomalies in global average surface temperature (1850-2006) relative to the 1961-1990 mean. Although there is a considerable year-to-year variability, an upward trend can be clearly seen; firstly over the period from about 1910-1940, with a small cooling from 1940-1950, followed by a sustained rise over the last five and half decades since then. 1998 was the warmest year in this time series, followed by 2002, 2003 and 2004. All of the 'top–ten' warmest years have been since 1990, and all the 'top-twenty' warmest years have been since 1981.

Warming has occurred in both land and ocean domains, and in both sea surface temperature (SST) and night-time marine air temperature over the oceans. However, land regions have warmed at a faster rate than the oceans. For the globe as a whole, surface air temperatures over land have risen at about double the ocean rate after 1979 (over 0.27°C per decade versus 0.13°C per decade), with the greatest warming during winter (December to February) and spring (March to May) in the Northern

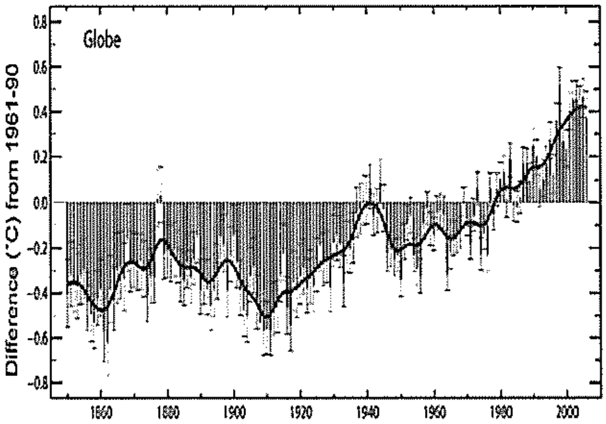

Figure 1. Global surface temperature anomalies (oC) from 1850 to 2006 relative to 1961 to 1990 mean, along with 5 to 95% error bar ranges and decadal smoothing curve [1].

Hemisphere. Changes in extremes of temperature are also consistent with warming of the climate. A widespread reduction in the number of frost days in mid-latitude regions, an increase in the number of warm extremes and a reduction in the number of daily cold extremes are observed in 70-75% of the land regions where data are available. The most marked changes are for cold (lowest 10%, based on 1961-1990) nights, which have become rarer over the 1951-2003 period. Warm (highest 10%) nights have become more frequent. Diurnal temperature range decreased by 0.07°C per decade averaged over 1950-2004, but had little change from 1979-2004, as both maximum and minimum temperatures rose at similar rates. Summer months (June to August) was the hottest since comparable instrumental records began around 1780 (1.4°C above the previous warmest in 1807) and is very likely to have been the hottest since at least 1500.

At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed, including changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weathers. Most of the observed increase in globally averaged temperature since the mid-20th century is very likely (>90% probability) due to the observed increase in anthropogenic greenhouse gas concentrations, with a higher confidence level than the IPCC TAR's conclusion that "most of observed warming over the last 50 years likely (>66% probability) have been due to the increase in greenhouse gas concentration".

Consistent with observed changes in surface temperature, there has been almost worldwide reduction in glacier and small ice cap (not including Antarctica and Greenland) mass and extent in the 20th century; snow cover has decreased in many Northern Hemisphere regions, and sea-ice extents have decreased in the Arctic, particularly in spring and summer; and the oceans are warming and sea level is rising.

In the context of global warming, extreme weather and climate events including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones have assumed significant changes in intensity, areas and frequency of occurrence (Table 1). More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas. Widespread changes in extreme temperature have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot day, hot nights, and heat waves have become more frequent. There is observational evidence for an increase of intense tropical cyclone (hurricanes in the North Atlantic and typhoons in the North Pacific) since about 1970, correlated with increase of tropical sea surface temperature. There is no clear trend in the annual numbers of tropical cyclones.

Patterns of precipitation change are more spatially and seasonally variable than temperature change, but where significant precipitation changes do occur they are consistent with measured changes in stream-flow. Precipitation has generally increased over land north of 30°N over the period 1900-2005 but downward trends dominate the subtropics since the 1970s. Among other findings by IPCC [1], downward trends are also present in some areas of the deep tropics from 10°N to 10°S, especially after 1976/1977 although most of the Southeast Asian region do not show much change. Tropical values dominate the global mean. It is likely that there have been increases in the number of heavy precipitation events (e.g., 95th percentile) within many land regions, even in those where there has been a reduction in total precipitation amount, consistent with a warming climate and observed significant increasing amounts of water vapour in the atmosphere. Increases have also been reported for more rare precipitation events (1 in 50 year return period), but only a few regions have sufficient data to assess such trends reliably.

Observed marked increases in drought in the past three decades arise from more intense and longer droughts over wider areas. Decreased land precipitation and increased temperatures that enhance evapotranspiration and drying are important factors that have contributed to more regions experiencing droughts, as measured by the Palmer Drought Severity Index (PDSI). The regions where droughts have occurred seem to be determined largely by changes in SSTs, especially in the tropics, through associated changes in the atmospheric circulation and precipitation.

Surface specific humidity has generally increased after 1976 in close association with higher temperatures over both land and ocean. Total column water vapour has increased over the global oceans by 1.2±0.3% per decade from 1988 to 2004, consistent in pattern and amount with changes in SST and a fairly constant relative humidity. Strong correlations with SST suggest that total column water vapour

Table 1. Recent trends, an assessment of the human influence on the trend, and projections of extreme weather events [1].

Phenomenon and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*	*Likely*	*Virtually certain*
Warmer and more frequent hot days and nights over most land areas	*Very likely*	*Likely (nights)*	*Virtually certain*
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*	*Very likely*
Area affected by droughts increases	Likely in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	Likely in many regions since 1970s	*More likely than not*	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)	*Likely*	*More likely than not*	*Likely*

has increased by 4% since 1970. Similar upward trends in upper tropospheric specific humidity, which considerably enhances the greenhouse effect, have also been detected from 1982 to 2004.

Atmospheric circulation variability and change is largely described by the relatively few well-known major patterns. El Niño Southern Oscillation (ENSO) is the dominant mode of global-scale variability on inter-annual time scales although there have been times when it is less apparent. There are substantial multi-decadal variations in the Pacific sector over the 20th century with extended periods of weakened as well as strengthened circulation. Cloud changes are dominated by ENSO. Widespread decreases in continental diurnal temperature range since the 1950s coincide with increases in cloud amounts. Radiation changes at the top-of-the-atmosphere from the 1980s to 1990s, possibly related in part to the ENSO phenomenon, appear to be associated with reductions in tropical upper-level cloud cover, and are linked to changes in the energy budget at the surface and in observed ocean heat content.

There is also observational evidence for an increase of intense tropical cyclone (hurricanes in the North Atlantic and typhoons in the North Pacific) since about 1970, correlated with increase of tropical sea surface temperature. However, there is no clear trend in the annual numbers of tropical cyclones. Variations in tropical cyclones, hurricanes and typhoons are also dominated by ENSO and decadal variability, which result in a redistribution of tropical storm numbers and their tracks, so that increases in one basin are often compensated by decreases over other oceans. Trends are apparent in SSTs and other critical variables that influence tropical thunderstorm and tropical storm development. Globally, estimates of the potential destructiveness of hurricanes show a significant upward trend since the mid-1970s, with a trend toward longer lifetimes and greater storm intensity, and such trends are strongly correlated with tropical SST. These relationships have been reinforced by findings of a large increase in numbers and proportion of hurricanes reaching categories 4 and 5 globally since 1970 even as total number of cyclones and cyclone days decreased slightly in most basins. The largest increase was in the North Pacific, Indian and Southwest Pacific Oceans.

Globally sea level has risen at an average rate of 1.8 (1.3 to 2.3) mm per year from 1961 to 2003. Faster rates of rise have been observed for the period 1993 to 2003, at about 3.1 (2.4 to 3.8) mm per year. This observed rate for the recent period is close to the estimated total of 2.8±0.7 mm per year for climate-related contributions due to thermal expansion (1.6±0.5 mm per year) and changes in land ice (1.2±0.4 mm per year).

OBSERVED SOUTHEAST ASIAN CLIMATE TRENDS

Chan and Yap [4] analyzed the annual mean, annual mean maximum and annual mean minimum temperature records of Malaysia and found significant warming trends for all the stations in the country. Updated records of annual mean surface temperature data for Malaysia by the Malaysian Meteorological Department has indicated significant warming trends with increase in temperature from 0.7°C to 1.3°C per half century for the country. The warming trend with interannual variability of temperature in Malaysia has been discussed [5]. It is understood that general temperature trends for Southeast Asia region for the last half century is also comparable to the trend experienced in Malaysia.

As reported by Toyoshima [6], sea level data measured at coastal stations in Peninsular Malaysia for nine years beginning in 1983 have positive relationships with on-shore wind speed and rainfall, but no trends were detectable from the time series of the data. Due to insufficient length of sea level records in Malaysia, it seems that new studies are not available in order to detect long-term sea level trends in Malaysia. It is also understood that there is also insufficient length of sea level records throughout Southeast Asia to access its past regional sea level rise.

Based on the Malaysian Meteorological Department rainfall stations since 1980s, there has been increasing number of days of extreme rainfall event (exceeding 90th percentile of total rainfall) for several stations over the Peninsular Malaysia. Over the past three years an increase in weather extremes have also been observed in Malaysia.

FUTURE GLOBAL CLIMATE CHANGE

To obtain a realistic estimate of the possible climate evolution in future, one has not only to know the internal dynamics of the climate system, but also the future emission of greenhouse gases and their concentration in the atmosphere. To estimate the human-induced effect, so called scenarios have been developed, which are based on different plausible pathways of future development of the world, population growths, standards and life style of living, energy consumption and energy sources. Each of these scenarios corresponds to a different level of emission of greenhouse gases (CO_2, CH_4, O_3, N_2O, NO_x, CFCs) and their concentration in the atmosphere. These scenarios have been compiled by a group of experts of the Intergovernmental Panel on Climate Change (IPCC), which published 35 Emissions-scenarios based on different story lines, which are called "SRES-Scenarios". However, the IPCC's [1] study focused its attention on three cases: a *low* case (B1), a *medium* case (A1B) and a *medium high* case (A2).

Based on the scenarios it is estimated that the global mean near-surface temperature will rise by the year 2100 between 1.1 to 2.9°C with a best estimate of 1.8°C for the *low* B1 scenario, 1.7 to 4.4°C with a best estimate of 2.8°C for the *medium* A1B scenario, and 2.0 to 5.4°C with a best estimate of 3.4°C for the *high* A2 scenario (Fig. 2).

As reported by the IPCC [1], the pattern of warming shows the highest temperature rises over land and in most high northern latitudes, and a reduced warming in part of the North Atlantic and the Southern Ocean. The warming does not display large differences between the different scenarios during the first three decades of the present century, while in the final two decades the amplitude of the warming pattern is directly related to the scenarios.

Sea level will continue to rise in the warming climate. The six SRES scenarios give a range of 180 to 590 mm rise in sea level by 2090-2099 relative to 1980-1999 levels, with B1 scenario projecting a rise of 180 to 380 mm, A1T scenario projecting a rise of 200 to 450 mm, B2 scenario projecting a rise of 200 to 450 mm, A1B scenario projecting a rise of 210 to 480 mm, A2 scenario a rise of 230 to 510 mm and A1FI scenario a rise of 260 to 590 mm.

As in the past, sea level change in the future will not be geographically uniform, with regional sea level change varying within about ±0.15 m of the mean in a typical model projection. Thermal expansion is projected to contribute more than half of the average rise, but land ice will lose mass increasingly rapidly as the century progresses. Figure 3 shows the evolution of global mean sea level in the past and as projected for the 21st century for the *medium* SRES A1B scenario.

The snow and ice-coverage will decrease in both hemispheres. Contraction of the Greenland Ice Sheet is projected to continue to contribute to sea level rise after 2100. Complete elimination of the Greenland Ice Sheet will result in contributing to sea level rise of about 7 m. Current global model studies project that the Antarctic Ice Sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamic ice discharge dominates the ice sheet mass balance.

The storm tracks of the mid-latitudes are

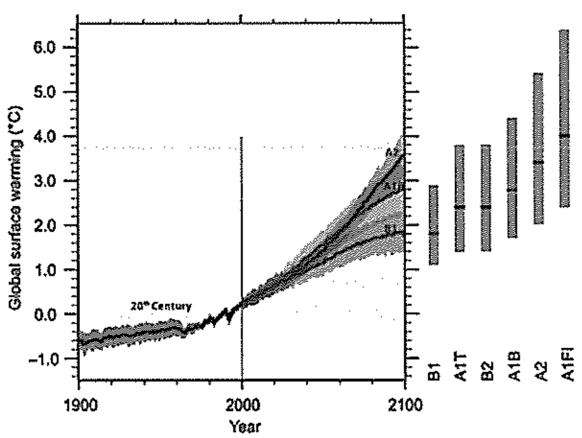

Figure 2. Multi-model means of surface warming relative to 1980-1999 for the scenarios A2, A1B and B1. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the SRES marker scenarios [1].

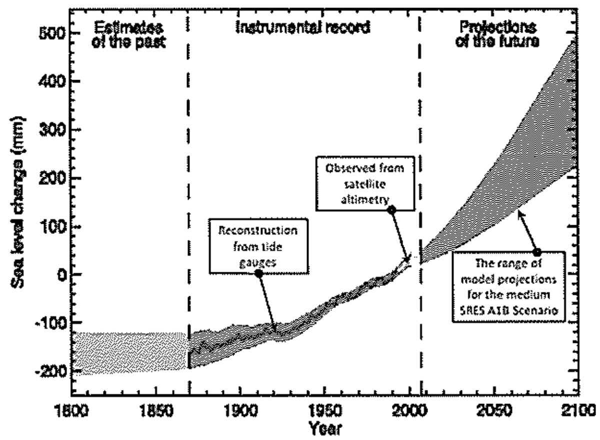

Figure 3. Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before1870, global measurements of sea level are not available. The grey shading shows the uncertainty in the estimated long-term rate of sea level. [1].

suggested to move further pole-ward. This is connected with a shift in the main precipitation areas. It leads to a decrease of precipitation in the subtropics, particularly during the months of winter in the northern hemisphere, and to an increase of precipitation in the mid to high latitudes. In summer in the northern hemisphere the subtropics exhibit a decrease of precipitation as well with the exception of the monsoon region of East Asia where it increases. It is likely that future tropical cyclones will become more intense.

As reported by Houghton [7], a recent modeling study has shown that if atmospheric CO_2 concentration is doubled from its pre-industrial value, the probability of extreme seasonal precipitation in winter is likely to increase substantially over large areas of central and northern Europe and likely to decrease over parts of the Mediterranean and North Africa. The increase in parts of Central Europe is such that the return period of extreme rainfall events would decrease by about a factor of five (e.g. from fifty years to ten years). Milly *et al.* [8] also show similar results in their study of major river basins around the world.

There are a number of phenomena (the number of warm days, warm spells and heat waves, heavy precipitation events, areas affected by drought, the number of intense tropical cyclones and of extreme high sea level events) which already now show a trend (Table 1). These trends will persist and become stronger in a future climate. It is very likely that hot extreme, heat waves and heavy precipitation will continue to become more frequent and future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical SST. There is less confidence in projections of a global decrease in numbers of tropical cyclones. However, intense tropical cyclone activity is likely to increase in the future warming. Areas affected by droughts will likely increase and incidence of extreme high sea level (excluding tsunamis) will be likely.

FUTURE CLIMATE CHANGE IN SOUTHEAST ASIA

IPCC [1] has reported that warming in Southeast Asia is likely to be similar to the global mean. Precipitation in winter will very likely increase in the southern parts of Southeastern Asia, and in summer it will likely increase in most of Southeast Asia. The IPCC [1] has also reported that there will very likely be an increase in frequency of intense precipitation events in parts of South and Southeast Asia. Extreme rainfall and winds associated with tropical cyclones are likely to increase in East Asia, Southeast Asia and South Asia.

Since the local climate pattern in Southeast Asia is greatly governed by regional synoptic features, therefore, the possible effects of global warming can be related to the key synoptic features which influence the climate in this region – monsoons, Indian Ocean Dipole, El Niño/La Niña, typhoons etc. However, because the major physical feature that governs the Asian monsoon is the distribution of Asian and Australian land masses and the surrounding oceans, the global warming is not expected to disrupt or shift the monsoon weather pattern in significant ways, rather the monsoon climate pattern over Malaysia will remain while its intensity may change [4].

In the initial national communication to the United Nation Framework Convention on Climate Change, Chan and Yap [4] found warming over Malaysia to be slightly higher during the Northern Hemisphere winter months than the Northern Hemisphere summer months and to be around the model global average values. Meanwhile, the Third Assessment Report of the IPCC [3] reported modeling results that showed warming to be slightly below global average for the Malaysia region.

As reported by the IPCC [1], the projected temperature change in Southeast Asian region for the early 21st century (2020-2029) relative to the period 1980-1999 is around 0.5°C to 1.0°C. Meanwhile the projected average temperature changes in the region for the late 21st century (2090-2099) relative to the period 1980-1999 are: around 2.0°C for a *low* (B1) scenario; around 3.0°C for a *medium* (A1B) scenario; and around 4.0°C for a *medium high* (A2) scenario.

Figure 4 shows the projected annual surface temperature changes (°C) in Southeast Asia region averaged for the 30-year period (2071-2100) relative to the period 1961-1990 for a *medium high* (A2) scenario. The pattern of warming shows the highest temperature rises over land, and a reduced warming in part of the South China Sea, Southern Philippine Sea, Molluca Sea and Banda Sea. This result was produced by the PRECIS regional climate model (RCM) simulated at the Malaysian Meteorological Department (MMD). PRECIS stands for "Providing Regional Climates for Impact Studies", which is

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2. Beveridge W.I.B. (1961) *The Art of Scientific Investigation*. Mercury Book, London.
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a high resolution RCM developed by the Hadley Centre, United Kingdom Meteorological Office.

As given by the multi-model ensemble projection in the IPCC report [1]: the projected Southeast Asia average precipitation changes for the late 21st century (2090-2099) relative to the period 1980-1999 for the *medium* (A1B) scenario during Northern Hemisphere winter (December to February) is mixed: -20% to +20% depending on localized areas. Meanwhile, the projected Southeast Asian average precipitation changes for the late 21st century (2090-2099) relative to the period 1980–1999 for the *medium* (A1B) scenario during Northern Hemisphere summer (June to August) is +5% to +20% throughout the region. It is important to note that increases in the number of heavy precipitation events within Southeast Asia is likely, even in those where there will be a reduction or small change in total precipitation amount, that is consistent with the projected warming climate which will increase the amounts of water vapour in the atmosphere.

Figure 5 shows the projected annual rainfall changes over Southeast Asia region, averaged for 30-year period (2071-2100) relative to the period 1961-1990 for a *medium high* (A2) scenario, as produced by the PRECIS regional climate model at MMD.

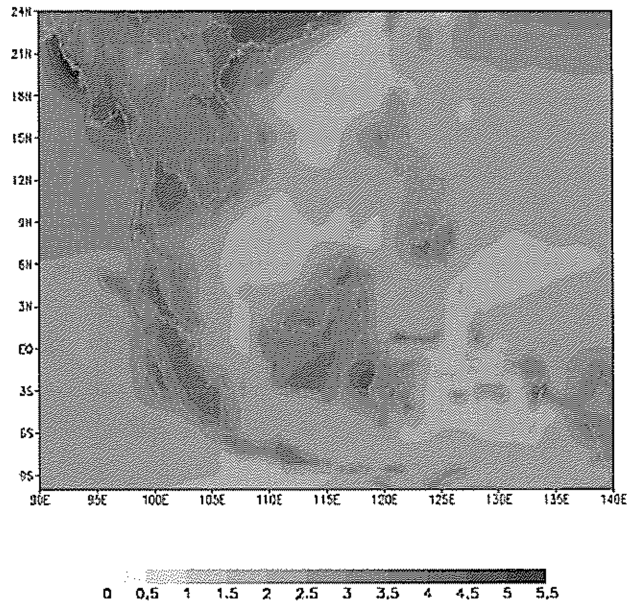

Figure 4. Projected Southeast Asia annual surface temperature changes (°C), averaged for 30-year period (2071–2100) relative to the period 1961-1990 for a *medium high* (A2) scenario, produced by the PRECIS regional climate model (RCM) simulation at the Malaysian Meteorological Department.

The pattern of annual rainfall change shows highest deficit over maritime area, and largest increase mainly over Indochinese Peninsular.

It is likely the characteristics of the monsoon systems over Southeast Asia will change in the future with global warming. In fact the characteristic of the northeast monsoon (or winter monsoon) over Southeast Asia has changed since the mid 1970s. Several factors have contributed to these changes with the El Niño predominance in the Pacific being one of the major reasons. In the future some studies

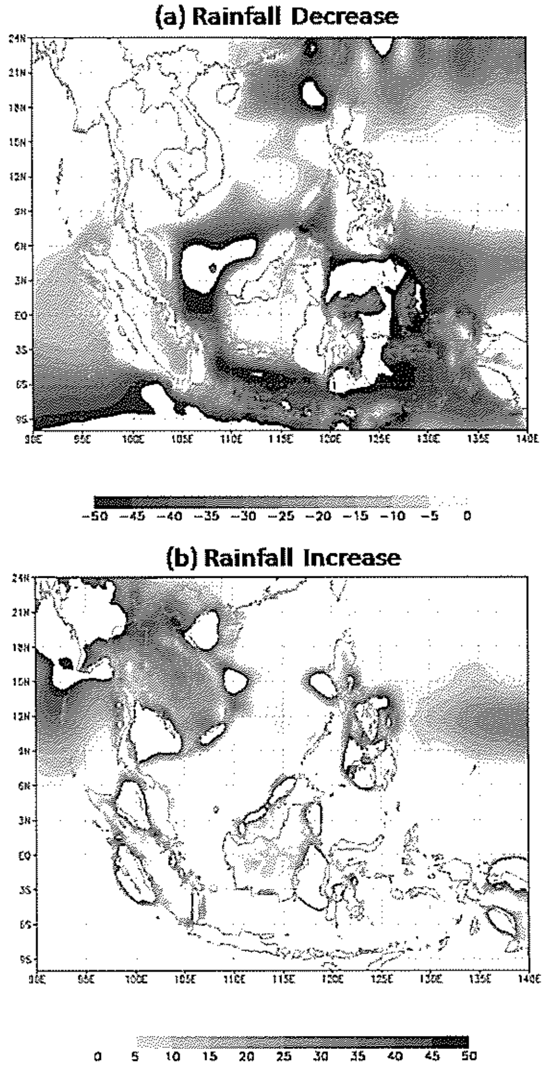

Figure 5. Projected annual rainfall changes (%) over Southeast Asia, averaged for 30-year period (2071-2100) relative to the period 1961-1990 for a *medium high* (A2) scenario, produced by the PRECIS regional climate model simulation at the Malaysian Meteorological Department. Shaded area in (a) indicates rainfall decrease; and (b) rainfall increase.

will have shown the northeast monsoon may weaken as the globe warms further and the characteristics may shift close to the northeast monsoon experienced in December 2006 and January 2007 [9].

During the winter monsoon, the maritime continent experiences increased convective activity due to the strengthening of the East Asia branch of the north-south Hadley circulation and the east-west Walker circulation. This is primarily due to extensive freshening of the low-level northeasterlies associated with a cold surge, which penetrates rapidly into the equatorial South China Sea enhancing the low-level convergence in the near-equatorial region. The impact on the low-level convergence depends on the degree of the air-sea interaction caused by the northeasterly surge. The warm equatorial waters interact with the colder waters in the South China Sea creating a temperature gradient perpendicular to the Borneo coast. The sea surface temperature (SST) gradient over the South China Sea extending from 3°N to 9°N and 104°E to 116°E are mainly driven by the easterly and northeasterly winds. The SST gradient enhances the near-equatorial vortices by intensifying the convective activities in the near-equatorial regions of the South China Sea. The 850 hPa vorticity and the averaged SST gradient are used to show the interaction between the South China Sea SST and the near-equatorial vortices.

The marked features for a strong (weak) winter monsoon include strong (weak) northerly winds along coastal East Asia, cold (warm) East Asian continent and surrounding sea and warm (cold) ocean from the subtropical central Pacific to the tropical western Pacific, high (low) pressure in East Asian continent and low (high) pressure in the adjacent ocean and deep (weak) East Asian trough at 500 hPa level.

The interannual variations are found to be closely connected to the sea surface temperature (SST) anomaly in both the western and eastern tropical Pacific. The results suggest that the processes associated with the SST anomaly over the tropical Pacific mainly influence the strength of the winter monsoon. The winter monsoon generally becomes weak when there is a positive SST anomaly in the tropical eastern Pacific (El Niño), and it becomes strong when there is a negative SST anomaly (La Niña). Moreover, the SST anomaly in the South China Sea is found to be closely related to the winter monsoon and may persist to the following summer.

Malaysian Meteorological Department used Winter Monsoon Intensity Index defined by Zhou *et al.* [10] to gauge the intensity or severity of the Northeast Monsoon (Winter Monsoon). This index was also used to analyze the interannual variability of the Asian monsoon, particularly the Northeast monsoon. Winter Monsoon Index (WMI) is defined as the area averaged SLP (sea level pressure) anomaly difference between (110-120°E, 20-45°N) and (150-160°E, 20-45°N).

The projected 850 hPa wind circulation pattern anomaly and the negative trends in the multi-model ensemble projection of the Winter Monsoon Index (2001-2099) show the overall weakening of the winter monsoon (Fig. 6).

Projected 850 hPa wind anomalies for the winter monsoon season (Dec-Jan-Feb) during the early 21st century (2020-2029), middle of 21st century (2050-2059) and the late 21st century (2090-2099) relative to the period 1990-1999 (last decade of the 20th century) based on SRES A1B scenario indicate the slackening of the winter monsoon northwesterlies flow over northern China to the Pacific Ocean, the weakening of Siberia High, the weakening and northward shift of the Aleutian Low as well as the apparent weakened pressure gradient in the eastern coast of the Asian continent.

The Fourth Assessment Report of the IPCC results [1] also indicate a weakening of the southwest monsoon (northern hemisphere summer monsoon) due to a reduction of the meridional thermal gradient between the Asian continent and the adjacent seas. However despite weakening of the dynamic monsoon circulation, atmospheric moisture build-up

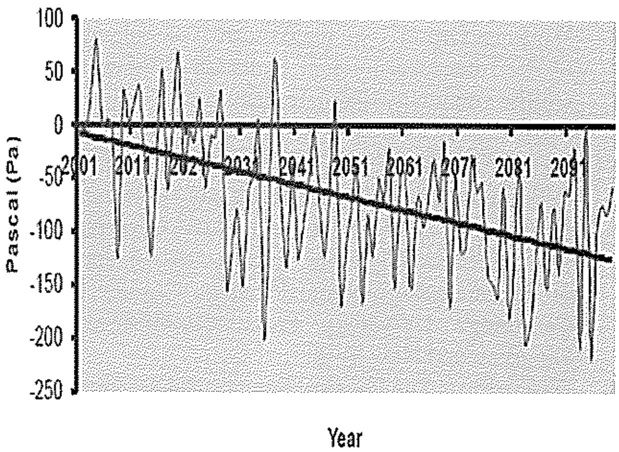

Figure 6. Multi-model ensemble projection of the Winter Monsoon Index.

due to increased moisture flux into the region results in precipitation increase in the Asian monsoon region during the summer months. As a manifestation of this climate and weather of Malaysia may exhibit greater variability with the possibility of extreme weather events become more frequent and severe.

According to studies on the response of El Niño/ Southern Oscillation (ENSO) to greenhouse warming by the Max-Planck Institute [11], the mean state of the Pacific Ocean would tend towards the 'El Niño-like' state by the middle of this century. The Fourth Assessment Report of the IPCC results also indicate a weak shift towards conditions which may be described as 'El Niño-like' with sea-surface temperatures in the central and eastern equatorial Pacific warming more than those in the west, with an eastward shift in mean precipitation associated with weaker tropical circulations. The models showed continued El Niño-Southern Oscillation (ENSO) interannual variability despite the change in basic state. However there is no discernible change in ENSO amplitude or frequency.

CONCLUSION

Human-induced climate change, evolving from continued increases in atmospheric greenhouse gas concentrations, represents a problem of great complexity. If the world warms as projected by global climate model simulations [1], there will be implications for climate-sensitive natural resources, and the communities that depend on them. A warmer climate will affect all aspects of the hydrologic cycle, including monsoon circulation changes leading to changes in stream flow and availability of water supplies. Demand for water is also likely to change, both for supporting human needs and activities as well as various ecosystems.

Some projected regional impacts of global warming in Southeast Asia are decrease in freshwater availability, greater risk due to flooding from the sea over coastal areas, and an increase in extreme weather events. This will result in increase pressures on natural resources, the environment and economic development. In view of its geographical location, which is surrounding by the ocean, one of the most threatening aspects of climate change to Southeast Asia is the likelihood that extreme weather events will become more variable, more intense and more frequent in the future warming climate system.

REFERENCES

1. IPCC (2007) Chapter 5: The Physical Science Basis, Observations: Oceanic Climate Change and Sea Level; Chapter 10: Global Climate Projections; and Chapter 11: Regional Climate Projections. In Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (Eds.) *Climate Change (2007): The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Online version available under: www.ipcc.ch.
2. IPCC (2007) Summary for Policymakers. In Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. and Miller H.L. (Eds.) *Climate Change (2007): The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York.
3. IPCC (2001) The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In Houghton J, Ding Y, Grigg D., Noguer M., van der Linden P., Xiaosu D., Maskell K. and Johnson C. (Eds.) *Climate Change (2001).* Cambridge University Press, Cambridge.
4. Chan A.K. and Yap K.S. (2001) National Climate Change Scenarios. In Chong A.L. and Mathews P. (Eds.) *Malaysia National Response Strategies to Climate Change* pp. 3-79. Ministry of Science, Technology and the Environment, Kuala Lumpur.
5. Tangang F.T., Juneng L. and Ahmad S. (2007) Trend and interannual variability of temperature in Malaysia: 1961-2002. *Theoretical and Applied Climatology* **89:** 127-141.
6. Toyoshima S. (1994) Tidal phenomena and mean sea level variations around Peninsular Malaysia. Paper presented at the Seminar on Tide & Tidal Phenomena, 10-11 January 1994, Kuala Lumpur.
7. Houghton J. (2004). *Global Warming: The Complete Briefing – 3rd ed.* University Press, Cambridge.
8. Milly P.C.D., Wetherald R.T., Dunne K.A. and Delworth T.L. (2002) Increasing risk of great floods in a changing climate. *Nature* **415:** 514-517.
9. Yasunari T. (2007) Local to global scale atmospheric circulation features associated with the floods in Malaysia in December 2006 and January 2007 – A

Preliminary Analysis. Paper presented at the National Seminar on Social-Economic Impacts of Extreme Weather and Climate Changes, 21-22 Jun 2007, Putrajaya.

10. Zhou W., Wang X., Zhou C. L. and Chan J.C.L. (2007) Interdecadal variability of the relationship between the East Asian Winter Monsoon and ENSO. *Meteorology and Atmospheric Physics* **98**: 283-293.

11. Timmermann A., Oberhuber J., Bacher A., Esch M., Latif M. and Roeckner E. (1998). *ENSO Response to Greenhouse Warming. Report No. 251.* Max-Planck Institute of Meteorology, Hamburg.

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The basic characteristics of geotectonics in the South China Sea area

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Abstract The basement of the South China Sea (SCS) and adjacent areas can be divided into six divisions (regions) – Paleozoic Erathem graben-faulted basement division in Beibu Gulf, Paleozoic Erathem strike-slip pull-apart basement division in Yinggehai waters, Paleozoic Erathem faulted-depression basement division in eastern Hainan, Paleozoic Erathem rifted basement division in northern Xisha (Paracel), Paleozoic Erathem strike-slip extending basement division in southern Xisha, and Paleozoic-Mesozoic Erathem extending basement division in Nansha Islands (Spratly) waters. With geological analysis, the history of geotectonic evolution of this sea area was rebuilt. The Pre-Cenozoic basement in the South China Sea and Yunkai continental area adjourning this sea area, are coeval within the Tethyan tectonic domain in Pre-Cenozoic Period. They are formed on the background of Paleo-Tethyan tectonic domain, and are important components of the Eastern Tethyan multi-island-ocean system. Three branches of the Eastern Paleo-Tethys tectonic domain – North Yunkai Sea Basin, North Hainan Sea Basin, and South Hainan Sea Basin – have evolved into the North Yunkai, North Hainan, and South Hainan suture zones, respectively. This shows a distinctive feature of localization for the Pre-Cenozoic basement. Since the Late Paleozoic Period, accompanying the formation and extinction of Paleo- and Meso-Tethys, the Pre-Cenozoic basement of this area had experienced five stages of evolution: (1) Devonian to Early Permian (D-P1), the development stage of multi-island-ocean system of eastern Paleo-Tethys; (2) Late Permian (P2), the emergence of Meso-Tethys (Paleo-SCS) and the extinction of Paleo-Tethys; (3) Triassic to Early Cretaceous (T-K1), the suturing stage of multiple blocks in eastern Paleo-Tethys; (4) Late Cretaceous to Early Miocene (K2-N11), the formation of modern SCS and the extinction of Meso-Tethys (Paleo-SCS); and (5) Middle Miocene (N12) to present, the SCS ceased seafloor spreading and the Australian Plate underthrust and extruded northwards.

Keywords Pre-Cenozoic basement – East Tethys tectonic domain – Tethyan sutures – Tectonic evolution – South China Sea area

INTRODUCTION

The South China Sea (SCS) is located south of the South China Caledonian fold zone and east of the Indochina Block. In the southeast, it is separated from the North Kalimantan Subduction-thrusting Zone by the Nansha trough (the Palawan trough). To the east it is bounded by the Manila Trench and the Luzon-Taiwan Arc. Problems related to the Pre-Cenozoic basement of the area, such as the direction of the seaward extending of the Paleo-Tethyan sutures, the transition between the East Tethys tectonic domain and Pacific tectonic domain, and so on, have attracted numerous geologists. To solve these problems, a systematic research on the geotectonic nature, division, and evolution of the Pre-Cenozoic basement over the SCS is of great importance. The division of basement described here is mostly based on the characteristics of geotectonic conversion of the basement in Cenozoic Period. We take the boundaries of plates (subduction-collision suture belt, ophiolite belt, deep-ocean radiolarian sedimentary rock belt, ocean ridge igneous rock belt, and deep strike-slip transform fault belt, etc.) as the primary boundaries for basement division, in a way similar to the division of terrane boundaries [1], and keep each division having its own development history. On the other hand, we consider the geotectonic development during the Cenozoic as well. Each type of basement division controlled the formation of a specific tectonic-type Cenozoic sedimentary basin due to specific geotectonic location of the basement division, but all the basement divisions are just within the same lithosphere. So, the Cenozoic geotectonic developments of the basement divisions were not similar to the terrane tectonics which shows remarkably distinctive lithospheric evolution history between different terranes. This kind of viewpoint can help understanding the tectonic development of Cenozoic sedimentary basins in this sea area and provides good evidences for their control of mineral resources.

THE TECTONIC DIVISION OF PRE-CENOZOIC BASEMENT

According to a comprehensive analysis based on geology, geophysics, geochemistry, and paleontology data, the pre-Cenozoic basement of SCS can be divided into six divisions (regions), that is, Paleozoic Erathem graben-faulted basement division in Beibu Gulf, Paleozoic Erathem strike-slip and pull-apart basement division in Yinggehai waters, Paleozoic-Mesozoic Erathem faulted-depression basement division in eastern Hainan, Paleozoic Erathem rift basement division in northern Xisha, Paleozoic Erathem strike-slip extending basement division in southern Xisha, and Paleozoic-Mesozoic Erathem extending basement division in Nansha (Fig. 1).

Beibu Gulf Paleozoic Erathem Graben-faulted Basement (I in Fig. 1)

The Beibu Gulf basement is the southwestward extension of the western Yunkai Block onshore. The north boundary of the Yunkai Block is a collision suture belt. We call the belt "North Yunkai Suture Zone" (NYSZ). The NYSZ east-northeastwards extends from Bancheng, Guangxi, to Gaoming, Guangdong, via southern Yulin, Cenxi, Luoding and Yunfu, then, directly into Pearl River Delta. Some tectonic mélanges comprising of pillow lavas, silicalites and metamorphic rocks occur from Cenxi to Yunfu [7, 8]. In Gaoming, there are silicalites which contain Mid-Upper Permian radiolarian fossils (*Follicucullus* cf. *scholasticus* Ormistone et Babcock, and so on) [9].

The NYSZ southwestwsrds extends from Bancheng to Hai Phong, Vietnam, via Fangcheng, Mong Cai, and Ha Long. In Fangcheng, there occur Silurian deepwater-facies turbidites. Upwards, there are Lower-Middle Devonian Xiaodong Group and silicates containing Late Devonian Conodont (*Palmatolepis delicatula*, etc.) and Early Carboniferous radiolarian (*Albaillella paradoxa* Deflandre, and so on) fossils, and the Upper Permian molasse-type formation, successively. In Mong Cai and Ha Long, the Silurian turbidites are appressed folds and covered uncoformableley by horizontal Jurassic red beds. There are Silicalites containing fossils of Early Carboniferous Conodonts and Radiolaria, and Late Permian Radiolaria in Ha Long [10].

The basement of Yunkai Block consists mainly of the late Proterozoic Yunkai Group and the Cambrian Bacun Group, and is composed mostly of medium metamorphic and migmatized formations of extremely thick flysch clastic rocks (containing medium-acid lava) [11].

The Pre-Mesozoic capping formation is a kind of marine facies sediment. The lower part of the capping formation founded in Do Son, south of Hai Phong, is composed of nearshore marine deposits of upper Silurian marl to lower Carboniferous limestone containing fossils of bivalve and *Retziella* brachiopod, similar to that in Cenxi, where the Silurian shallow water-nearshore facies siltstones are covered by the Lower-Middle Devonian sandstones containing fossils of fish [10]. Horizontal Carboniferous-Permian deeper-water platform-type limestones (mixed with strip-type firestones) can be found from Cat Ba Island in the northwestern Beibu Gulf to the Halong Bay of Vietnam (Fc in Fig. 2). In addition, Zhang *et al.* [7] have found some late Paleozoic pillow lava and tectonic melange in Luoding (Fig. 2). In the paleo-buried mountains under the Teriary of Weizhou Island, in the Beibu Gulf, Carboniferous shallow-sea-lagoon facies limestones were found in drill-wells of z244, z245 and D41. All these evidences show that some branches of Paleo-Tethys (called as North Yunkai or Qinfang sea-basin, an inter-arc oceanic basin between Dayao and Yunkai former island arcs started spreading at about Middle or Upper Ordovician Period) have once spread into this area and disappeared here.

This also can be proven by the remnants of mid-basic volcanic eruptives of Upper Ordovician Period in the southeast of Daming Mount and the long and narrow distribution of flysch-like formation and graptolitic shale formation near Liantan of Yu-nan and Yuecheng of Gaoyao.

The collision and suturing process between Dayao-Dayao Pre-Cambrian island arc terrane (Fig. 2). which is at the southeast margin of Yangtze Plate and Yunkai former island arcs, and the closure of the

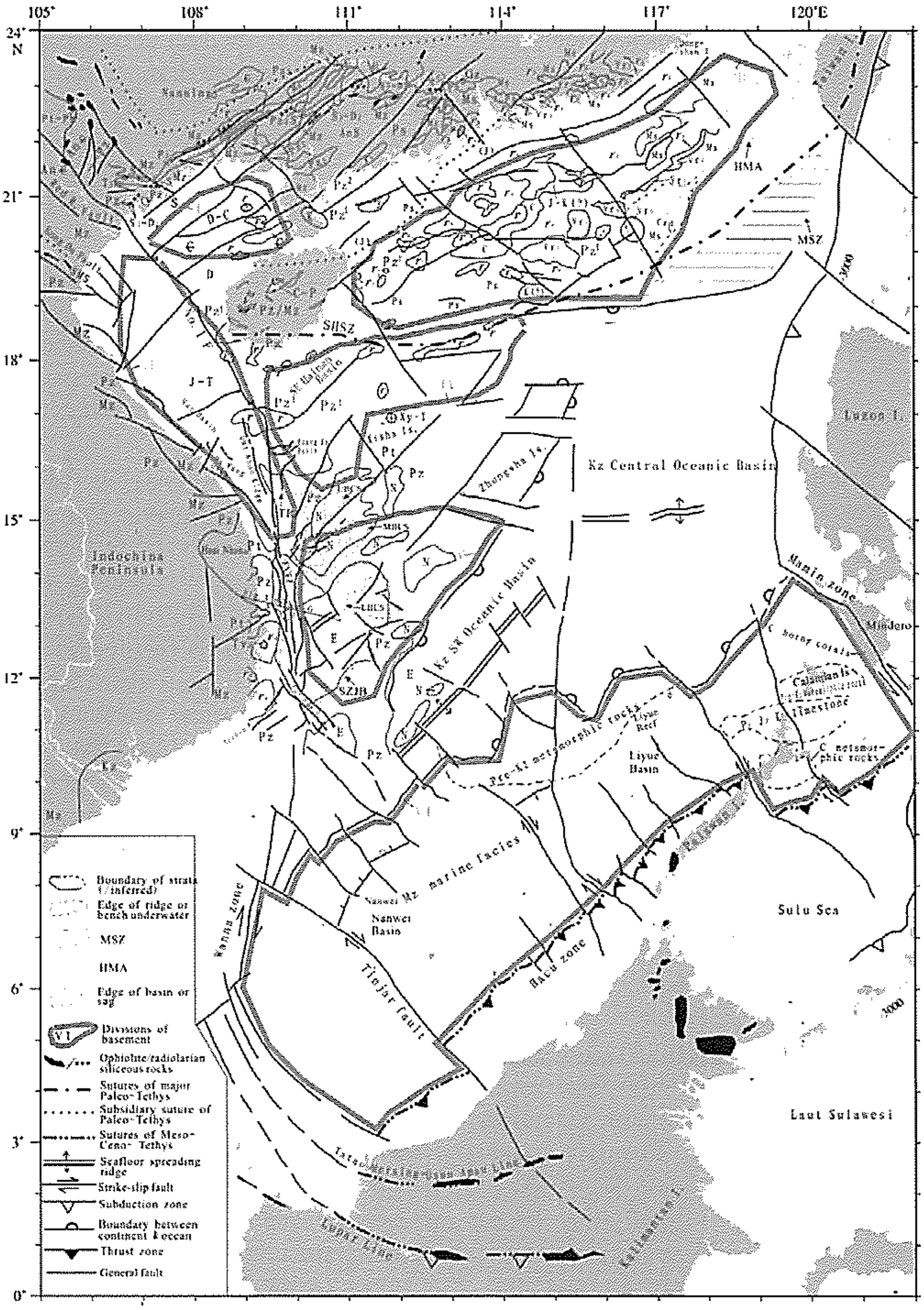

Figure 1. Tectonic divisions of Pre-Cenozoic basement in South China Sea.

No.1 F = No.1. Fault in Yinggehai basin; Bacu, Baxian Shoal-Cuyo Island thrust nappe zone; Br, Black river fault zone; Є, Cambrian; C, Carboniferous; Claire R, Claire River Fault; C-P, Marine-facies Carboniferous-Permian strata; Csd, Chaoshan depression; D, Devonian; E, Eogene; Gz, Guangzhou; HMA, high magnetic anomaly indicating Paleo-Tethyan ophiolite melange accumulative body; J, Jurassic; J_3 Late Jurassic; K, Cretaceous; Kz, Cenozoic; K_1 Early Cretaceous; K_2 Late Cretaceous; LBCS, lower bench of continental slope (>2800 m in water depth); MBCS, middle bench of continental slope (1300-1500 m in water depth); Ms, Mesozoic sedimentary rocks; MSZ, magnetostatic zone indicating remnant Paleo-Tethyan No.2 oceanic layer; Mz, Mesozoic; N, Neogene; P_1 Early Permian; P, Permian; PЄ, Pre-Cambrian; Ps, Paleozoic sedimentary rocks; Pt, Proterozoic; Pz, Paleozoic; Pz^1, Lower Paleozoic; Pz^2, Upper Paleozoic; Red R, Red River fault; S, Silurian; SHSZ, Southern Hainan (Island) suture zone; SZJB, South Zhongjian BasinSong Ma, Song Ma (or Ma river). **Fault:** T, Triassic. TR, Triton Ridge (<500 m in water depth); UBCS, upper bench of continental slope (800-900 m in water depth); Xy-1, Xiyong-1drilling well. Γ, Granite; γ_4, Indosinian Period granite; γ_5 Yansha Period (Jurassic-Cretaceous) granite; Vr_5 Yansha Period volcanic rocks. **Basement divisions:** I, Beibu Gulf Paleozoic Graben-faulted Basement; II, Yinggehai Paleozoic Erathem strike-slip and pull-apart basement; III, East Hainan Paleozoic Erathem faulted-depression basement; IV, North Xisha Paleozoic Erathem rifted basement; V, South Xisha strike-slip extending basement; VI, Nansha Erathem extending basement. Partially from Zhou *et al.* [2], Dien [3], Zhang [4], Huang *et al.* [5] and Chen [6].

inter-arc oceanic basin between them started at a later time of Late Permian Period.

The collision that led to the orogenic belt shows an apparent feature of migration from southeast to northwest. One of most supportive facts is about the sedimentary center which shows that the center moves to northwest with time [12]. In Ordovician-Silurian Period, the sedimentary center was at Bobai Depression (I in Fig. 2), which is at the north most boundary of Yunkai Terrane. During Silurian and earlier ages of late Permian Period, the center moved westwards to Qinzhou Depression (III in Fig. 2), and during Upper Jurassic and Upper Cretaceous, it evolved into a inland sedimentary basin of Shiwan Depression (IV in Fig. 2). The entire evolutional process is similar to that of foreland basin.

The molasse-red bed sediments, which are considered as the symbols of the completion of orogenic process, are also younger in west than those in east. In Bancheng area, northeast of Qinzhou, molasse of Upper Permian Series are on the top of radiolarian siliceous rocks of Upper Devonian Series and Upper Permian Series. In the area from southwest of Fangcheng to the border between China and Vietnam, Jurassic red beds directly cover the strongly folded structures of Silurian flysch Series in the north beach of Beibu Gulf [10].

In addition, the heat produced in the process of collision partially melted or re-melted continental crusts and resulted in granite intrusion along the faulted zone; faulting becomes weaker and weaker from southeast to northwest while the age of granite becomes younger; and from east to west, petrographic facies show a tendency from intrusive rock to super-epicrustal rock, and from sub-volcanic rock to volcanic rock.

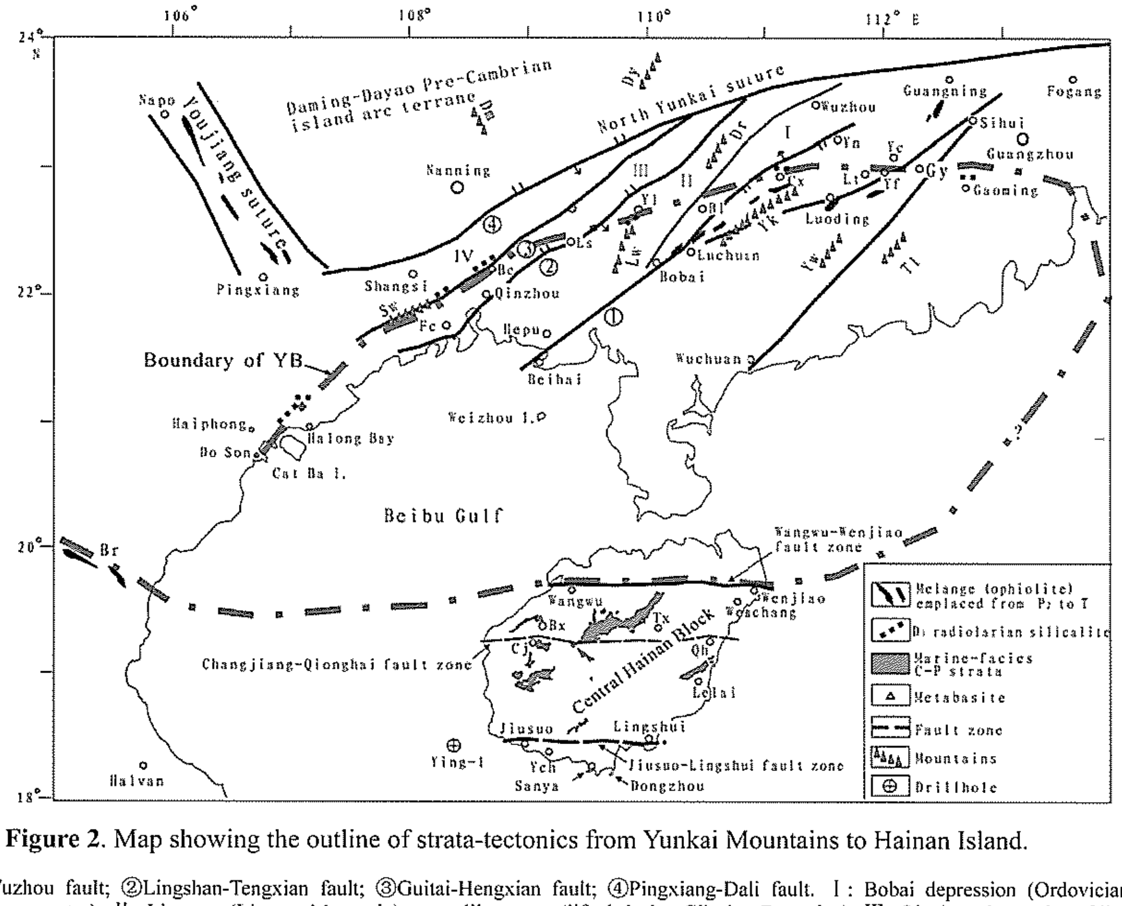

Figure 2. Map showing the outline of strata-tectonics from Yunkai Mountains to Hainan Island.

Bobai-Wuzhou fault; ②Lingshan-Tengxian fault; ③Guitai-Hengxian fault; ④Pingxiang-Dali fault. Ⅰ: Bobai depression (Ordovician-Silurian sedimentary center); Ⅱ: Liuwan (Liuwan Mountain) upwelling zone (lifted during Silurian-Devonian); Ⅲ: Qinzhou depression (Silurian-Mid-Permian deep-sea sedimen-tary center); Ⅳ: Shiwan (Siwan Mountain) depression (Early Jurassic-Early Cretaceous inland sedimentary center); Bc, Bancheng; Bl, Beiliu; Br, Black River ophiolite zone; Bx, Bangxi; C-P, Carboniferous to Permian; Cj, Changjiang; Cx, Cenxi; D_3, Upper Devonian; Dm, Daming Mounts; Dr, Darong Mounts; Dy, Dayao Mounts; Fc, Fangcheng; Gy, Gaoyao; K, Cretaceous; Ls, Lingshan; Lt, Liantan; Lw, Liuwan Mounts; P2, Late Permian; Qh, Qionghai; Sw, Shiwan Mounts; T, Triassic; Tl, Tianlu Mounts; Tx, Yunxi; YB, Yunkai Block; Yc, Yuecheng; Ych, Yacheng; Yf, Yunfu; Yk, Yunkai Mounts; Yl, Yulin; Yn, Yu-nan; Yw, Yunwu Moubts; Ying-1, Ying-1 drilling well. Partially from Wu *et al.* [10], Li *et al.* [13], Zhong *et al.* [14], Wang and Mo [15], Peng *et al.* [16], Shao and Peng [17], Bureau of Geology and mineral Resomrces of Guangxi Province of China [18], and Wu *et al.* [19].

All these characteristics indicate that the collision and orogenic process represent the closure of a paleo-sea-basin named North Yunkai sea-basin (NYS), a branch of the East Paleo-Tethys. Along with the continuous extension of Yunkai terrane to north and northwest direction, the Paleo-Tethys disappeared from east to west, and finally formed the West-Guangdong – East-Guangxi Hercynian-Indosinian collision orogenic belt.

Meanwhile, in the west of NYSZ, North Indochina (North Vietnam) Terrane, a fragment of continental Block near the northern margin of Indochina Plate, moved continuously to northeast, and collided and sutured with the southwest boundary of Daming–Dayao Pre-Cambrian Former Island Arc Terrane. This caused the closure of Youjiang Oceanic Basin, which opened in Devonian Period and closed at late Triassic Epoch, and formed northwest-direction Napo-Pingxiang Tectonic Melange Zone. This zone is also called Youjiang Suture Zone (Figs. 1, 2). Deep-ocean sediments and ophiolites formed between Permian and Triassic Period have been found on this suture zone [20, 21].

Yinggehai Paleozoic Erathem Strike-slip and Pull-apart Basement (II in Fig. 1)

The Pre-Cenozoic basement of Yinggehai is the seaward extension of the Pre-Cenozoic (from Pre-Cambrian to Late Paleozoic, locally to Mesozoic) strata of northeast part of the South Indochina Block and southeast part of the North Indochina Block in this sea area. The Early Paleozoic metamorphic rock was drilled in Ying-1 Well [22] (Fig. 2). There occur the Early Paleozoic Zenghe (i.e. Songtrann) Formation's two-mica schist, cyanite, sillimanite, gneiss, amphibolite and migmatite in Binhson and Chulai along the southwest coast of Yinggehai waters. Also there outcrops the Proterozoic two-mica staurolite schist on the islands and islets east to Donghoi, and metamorphic rocks made up of staurolite, cyanite and sillimanite along the coast from Donghoi to Halvan [23]. It is separated from Beibu Gulf and North Xisha basements by the extension section (No.1 fault and its extension, East-Vietnam-Wanna strike-slip fault) of Red River strike-slip fault in this sea area (Fig. 1).

The transition zone of crust from Yinggehai area to neighboring areas in the east appears at about the southwest side of No.1 fault (Fig. 1) in Yinggehai Basin. Some gravity inversion maps[24] show that this fault may cut through the Moho discontinuity surface. It can be clearly seen even on the regional gravity anomaly map of upward extrapolation to 12km, where it appears as the eastern boundary by a 40 km-wide gravity high band in this area. It may connect with the onshore Lujiang (River Claire) Fault (Fig. 1) when extended to northwest. A Sino-Germany joint wide-angle seismic detection survey conducted in 1996 [25], has achieved the similar deduction that the zone symbolize an ancient suture zone, and forms a 'Y' suture system together with the Napo-Pingxiang Suture Zone in the northwest, and Qinzhou-Guangning Suture Zone in the northeast (Fig. 2). It is considered that the gravity high band is the response of high-density bodies of relict ancient metamorphic rocks between faults. The high-density bodies were formed in Proterozoic Era (Pt) and similar to the lens-shaped, bedded iron-rich Pre-Cambrian metamorphic complex (called as Red River Complex) occurred along the section from Lao Cai, Vietnam to Yen Bai of Red River fault zone. They were originally small continental fragments drifting in Paleo-Tethys Ocean, and left in the converging zone between Indochina Block and South China Block with the disappearance of Tethys Ocean. This is similar to Simao and Baoshan Blocks, which are left in the jointing zone of Yangtze and Shan-Thai Blocks, can be considered as the evidence of East Tethys multi-island-ocean system.

East Hainan Paleozoic-Mesozoic Erathem Faulted-depression Basement (III in Fig. 1)

East Hainan Basement sits under Pearl River Mouth Basin. Drillings in this area have revealed Pre-Cenozoic metamorphic rocks at several sites. Geophysical data show that the Pre-Cenozoic basement of Chaoshan Depression (Fig. 1), which is in the east of Pearl River Mouth Basin, is the remnant of a large Mesozoic depression. Its lower structural layer is composed of Mesozoic sediments of marine facies. The distribution of its seismic interval velocities is: 3.6-4.6 km/s for Lower Cretaceous Series (comparable to the 3.8-4.4 km/s seismic interval velocity of downhole Cretaceous series in CFS-3, CFS-5, CFC-10, and other drilling wells in Southwest Taiwan Basin), 4.5~5.0 km/s for Middle and Lower Jurassic Series, and 4.9~5.2 km/s for Upper Triassic Series [26]. Drilling wells in Beikang, Yunlin and Tongliang of Penghu (Pescadores) Islands in west Taiwan, have revealed some Mesozoic strata which are composed mostly of altered sandstones with fossils of Cretaceous Ammonites and Molluscs and altered arkoses and volcanic rock series. These marine facies strata are considered as the sediments developed in a remnant sea basin of South China continental margin Paleo-Tethys (We call this Paleo-Tethyan basin "South Hainan Basin") in late Triassic to early Cretaceous period.

This basement division connects with Central Hainan Block in the west. The ancient geography of Carboniferous sediments in Central Hainan Block is different from that in Guangdong continent. The former consists of deep-water sediments of continental shelf facies and are mostly argillaceous rocks, while the latter is mostly carbonate of shallow-water platform. The fact that there is no transitional sediment between these two areas indicates that they belong to different crustal blocks separated by North Hainan Sea-basin [27]. In pre-Cenozoic, there developed four sedimentary cycles in the Central Hainan Block [28, 29]. The four sedimentary cycles are Pre-Sinian Period (Pre-700 Ma) cycle, Proto-Tethyan (Early Paleozoic) marine cycle, Paleo-Tethyan marine cycle and Meso-Tethyan cycle. In the Pre-Sinian cycle, there developed the oldest strata, namely, the Middle Proterozoic Baoban Group with a thickness of 1070-2928 m and conformable-overlapped micaceous quartzite schist of Ewenling Formation, in which protolith was sandy-and-pelitic rocks. The Upper Proterozoic strata comprise dolomitite and crystalline limestone of Shilu Group with Chuaria-Tawuia Biota fossils. That unconformable- overlapped on the Pre-Sinian formations is a suit of strata, reflecting the marine sediments of the Proto-Tethys. The lower part of the Proto-Tethyan sedimentary cycle is the Sinian Shihuiding Formation mostly with metamorphic quartzose sandstone and quartzite, interbedded mudstone, siliceous rock and hematitic meta-siltstone, producing Shouhsienia shouhsienensis fossils. This stratum seems to indicate the commencing of the Proto-Tethys, then, and development after the Cambrian to Late Silurian marine (including abyssal) facies sedimentary strata with huge thickness piled up to 6734-11742 m. The Caledonian orogeny closed the marine sedimentary cycle of the Proto-Tethys. The Paleo-Tethyan sedimentary cycle commenced until Carboniferous Period. The Carboniferous (perhaps containing Devonian) to Late Permian marine sedimentary strata overlay on the underlying strata in angular unconformity. The Indosinian movement closed the Paleo-Tethys. Thereby, since the Mesozoic Era, the Central Hainan Block shifted into a terrestrial deposit environment characterized by intracontinental basin sediments since the Late Triassic, interbedded collision-type intermediate-acidic volcanic rock formations.

As to the magmatic rock, the lenticular fragments of metabasites (see Fig. 2) found in Paleozoic group in Bangxi, Changjiang, and Chenxi, Tunchang, Hainan Island, are composed of typical N-MORB geochemical components that are similar to those of basalts in depleted mid-ocean ridges. This fact shows that these fragments came from highly depleted mantle sources. Also, the abundance of LREE elements is extremely low and depleted, $La_N = 1.1 \sim 2.3$, $(La/Yb)_N = 0.13 \sim 0.26$ [13], like that of basic rocks of ophiolites in Shuanggou, western Yunnan Province [30] and ophiolites in Babu, southeastern Yunnan Province [30]. These facts indicate that these lenticular fragments of metabasites may be the remnants of Paleo-Tethys [13]. Most of granitoid rocks in the Central Hainan Block felled into two periods [28, 29]. One is from 280 to 220 Ma in the Hercynian (Early Devonian to the end of Permian) to Indosinian (225-190 Ma) Cycles. The other one is from 120 to 80 Ma in Late Yanshan (190-70 Ma) Cycle. The Late Triassic A-type granites are characterized by enrichment of Alkali-Al-Ca, paucity of Fe-Mg, and higher-abundance of metal elements with higher valence bond, similar to that of the A-type granites in the eastern Fujian Province, Southeast China. These A-type granites resulted from the differentiation of basalt magma in plutonism-derived rifts of orogenic belts [31], and represent a low-pressure, high-temperature, relatively water-poor geological environment in which the lithosphere was extended and the mantle was upwelled-underplated due to decompression and unloading and the crust was thinned due to rifting [32], also indicate a transition period from the end of compression of orogenic movement into the commence of extension and collapse of orogenic belt [33].

The northern boundary of the Central Hainan Block may have extended to the present-day sea area along the Wangwu-Wenjiao tectonic belt of Hainan Island (North Hainan Suture Zone, see Fig. 2). In this tectonic belt the intrusion of mantle-sourced magma has occurred in Pre-Hercynian epoch. The belt remained to be active to Indosinian epoch and recent ages, and controlled the formation of Mesozoic basins, intrusion of magma, the effusion of Cenozoic

deep basalt magma, and the occurrences of hot springs. The North Hainan Sea Basin, which might link with the Song Da Sea--an important branch of Paleo-Tethys to west, disappeared due to the collision of Yunkai Block with Central Hainan Block along this tectonic belt.

North Xisha Paleozoic Erathem Rifted Basement (IV in Fig. 1)

North Xisha Basement is underlie (cradle land) of Southeast Hainan Basin and North Xisha Trough. Based on outcrops of the Cambrian stratum in Sanya, south Hainan Island, and core samples of Paleozoic strata [34] in Xiyong -1 drilling well, Xisha (Paracel) Islands, it can be deducted that the strata of the basement were mostly formed in Paleozoic, even earlier to Pre-Cambrian periods. In the Sanya area, there are three main Pre-Cenozoic (Cambrian to Early Cretaceous) sedimentary cycles [28, 29, 35]. The sediments in the first cycle (from the Early Cambrian to the Mid-Cambrian) are characterized by the mixture of marine-facies terrigenous clastic rocks with carbonate rocks. The basinal region and their provenance were characterized by frequently elevation and subsidence. The second cycle (from the Early Ordovician to Late Ordovician periods) is characterized by deposit of only marine-facies terrigenous clastic rocks. The last cycle (since the Early Cretaceous) features deposits of mud-rock flow and tuff rocks of inland lakes. The marine facies of the first and the second cycles are considered as components of Proto-Tethyan. By comparison with the Central Hainan Block, a definite relation can be found between the lithofacies-and-paleogeography of Sanya and Central Hainan Blocks. In the Early Paleozoic, both areas were deposited with marine facies, therefore belonging to the Proto-Tethyan realm. In contrast, nobbut, the Central Hainan Block located in an abyssal area far deeper than in Sanya. The distinct differences between them come forth until the Late Paleozoic Period. The Sanya area become a long-term uplifted denudation area, while the Central Hainan area entered the evolution regime of Paleo-Tethyan realm (the South Hainan Sea Basin) and continued to receive the marine-facies sediments. The South Hainan Sea Basin closed in early Mesozoic Period due to the Indosinian movement. Since the Late Mesozoic Period, Sanya and Central Hainan reunited together and entered into the continental facies sedimentary environment.

The characteristics of magmatic rocks in Sanya area indicate that strong subduction-collision-orogenic events once happened along northern boundary fault zone (Jiusuo-Lingshui Fault Zone, see Fig. 2) of Sanya block during Indosinian Period. The magmatic activities in Sanya commenced at the end (about 220 Ma) of Indosinian Cycle and stopped at the start (about 120 Ma) of the Yanshan Cycle, lasting about 100 Ma [29, 36]. It is very different from that in the Central Hainan Block where the activity times of the granitoid rocks fell in the two ranges of 280-220 Ma of the Hercynian-Indosinian cycles and 120-80 Ma of Yanshan cycle. As to the genetic types, there are three 'granite pairs' (i.e., three pairs of 'I-type and S-type granite) in Sanya [37]. The first 'granite pair' is the pre-collision (corresponding to the B-kind of Batchelor, i.e. destructive mobile plate margin) mid-Triassic Liudao (north of Sanya) I-type biotite adamellite (with 231 Ma of Rb-Sr age) and Early Jurassic Dongzhou S-type biotite syenogranite (with 205 Ma of Rb-Sr age). The second 'granite pair' is Early Jurassic I-type anatectic magmatites (such as Sanya-Yacheng amphibole biotite adamellite, 195-187 Ma) and Mid-Jurassic (middle orogenic period) Xiaodongtian (south of Yacheng) S-type biotite syenogranite (175 Ma) in the post-collision uplift period (corresponding to the C-kind of Batchelor, i.e. early synorogenic F-type). And the third 'granite pair' is Late Jurassic Nanshanling (southeast of Yacheng) amphibole biotite adamellite (with 152 Ma of Rb-Sr age) in the late orogentic period (corresponding to the D-type of Batchelor, i.e. late synorogenic F-type) and Early Cretaceous Shigui-Tielu (east of Sanya) S-type calc-alkali biotite adamellite (with K-Ar age of 97 Ma) in the end of synorogenic period. The C-type and D-type can be combined as the main type F of synorogenic period. The above-mentioned characteristics of magmatic activities imply a subduction-collision-orogeny process of the South Hainan Paleo-Tethyan Sea-basin.

Together, we call Sanya, Xisha, Zhongsha (Macclesfield bank), Nansha (Spratly) Islands (Fig. 1) and other blocks as South Hainan Block (SHB). Both South Hainan and Central Hainan blocks originated from Gondwanaland as drifting blocks in East Paleo-Tethys multi-Island-Ocean System. In Indonesian Orogeny, they sutured with each other along Jiusuo-Lingshui Fault in Hainan Island and a northward- dipping crustal fault [38] in North Xisha Trough. The crustal fault might extend eastward, passing through Dongsha islands, south Yitong (Helen) Shoal, the boundary of basin and slope at 2000~3000 m depth of the Central Ocean Basin of the SCS and to the Beigang-Penghu Uplift in west Taiwan Island. Geological and geophysical evidences are as following.

The Dongsha-Beigang Uplift Zone is a belt with high magnetic anomaly (HMA in Fig. 1), whose characteristics are different from those of the Cenozoic basic-ultrabasic eruptive rocks. It is deducted that the rock body of the uplift zone might be a sheet body formed by ocean crustal substances on obduction plate with no root, buried in depth of 4~6 km, that is, a melange accumulative body of ophiolites. According to seismic data, the upper covering stratum in the high magnetic anomaly belt is a layer of sediments of marine facies, under which there are two sets of slightly deformed but not yet metamorphosed strata, possibly strata of T_3-J_1 and J_3-K [39] layer. We deduced that the Mesozoic sediments belong to Indosinian suture zone, and the distinctive thickening of the crust in this high magnetic anomaly belt might be caused by convergence and subduction of plates.

In the south of the high magnetic anomaly belt and between the continental slope fault and southern marginal fault in north of SCS, there exists a magnetic quiet zone (MSZ in Fig. 1) with gentle magnetic anomalies variation within the range of ±20 nT [40]. According to the results of joint inversion of seismic and magnetic anomaly, the crust of the magnetic quiet zone can be divided into 2 magnetic layers. The lower layer, corresponding to the lower crust, is composed of uniformly magnetized substances with 6~8 km thickness. The 1~2 km thick upper layer is composed of reversely magnetized substances with medium susceptibility. The later might be related to the long-termed reverse of magnetic fields in Mesozoic era, and the thickness and magnetic strength are very similar to those of the Layer 2 of oceanic crust. A comprehensive interpretation points to the existence of Layer 2 of a remnant Mesozoic oceanic crust.

All these can lead to one assumption that at a time between late Paleozoic and late Triassic, there was an east-west trending oceanic basin, we called it "South Hainan (or Qiongnan) Sea-basin (SHS)", have been existing between the south of the recent north continental shelf of SCS and the north of Sanya-Xisha- Zhongsha- and Nansha- blocks [41]. The SHS likely was a part of the Early-Middle Triassic main Paleo-Tethys Ocean Basin, which once connected with the main Paleo-Tethys Ocean Basin segment on the west of the Indochina Block corresponding with the Nan- Uttaradit- Bentong- Raub Suture, and through the Tianxiang ocean in Taiwan, which was in the east of the basin, even across the shelf of East China Sea into the South Hida Main Paleo-Tethys Ocean Basin reflected by the Hida marginal Pre-Jurassic ophiolite belt (⑤ in Fig. 5) between Hida Pre-Jurassic and Tamba-Mino-Ashio Jurassic--Early Cretaceous terrane groups in the Southwest Japan. In the Late Triassic, the SHS closed, and the SHB collided with Central Hainan Block here to form the South Hainan Suture Zone (SHSZ in Fig. 1) offset with the Nan-Uttaradit-Bentong-Raub Suture Zone (⑩ in Fig. 5) by Red River-East Vietnam-Wanna Strike-slip Fault Zone (RW in Fig. 5) and the escaping of Indochina Block.

South Xisha Paleozoic Erathem strike-slip extending Basement (V in Fig.1)

South Xisha Basement Division is the northwest continental margin of the Southwest Ocean Sub-basin of the SCS. According to the Paleozoic granite gneiss revealed in the Xiyong-1 Drilling Well, which penetrates through Tertiary system directly covering above the Paleozoic granite gneiss, it is deduced that the basement in this area is the extension of the basement of Xisha Islands that was complicated by Mesozoic magmatism.

The South Xisha Basement differs from the Indochina Block, which locates on the west of the East Vietnam Fault Zone (EVFZ in Figs. 1, 3). In the east of the fault zone, the magnetic anomalies are mainly of negative values complicated by regional anomalies and local isolated anomalies, with low gravity not matching with local sedimentary depressions, thus can be considered as the reflection of intrusive granites in metamorphic rock of the basement. Bouguer gravity anomaly is roughly in NE direction, and increases southeastward. In the west of the EVFZ, the magnetic anomalies are in higher value with low amplitude, the free air gravity anomalies are extremely low and gentle. Bouguer gravity anomaly displays a sharp, narrow linear high along the EVFZ in roughly NS direction.

The basement can be divided into 4 tectonically sub-areas - Triton Ridge (TR in Fig. 1), upper bench of continental slope (UBCS in Fig. 1), middle bench of continental slope (MBCS in Fig. 1), and lower bench of continental slope (LBCS in Fig. 1), from north to south. The South Zhongjian Basin (also called Nha Trang Basin, SZJB in Figs. 1 and 3) just develops on the LBCS. The extension factor (β) increases from Triton Ridge to South Zhongjian Basin, and maximized at the Southwest Ocean Basin. According to the estimation of Marquis *et al.* [42] and Roques *et al.* [43], the total extension amount of Mid-Vietnam continental margin exceeds 165 km; the extension started from 28 Ma (i.e. magnetic isochron 8) or earlier than 29 Ma, strengthened since 26 Ma (magnetic isochron 7) and ended at 20.5 Ma (magnetic isochron 6). These show that the opening of SCS was in the period between 29~26 Ma, after the dextral movement of the EVFZ. Some volcanic seamounts can be seen in South Zhongjian Basin, corresponding to short wavelength gravity and magnetic anomalies. The basement of the South Xisha Division includes two sub-units of the East Kontum and South Xisha blocks in the waters (Fig. 3). The East Kontum Block is the eastward extending part of the Kontum Block onshore Vietnam (Fig. 3), which is a Pre-Cambrian continent mostly covered by Meso-Cenozoic strata [44]. The Archaeozoic and Proterozoic crystalline metamorphic complex of the Kontum Block outcrops occur in many places. The EVFZ divided these two sub-areas. On the south side of this basement section, the northwestward extension of Buonho-Tuyhoa Fault Zone (Fig. 1) is the southern boundary. The East Kontum Block is very old, ranging from the Proterozoic to the Mesozoic [44]. The Pre-Cenozoic basement on the continental shelf deeply downwarped and formed a continental shelf depression filled with the Cenozoic upwarping crescent strata which are incumbent each other. The basement on the continental slope sharply uplifted above neighboring continental shelf and grabens, and formed a flexural slope zone lacking of Cenozoic sediments.

Eastward across the EVFZ, the South Xisha Block can be further divided into several small units, such as, the Southwest Xisha Graben on the outer slope (i.e. the 109° E Longitudinal Graben, D in Fig. 3), the Nay Block (F in Fig. 3) and the South Zhongjian Basin (that is the Southeast Xisha Basin, G in Fig. 3), and so on. There are very thick Cenozoic sediments in the Southwest Xisha Graben. The basements of the Southwest Xisha Graben may be inferred to include Archaeozoic strata because that in the Hoai Nhon offshore waters along the middle segment of the East Vietnam, there are banded Archaeozoic strata consisting of sillimanite crystalline schist, migmatite and gneiss. Short distant northwards from Hoai Nhon offshore, in the waters nearby Binhson and Chulai, there emerge the Early Proterozoic two-mica schist, cyanite, sillimanite, gneiss, amphibolite and migmatite of the Songtrann Formation [23]. The EVFZ becomes a graben with 'reversed-in-lower and normal-in-upper" I-type faults and magmatism. In the stratum of the Nay Block and the South Zhongjian Basin, there are unconformity resulted from the two factors of the distribution of strata and younger or synchronous tectono-magmatism. There developed two structural layers of the lower and upper parts. The lower structural layer covers on an appreciably differentiated basement, which may be an antiquated peneplain and consists of the Paleozoic and Mesozoic deposits. Lower structural layer, had been differentiated into uplifts and depressions [45]. Faults, younger and recent synchronous extrusive and intrusive rocks, and Late Cenozoic volcanic rocks incised the basement and the two structural levels.

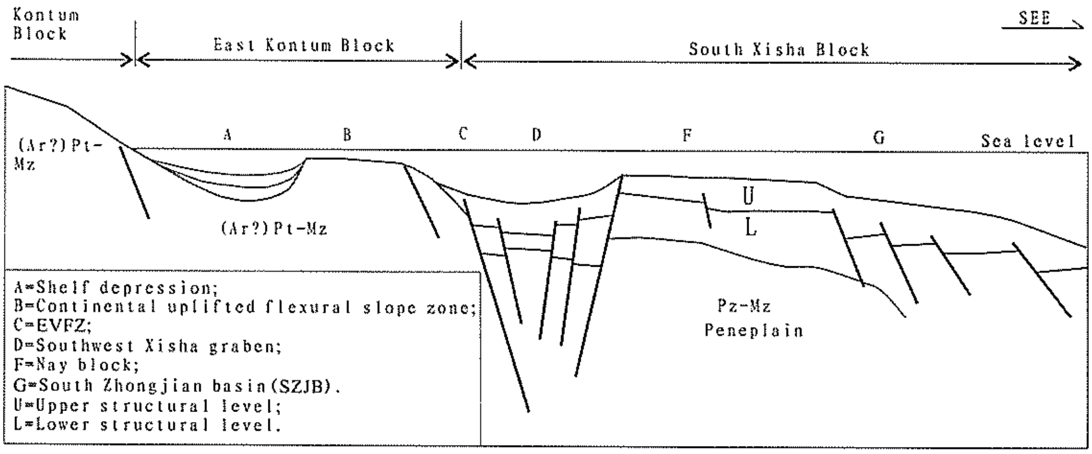

Figure 3. Profile map across west boundary of South Xisha basement. EVFZ, East Vietnam Fault Zone.

Nansha Paleozoic-Mesozoic Erathem extending Basement (VI in Figs.1, 4)

In Triassic, there were abyssal facies deposits, such as radiolarian firestones, middle Triassic conodonts, and late Triassic foram fossils etc., distributing from the northern Palawan Island to Calamian Islands. Abyssal facies deposits, with siliceous shales, middle to late Triassic bivalve fossil molds were dredged from the areas over Ren'ai and Meiji Reefs were also found with [46].

In Jurassic, neritic and delta facies sediments have deposited over Xian'e, Ren'ai and Meiji Reefs, and Calamian Islands; some brown and thin layers of siltstone contained bivalve and plant (fern) fossils. On Coron Island and several other Calamian Islands, limestones containing foraminiferal fossils of Lias (J_1) are observed. On Busuanga Island and in Cadlao-1 well on north Palawan shelf, Oxfordian (J_3) classopollis and other sporo-pollens are found. On Linapacan, Yili, and Imorique Islands of northern Palawan, and in Guntao-1 well on north Palawan shelf, fossils of Oxfordian algae, forams, and radiolarians are identified [47]. However, the seismic facies of Mesozoic strata in Nanwei Basin are of rather high frequency in dipping occurrences, different from those in Liyue Basin, which are of low frequency (Fig. 4). From this feature, we can deduce that between late Triassic and Early Jurassic, areas

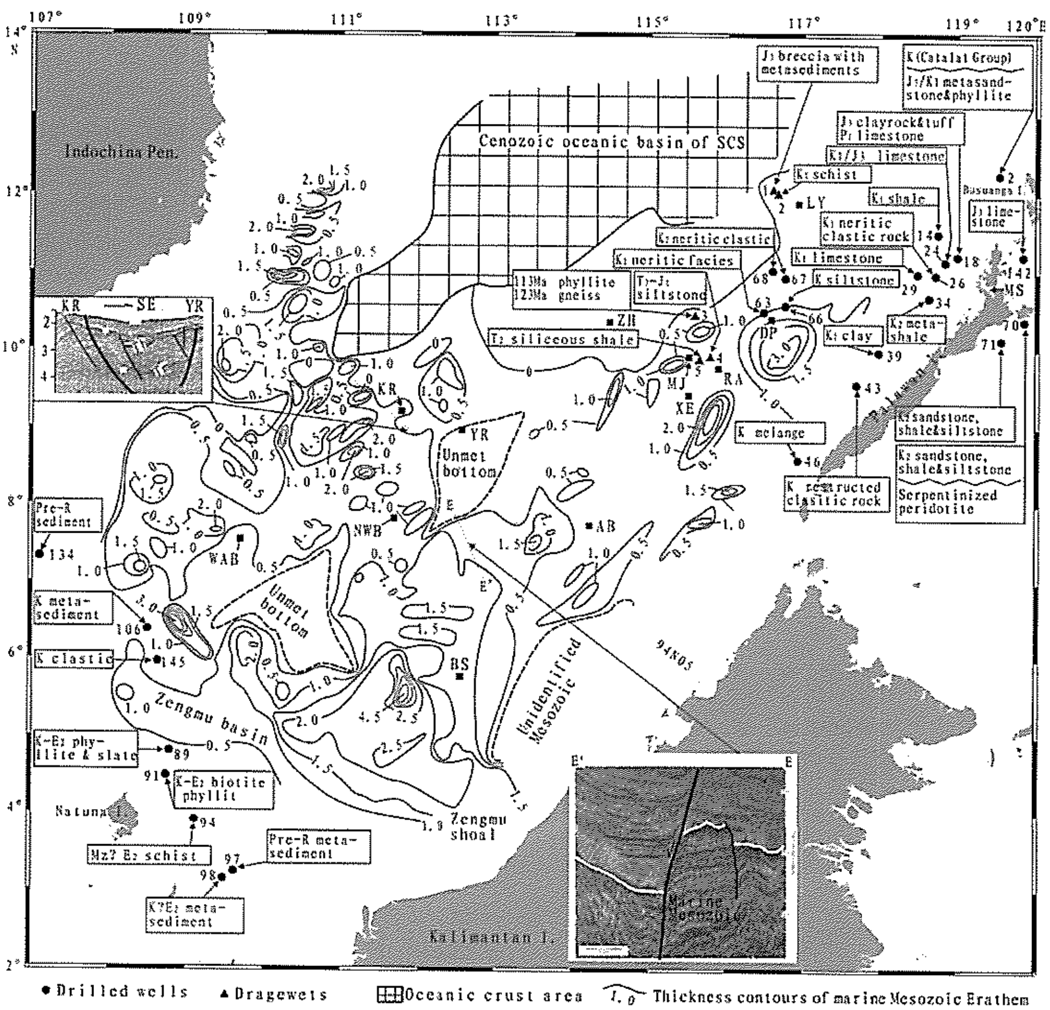

Figure 4. Isopach map of Mesozoic Erathem in Nansha waters of China.

AB, Andu Bank; BS, Beikang Shoal; DP, Dongpo (Pennsylvania) Reef; KR, Kangtai Reef; LY, Liyue Bank; MJ, Meiji Reef; MS, Malampaya Strait; Nanwei Bank; RA, Ren-Ai Reef; WAB, Wan'an Bank; XE, Xian'E Reef; YR, Yinqing Reefs; ZH, Zhenghe Reefs. **Names of drilled wells**: 2, Malajon-1; 4, San Martin A-1x; 5, Galoc-1; 14, Destacado A-1x; 18, Cadlao-1; 24, Guntao-1; 25, N. Nido-1; 26, Nido-1; 29, Nido 2x-1; 34, Catalat-1; 39, Penascosa-1; 43, Albion Head-1; 46, Kamonga-1; 63, Sampaguita-1; 66, Kalamansi-1; 67, Reed Bank-B1; 68, Reed Bank-A1; 70, Dumaran-1; 71, Roxas-1; 87, AP-1X; 89, Paus NE-2; 91, Paus S-1; 94, Panda-1; 95, J-5-1; 96, CC-1x; 97, CC-2x; 98, CB-1x; 106, CIPTA-A; 134, 29-A-1x; 142, GNT1; 143, CFC-1; 144, PK-2; 145, CTA1. **Dragnets**: 1, S023-36; 2, SO23-37; 3, SO27-21; 4, SO23-23; 5, SO27-24. K, K_1, K_2, J_3 and P_1 are the same as Fig. 1.

over Liyue Basin were in a sedimentary environment featuring of mudstone and shale.

In Cretaceous period, the area from Liyue to north Palawan was in the epicontinental to inner-epicontinental sedimentary environment. The Reed Bank-A1 and -B1 wells in Reed Bank, Sampaguita-1 well in Liyue Basin, and Catalat-1 and Nido-1 wells in Palawan Basin have all revealed Pre-Cretaceous clasolites of coastal or neritic facies (Fig. 4). Southwestwards, paleo-water became deeper and deeper [48]. Some black-grayish shale strata of Pre-Cretaceous abyssal facies have been revealed in Penascosa-1 well in the West Palawan Basin. Over Nanwei, Zhenghe, and Liyue basins, the Cenozoic sedimentary layers are all very thin, with mainly of late Oligocene to Recent layered neritic carbonates and organic reefs. This absence of Paleogene deposits indicates that the Mesozoic sedimentary layers once have been uplifted for a long

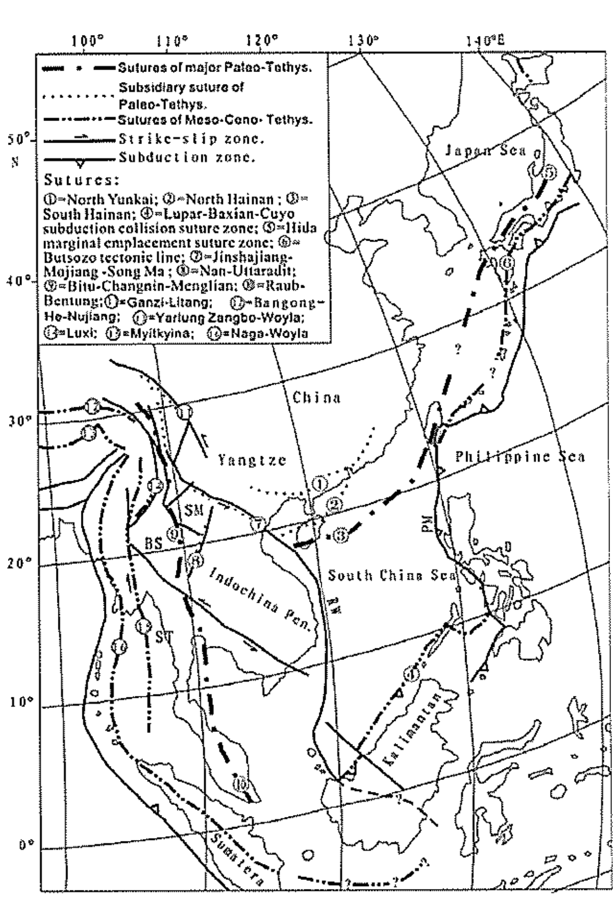

Figure 5. Possible remnants of Tethys in South China Sea and its adjacent areas.

BS, Baosha block; PM, Philippine-Manila trench strike-slip system; RW, Red River-EVFZ-Wanna strike-slip zone; SM, Simao block; ST, Shan-Thai block. Partially from Zhong *et al*. [52], Ichikawa [53] and Metcalfe [54].

period and were denuded after Cretaceous period. This is similar to that in Xisha, where Neogene and Quaternary coral limestones cover directly on Pre-Paleozoic basement rocks. It is very possible that Xisha, Zhongsha, Dongsha, and the west part of Nanwei, Zhenghe, Liyue, and western Mindoro have once been within the same uplift with Pre-Mesozoic crystal basement. The Mesozoic marine facies strata developed on the basement suggest that Liyue, north Palawan, West Palawan basins, and Andu, Nanwei, Nansha Trough, and Zengmu basins in southwest, were all in marine facies environment. In addition, the paleo-seawater became deeper and deeper from northeast to southwest. All these features indicate that the areas above-mentioned were once within the same sea basin, the Paleo-SCS, which was one part of Meso-Tethys (Figs. 5, 6).

Nansha Meso-Tethys was developed on the basement of Paleo-Tethys. The latter have produced marine basins along the southeast margin of Asia continent in Carboniferous or earlier times. One fact is that the sedimentary basement found in middle Palawan is composed of meta-arkose, and is covered by Carbonic schist and phyllite in a non-integrated manner (unconformity) [49]. Also, some Carboniferous horny corals (*Gshelia* sp.) were found in Pliocene Punso gravelstones in southwest Mindoro (Fig. 1). One thing worthy of further notice is that the oldest autochthony fossils in this area have been found in metamorphic rocks in the mid-lower part of Malampaya Strait Group in the northern Palawan. The oldest autochthony fossils include the early- to mid-Permian conodonts found in firestone of Bacuit Formation and the mid- to late-Permian Fusulina category founded in limestones of Minilog Formation [50]. All of these rocks and fossils above-mantioned indicate the existence of Paleo-Tethyan marine depositional environment. As the disordered formation of the top layer of Bacuit Formation shows slumping and broken configuration, and there existed trilobites in firestones in lower layer of Bacuit Formation, it can be deducted that before the deposition of limestones in mid-Permian, there was a time when the hinterland was uplifted. The top surface of the uplift basement was composed of phyllites and schists with rich content of chloritoid. Furthermore, if we take the highly metamorphosed Pre-Cambrian granite gneiss found in Xisha into consideration, we can achieve a further deduction, i.e., the Pre-Mesozoic crystallized basement in

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Mindoro – Calamian – north Palawan – Liyue – Zhenghe – Nanwei area should be similar to that in Xisha – Zhongsha – Dongsha area, all of which can be considered as within the framework of South China Sea Platform, i.e. the SHB. The southeast part of the SHB, that is the area from Liyue Bank to northern Palawan, commenced Paleo-Tethyan marine sediment in the Permian Period. Although the Indosinian orogeny movement developed in the Late Triassic had not led to the marine facies sedimentary environment to end, the older basemental strata had been folded [51] and the sedimentary environment of

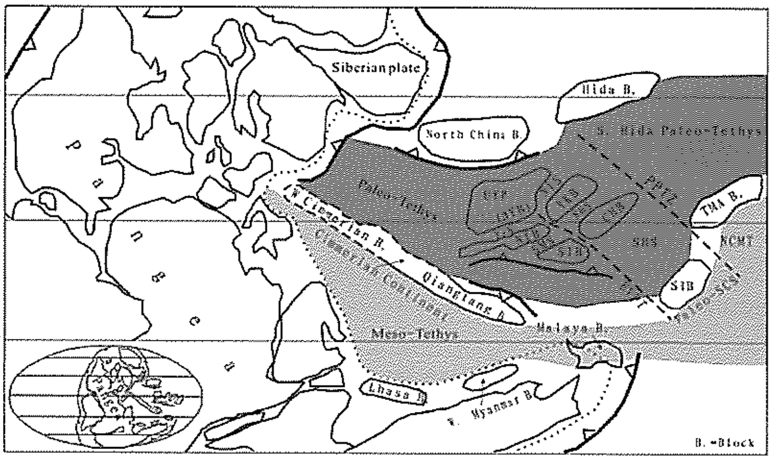

Figure 6. Relationship between Pre-Cenozoic basements in South China Sea and Tethys.

CHB, Central Hainan block; DYB, Dayao block; EVPT, East Vietnam paleo-transform fault; NCMT, North Chichibu Meso-Tethys; NHS, North Hainan sea-basin; NIB, North Indochina block; NYS, North Yunkai sea-basin; PPTZ, Philippine paleo-transform zone; PSCS, Paleo-South China Sea; SHB, South Hainan block; SHS, South Hainan sea-basin; SMS, Song Ma sea-basin; SIB, South Indochina block; TMA, Tamba-Mino-Ashio terrane group; UYP, Upper Yangtze plate; YJS, Youjiang sea-basin; YKB, Yunkai block. Drawn up partly based on Metcalfe [54, 55] and Pan [56].

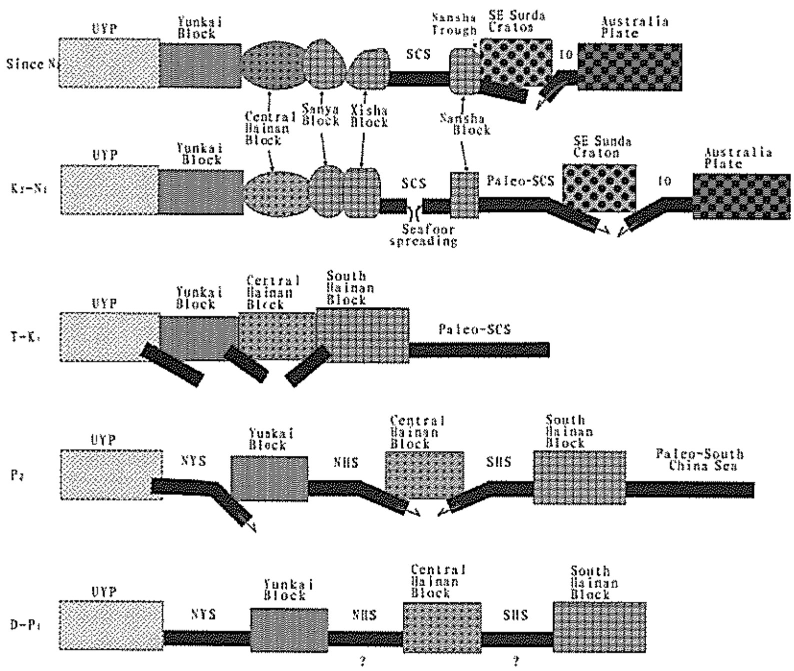

Figure 7. Tectonic evolution of pre-Cenozoic basement in South China Sea.

See the text for description. IO, Indian Ocean; NHS, NYS, SHS and UYP mean the same as in Fig. 6.

this area had been changed into the neritic facies of Jurassic to Early Cretaceous Meso-Tethyan period from the deep-sea facies of the Late Triassic Epoch, and became deep-sea facies southwestward to around Nanwei, due to the Indosinian Orogeny.

EVOLUTION OF THE BASEMENT STRUCTURE

We have rebuilt the history of geotectonic evolution of East Tethys over South China Sea. In Pre-Cenozoic period, the Pre-Cenozoic basement of SCS, together with the offshore Yunkai area, and the Paleo-SCS, which was in the south of the basement, were all within the same Tethys tectonic domain, and have experienced a evolution through Paleo-Tethys to Meso-Tethys (Fig. 6).

The entire history of geotectonic evolution can be divided into five stages as follow (Fig. 7).

A. Devonian – Early Permian Period: Development Stage of East Island-Ocean System of Paleo-Tethys

In this period, a component of multi-Island-Ocean System of East Paleo-Tethys might have been formed in areas from Beibu Gulf to Nansha, and there was the NYS between Beibu Gulf – Yunkai and Yangtze Blocks. Yunkai, Central Hainan, and South Hainan blocks were separated by North Hainan sea-basin (NHS in Figs. 6, 7) and the SHS. And the SHB might still be linked with Gondwanaland.

B. Late Permian: The emergence of Meso-Tethys (Paleo-SCS) and the extinction of Paleo-Tethys

The SHB began to drift away from Gondwanaland, and the Paleo-SCS emerged. The NYS floor subducted under the Upper Yangtze Block, while the North Hainan and South Hainan Sea floors started subducting under the Central Hainan Block. The Central Hainan Block was greatly modified by strong tectonism and magmatism, and showed sharply varying magnetic anomaly and other characteristics of geophysical field [57].

C. Triassic - Early Cretaceous: Suturing of Multiple Blocks in East of Paleo-Tethys

In early stage of this period (at about late Triassic), the Upper Yangtze, Yunkai, Central Hainan, and South Hainan Blocks started suturing with each other, and have formed the Indochina-South China continent together with Indochina Block. After suturing, these blocks co-experienced the modification of Yanshan Movement that came later, and formed the famous Mesozoic underthrust magmatic belt.

D. Late Cretaceous – Early Miocene: The Formation of Early Miocene Modern SCS and the Extinction of Meso-Tethys (Paleo-SCS)

From late Cretaceous, an extensive and large-scale movement, called the Cenozoic East Asia epicontinental splitting tectonic movement, started its activity. The SCS area was controlled by the joint roles of plate subduction of Pacific tectonic domain and de-rooting-and-delamination of the former Tethyan tectonic domain. As a result, Nansha, Xisha-Zhongsha, and Hainan Island blocks of the SHB started splitting away from Indochina-South China continent, and successively formed some fault basins [58, 59], such as Beibu Gulf Fault Basin, Pearl River Mouth Basin, Southeast Hainan Rifting Basin, and South Zhongjian Extension Basin etc., with various extension on their north margins. They also caused the large-scale strike-slip movement along dextral Red River–East Vietnam–Wanna Strike-slip Fault Zone (RW for short in Fig. 5) [60] and the Sinistral Philippine-Manila Trench Strike-slip Fault System (PM in Fig. 5); and the formation of a chain of strike-slip pull-apart basins, such as Yinggehai, Hue, Qui Nhon, North Wan'an basins, along the RW. In late Oligocene, the splitting reached its peak, and the SCS started seafloor spreading. The Paleo-South China Sea subducted southward and consumed under the north boundary of Kalimantan until the early Miocene.

E. Middle-Miocene to Present: SCS Stopped Spreading and Australian Plate subducted and Extruded Northwards

In mid-Miocene, the seafloor spreading of SCS stopped, and most of the Paleo-SCS was disappeared along a tectonic line from Lupar (line) to Cuyo (island) through Baxian (shoal)-Nansha Trough-Northwest Palawan Trough (Bacu Zone for short, ④ in Fig.5). The Australian Plate began to subduct and extrude northward and became the leading force in the south of this area.

CONCLUSION

Paleozoic Erathem dominates the Pre-Cenozoic basement of SCS. It was formed in the background of Paleo-Tethys tectonic domain, and was an important component of East Tethys multi-Island-Ocean System. The three branches of the eastern parts of Paleo-Tethys tectonic domain in this area, which are North Yunkai Sea-basin, North Hainan Sea-basin, and South Hainan Sea-basin, were the origins of the present North Yunkai, North Hainan, and South Hainan suture zones or fault zones. This shows a distinctive feature of regionalization for the Pre-Cenozoic basement of this area. Since late Paleozoic Period, and accompanying the formation and extinction of Paleo and Meso-Tethys, the Pre-Cenozoic basement of this area had experienced 5 stages of evolution: (1) D-P_1, the development of East Multi-Island-Ocean System of Paleo-Tethys; (2) P_2, emergence of Meso-Tethys (Paleo-SCS) and extinction of Paleo-Tethys; (3) T-K_1, the suturing of multiple blocks in eastern Paleo-Tethys; (4) K_2-N_1^1, the formation of modern SCS and the extinction of Meso-Tethys (Paleo-SCS); and (5) N_1^2, the SCS stopped spreading and the Australian Plate underthrusted and extruded northward. Especially in the late stage, influenced by the tensional break-up, splitting, strike-slip, and pull-apart of South China continental margin starting from Cenozoic, the Pre-Cenozoic basement directly controlled the formation of a series of offshore Cenozoic sedimentary basins.

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REFERENCES

1. Guo L.Z., Shu L.S., Lu H.F. *et al.* (2001) A synthetical review on research advances on the terrane tectonics in China. In Guo L.-Z. *et al.* (Eds) *The Tectonics of South China* pp. 230-252. Geological Publishing House, Beijing.
2. Zhou X., Wei C. and Xia K. (1991) Stratigraphic division and correlation in Liyue (Reed) Bank and its neighborhood waters. In *Nansha comprehensive scientific investigating team of Chinese Academy of Sciences. Research papers on geology, geophysics, islands and reefs of Nansha Islands (I)* pp. 81-92 (in Chinese). Ocean Press, Beijing.
3. Dien P.T. (1995) Some Cenozoic hydrocarbon bearing basins on the continental shelf of Vietnam. *Geological Society of Malaysia Bulletin* **37**: 33-54.
4. Zhang Q. (1995) *Evolution history and tectonic-thermal regime of basin types of Yinggehai-Southeast Hainan basin in northern South China Sea.* Research report of Western South China Sea Institute, China National Offshore Oil Corp. (Personal communication)
5. Huang C., Su D., Chen H. *et al.* (1997) *Comprehensive Investigation and Research of Geology, Geophysics and Geochemistry in Western Taiwan Strait.* Xiamen University Press, Xiamen. (in Chinese)
6. Chen C., Shi H., Xu S. *et al.* (2003) *Conditions for formation of Tertiary Oil and Gas Accumulation in Eastern Pearl River Mouth Basin.* Science Press, Beijing (in Chinese).
7. Zhang B., Zhou Z. and Shi M. (1997) The first formulate of Permian arc-type basalt and its implication to tectonics: important evidence of Tethyan tectonic zone on boundary between Guangxi and Guangdong Provinces. *Chinese Science Bulletin* **42**: 413-417 (in Chinese).
8. Zhang B. and Yu H. (1994) *On the Deep-level Nappe Structure in Hercynian-Indosinian Collision Belt in Western Guangdong.* Geology Press House, Beijing. (in Chinese)
9. Zhang H., Cheng J., Wang X. *et al.* (1999) New data for age of silicalites in Changkeng-Fuwan electrum area, Guangdong Province, and its significances. *Geological Review* **45**(1): 36. (in Chinese)
10. Wu H., Kuang G. and Wang Z. (2001) The Yunkai block since Silurian. *Journal of Palaeogeography* **3**: 32-40. (in Chinese)
11. Bureau of Geology and Mineral Resources of Guangdong Province, P. R. C. (1988) *Regional geology of Guangdong Province.* Geology Publishing House, Beijing. (in Chinese)
12. Xu X., Yin F., Wan F. *et al.* (2001) The migration of the Qinzhou-Fangcheng trough in Guangxi and associated sedimentary-tectonic transform surface. *Sediment and Tethyan Geology* **21**: 1-10. (in Chinese)
13. Li X., Zhou H., Ding S. *et al.* (2000) MOR-type metabasites in Hainan Island: Remnant slices of Paleo-Tethyan oceanic crust? *Chinese Science Bulletin* **45**: 84-89. (in Chinese)
14. Zhong Z., You Z., Zhou H. *et al.* (1996) Composition evolution and basic structural framework of basement of Yunkai uplift between Guangxi and Guangdong Provinces. *Regional Geology in China* (1): 36-43.
15. Wang H. and Mo X. (1995) An outline of the evolution of China. *Episodes* **18**(1-2): 6-16.
16. Peng S., Zhan M., Zhang Y. *et al.* (2000) Sm-Nd and Pb/Pb isotopic dating of Pre-Caledonian granitic rocks in Yunkai area and its significance. *Acta Geoscientia Sinica-Bulletin of the Chinese Academy of Geological Sciences* **21**(1): 52-57. (in Chinese)

17. Shao J. and Peng S. (1995) Characteristics of isotopic dating for Pre-Hercynian tectonic evolution in Yunkai region. *Geology in Guangdong Province* **10**(2): 41-50. (in Chinese)
18. Bureau of Geology and Mineral Resomrces of Guangxi Province of China (1985) *Regional geology of Guangdong Province.* Geological Publishing House, Beijing. (in Chinese).
19. Wu H., Wang Z. and Kuang G. (1997) Late Paleozoic deep-waterfacies in Guangxi, South China and its tectonic implications. In Wang N.W. and Remane J. (eds) *Proceeding 30th International Geology Congress Utrech V SP* **11**: 163-170.
20. Ma L., Chen H., Gan K. *et al.* (2005) *Tectonics of southern China and geology of marine gas-oil.* Geology Press, Beijing. (in Chinese)
21. Wu Y. *et al.* (2001) Indosinian accretionary arc orogenic belt along boundary between Yunnan and Guangxi Provinces, southwestern China. *Petrolum Experimental Geology* **2**(23): 8-18. (in Chinese)
22. Jin Q. (1989) *Geology and Oil-Gas Resources in The South China Sea.* Geology Press, Beijing. (in Chinese)
23. Nguyen B. (1991) Geological characteristics in sea bottom and islands along offshore zone of Vietnam. In *Proceedings of the Second Conference on Geology of Indochina*, Hanoi **1**: 53-59.
24. Wang W. *et al.* (1999) *Report on Data Processing and Results Explanation of Gravity and Magnetism of Yinggehai basin.* (Personal communication)
25. South China Sea Institute of Oceanology, Chinese Academy of Sciences (2000) *Summary report on wide-angle seismic detection survey and research of Crust deep-seated structure in Southwestern South China Sea.* (Personal communication).
26. Hao H., Lin H., Yang M. *et al.* (2001) Mesozoic Erathem in Chaoshan Depression, NE Margin of South China Sea--New field of Oil and Gas exploration. *Chinese Offshore Oil and Gas (Geology)* **15**: 157-163. (in Chinese)
27. Qiu Y. (1993) Tectonic evolution of Yunkai Mountain and its adjacent area. In Qiu Y., Chen H. (Eds) *Paper anthology on Geological Tectonics of Yunkai Mountain and its adjacent area* pp. 1-11. Geology Press House, Beijing. (in Chinese).
28. Bureau of Hainan Island Geol. and Mineral Resources Exploration and Development (1998) *Explaination for Digital Geological map of Hainan Province, China* (1:500000). (Personal communication. In Chinese)
29. Zeng Q. (1992) *Fundamental geological investigation of Sanya, Hainan Island.* The Press of the the China University of Geosciences, Wuhan. (in Chinese)
30. Zhang Q., Zhou D., Li X. *et al.* (1995) Characteristics and Origin of Ophiolites in Shuanggou, Yunnan. *Journal of Petrology* **11** (supplement): 190-202. (in Chinese)
31. Wang D. and Yun P. (1999) Basic Characteristics of Late Triassic A-type Granite in Ledong area, Hainan Island. *Geol. of Guangdong* **14**(4):19-21. (in Chinese).
32. Wei C. (2000) Mode of Origin of A-type granite and its implication to geodynamics. *Earth Science Frontier* **7**(1): 1-238. (in Chinese)
33. Lu X., Dong Y., Wei X. *et al.* (2004) *Age of A-type granite in Tuwu mountain, East Qinling Mountain range and its implication to tectonics.* http://www.scienceichina.com/kz/9909/ko975/k0975.htm.
34. Sun J. (198)7 A discussion on the formation ages of the bedrock in the Xisha Islands. *Marine Geology and Quaternary Geology* **7**: 5-6. (in Chinese)
35. Wang X., Ma D. and Jiang D. (1992) *Geology of Hainan Island, China,* (1st) – *Stratigraphic Paleontology.* Geology Press House, Beijing (in Chinese)
36. Wang X., Ma D. and Jiang D. (1991) *Geology of Hainan Island, China,* (2nd) – *Magmatites.* Geology Press House, Beijing. (in Chinese)
37. Yang S. (1987) *Paired granite belt and plate tectonics.* Science Press, Beijing. (in Chinese)
38. Yao B., Zeng W., Chen Y. *et al.* (1994) Xisha trough of South China Sea: a paleo-suture line. *Marine Geology and Quaternary Geology* **14**: 1-9. (in Chinese)
39. Huang C. (2002) The Relationship Between Mesozoic Tectonic Structure of South China Sea and Neighboring Areas and Tethyan Ocean. In *Collected Papers of the 5th Marine Science Forum Concerning Offshore Ocean of Taiwan for Researcher From Two Sides of the Taiwan Straits* pp.191-192. (in Chinese)
40. Zhang Y. (2002) The magnetostatic zone in northern margin of South China Sea and its geological signification. In *Collected Papers of the 5th Marine Science Forum Concerning Offshore Ocean of Taiwan for Researcher From Two Sides of the Taiwan Straits* pp.146-147. (in Chinese)
41. Liu H. L., Yan P., Liu Y. C. *et al.* (2006) On existence of Qiongnan Suture in northern margin of South China Sea. *Chinese Science Bulletin* **51**(Supplement II): 107-120.
42. Marquis G., Roques D., Huchon P. *et al.* (1997) Amount and timing of extension along the continental margin off central Vietnam. *Bulletin Society of Geology France* **168**: 202-216.
43. Roques D., Rangin C. and Huchon P. (1997) Geometry and sense of motion along the Vietnam continental margin: onshore/offshore Da Nang area. *Bulletin Society of Geology France* **168**: 413-422.
44. Vu X.D.O. (1991) Rebuild and uplifted circularity tectonics of Mesozoic Indochina continental. In *Proceedings of the Second Conference on Geology of Indochina, Hanoi* **1**: 322-330.
45. Tiep D.M. (1993) Geology of surface layer in continental shelf of Vietnam. In *Proceedings of the Second Conference on Geology of Indochina, Hanoi* **1**: 357-364.
46. Kudrass H.R. *et al.* (1986) Mesozoic and Cenozoic rocks dredged from the South China Sea (Reed Bank area) and Sulu Sea and their Significance for plate tectonic reconstructions. *Marine and Petroleum Geology* **13**: 19-30.
47. Fontaine H., David P., Pardede R. *et al.* (1983) The

Jurassic in Southeast Asia. *United Nations ESCAP, CCOP Technical Bulletin* pp. 1-28.
48. Liu H.L., Xie G.F., Yan P. *et al.* (2007) The basic characteristics of Mesozoic Erathem in Nansha Waters of China and its significance. *Oceanologia et Limnologia Sinica* **38**(3): 272-278. (in Chinese)
49. Almasco J.N., Rodolfo K., Fuller M. and Frost G. (2000) Paleomagnetism of Palawan. *Philippines Journal of Asian Earth Sciences* **18**: 369-389.
50. Hashimoto W. (1984) *Geological Development of Philippines* (translated by Yang G. in Chinese), *Geology of Peripheral South China Sea* (1). Information Library of South China Geological Survey Headquarter. (Personal communication)
51. Yan P. and Liu H. L. (2004) Tectonic-stratigraphic division and blind fold structures in Nansha Waters, South China Sea. *Journal of Asian Earth Science* **24**: 37-48.
52. Zhong D., Wu G., Li J. *et al.* (1998) Discovery of Ophiolites in Southeastern Yunnan Province. *Chinese Science Bulletin* **43**: 1365-1370. (in Chinese)
53. Ichikawa K. (1990) Pre-Cretaceous Terranes of Japan. In Ichikawa, K. *et al.* (Eds) *Pre-Cretaceous Terranes of Japan* pp. 1-12. Nippon Insatsu Shuppan Co Ltd, Osaka.
54. Metcalfe I. (1996) Pre-Cretaceous evolution of SE Asian terrenes. In Hall R. and Blundell D. (Eds) *Tectonic evolution of Southeast Asia. Geological Society Special Publication* **106**: 97-122.
55. Metcalfe I. (1996) Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys. *Australian Journal of Earth Science* **43**: 605-623.
56. Pan G., Chen Z., Li X. *et al.* (1997) *Geotectonic formation and evolution of East Tethys*. Geology Press, Beijing. (in Chinese)
57. Jiang W., Song H. and Hao T. (2000). The characters of geological and geophysical fields and deep structure of northwestern of South China Sea. *Advance of Geophysics* **16**: 1-11. (in Chinese)
58. Liu H.L., Sun Y., Guo L. *et al.* (1999) On the boundary faults' kinematical characteristics and dynamic process of Nansha ultra-crust layer-block. *Acta Geologica Sinica (English edition)* **73**: 452-463.
59. Liu H.L., Guo L., Sun Y. *et al.* (2002) *Study on fault system in Nansha block (South China Sea) and the Block's lithospheric dynamics.* Scientific Press House, Beijing. (in Chinese)
60. Liu H.L., Yan P., Zhang B.Y. *et al.* (2004) Role of the Wanna Fault System in the Western Nansha Islands (Southern South China Sea) Waters Area. *Journal of Asian Earth Sciences* **23**(2): 221-233.

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EXECUTIVE SUMMARY

The South China Sea: Sustaining ocean productivities, maritime communities and the climate

A Conference for regional research cooperation in ocean and earth sciences for the South China Sea (SCS) was held from 25 until 29 November 2008 at Hyatt Hotel, Kuantan, Pahang. The conference was jointly organized by the National Oceanography Directorate (NOD), Ministry of Science, Technology and Innovation (MOSTI), Malaysia, the Institute of Ocean and Earth Sciences (IOES), University of Malaya (UM) and the Malaysian Society for Marine Sciences (MSMS). In conjunction with the conference, side event workshops were also organized, namely (i) Post "IOC-WESTPAC Follow-up Workshop on the South China Sea" held on 25 November 2008, (ii) "Bay of Bengal Large Marine Ecosystem Programme – Malaysia's Commitments" held on 28 November 2008 and (iii) "Marine Sources of Short-lived Halocarbons and their Atmospheric Effects" held on 29 November 2008, whereby the latter was jointly organized with Cambridge University, UK.

The Chief Minister of Pahang, the Honorable YAB Dato' Sri Adnan bin Yaakob officiated the Opening Ceremony of the conference, with the presence of Datin Paduka Prof. Dr. Khatijah binti Mohd. Yusoff, Deputy Secretary General (Science) representing MOSTI, Dato' Prof. Dr. Mohd. Amin bin Jalaludin, Deputy Vice Chancellor representing UM, the co-chairs of the conference Prof. Dr. Nor Aieni Mokhtar, Director of NOD and Prof. Dr. Phang Siew Moi, Director of IOES cum President of MSMS.

The international conference was successfully organized with the attendance of 180 delegates from 17 countries. The participants were representing the countries bordering the South China Sea except for Brunei and Taiwan. The Conference was divided into eight scientific sessions with areas in:

IA – Marine Biotechnology
IB – Marine Biodiversity
IIA – Maritime Societies and Cultures
IIB – Fisheries
III – Safety of Navigation, Maritime Security and Marine Pollution Co-operation in the South China Sea
IV – Geology and Geological Resources
V – Education, Awareness and Community Development in Coastal Ecosystems
VI – Ocean -Earth -Atmospheric Interactions and Climate Change
VII – Eco-engineering Technologies for Coastal Protection

A total of 72 oral presentations and 55 poster papers were presented during the 3-day conference. The papers presented at the conference were aimed to be published in the December Special Issue of Journal of Science and Technology in the Tropics (JOSTT).

Some of the findings or highlights of the conference based on thematic areas are summarized as follows.

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Geotextile tube containment for coastal protection

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Abstract Geotextile containment is used to encapsulate sandy soils to enable their use as flexible, erosion-resistant, mass-gravity structures in coastal protection applications. The paper introduces the variety of geotextile containment units in use and discusses their range of applications in general, but then concentrates specifically on geotextile tube containment. Important stability aspects of design are presented along with geotextile tube mechanical and hydraulic property requirements. Ways of enhancing geotextile tube durability are also discussed. Several case studies are presented that demonstrate the effective use of geotextile tubes for a variety of coastal protection applications.

Keywords geotextile – geotextile containment – geotextile tubes – coastal protection

INTRODUCTION

Geotextile containment, in one form or another, has been used for many years for a wide variety of hydraulic and marine applications. The most universal, and widely used, geotextile containers are the well-known, ubiquitous sand bags which are seen the world over shoring up flood defences in times of natural calamity.

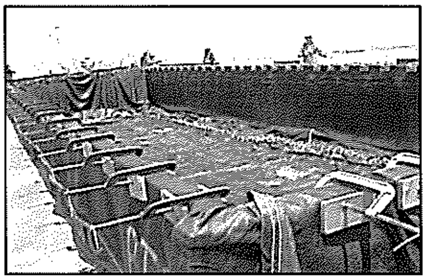
Three fundamental types of geotextile containment units exist, differentiated by geometrical shape and volume. These are geotextile tubes, geotextile containers and geotextile bags. Geotextile tubes, Figure 1a, are tubular containers that are formed insitu on land or in water. Geotextile containers (Fig. 1b) are large-volume containers that are filled in barges above water and then deposited into submarine environments. Geotextile bags, Figure 1c, are small-volume containers that are filled on land or above water and then pattern-placed either near water or below water level.

Geotextile tubes are laid out and filled onsite to their required geometrical form. The tubes are filled by hydraulically pumping fill into the tube. Geotextile tubes range in size from 1 m to 10 m in diameter, and up to 200 m in length.

Geotextile containers are large-volume containers that are filled above water and then positioned and placed at water depth. The volumes of these containers more commonly range from 100 m^3 to 700 m^3, although containers as large as 1,000 m^3 have been installed. To facilitate the installation of geotextile containers of this magnitude an efficient and practical installation system must be utilised. To date, this has been accomplished by means of split-bottom barges.

Geotextile bags are manufactured in a range of shapes, and they are installed in a pattern-placed


a) Geotextile tubes


b) Geotextile containers


c) Geotextile bags

Figure 1. Types of geotextile containment units.

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arrangement that greatly improves their overall stability and performance. Today, geotextile bags range in volume from 0.05 m^3 to around 5 m^3, and may be pillow-shaped, box-shaped or mattress-shaped depending on the required application.

When considering geotextile containment, distinction must be made between those applications where the geotextile containment is required for only temporary or expedient use and those applications that require long-term performance. For example, for temporary or expedient works the requirements of the geotextile container is fairly basic as it only has a short life expectancy over which it has to perform; however, for long-term applications the performance requirements of the geotextile container are more severe. With regard to long-term performance, distinction also must be made according to the type of hydraulic environment acting on the geotextile container. For example, the action of still water will have a different effect on the geotextile container than the action of breaking waves.

This paper concentrates on the use of one type of geotextile container unit – the geotextile tube – in hydraulic and coastal engineering applications. However, much of what the paper covers will also be relevant to other geotextile containment unit types.

GEOTEXTILE TUBES FOR COASTAL ENGINEERING APPLICATIONS

Engineering features of geotextile tubes

Geotextile tubes are laid out and filled hydraulically onsite to their required geometrical form. The typical features of a geotextile tube are shown in Figure 2. Hydraulic fill is pumped into the geotextile tube through specially manufactured filling ports located at specific intervals along the top of the geotextile tube. During filling, the geotextile tube, being permeable, allows the excess water to pass through the geotextile skin while the retained fill attains a compacted, stable mass within the tube. For hydraulic and marine applications the type of fill used is sand, or a significant percentage of sand. The reasons for this are that this type of fill can be placed to a good density by hydraulic means; this type of fill has good internal shear strength; and this type of fill, once placed, will not undergo further consolidation, which would change the filled shape of the geotextile tube. Once filled, the geotextile tube behaves as a mass-gravity unit and can be designed accordingly.

The geotextile tube skin performs three functions that are critical to the performance of the filled geotextile tube. First, the geotextile skin must have the required tensile strength and stiffness to resist the mechanical stresses applied during filling and throughout the life of the units, and must not continue to deform so that the geotextile tube changes shape over time. Second, the geotextile skin must have the required hydraulic properties to retain the sand fill and prevent erosion under a variety of hydraulic conditions. Third, the geotextile skin must have the

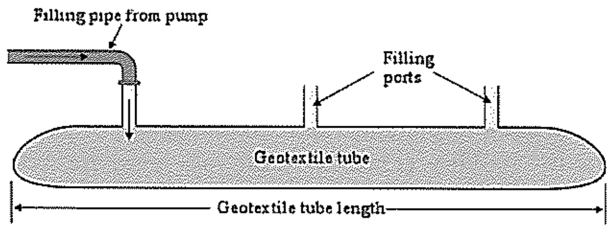
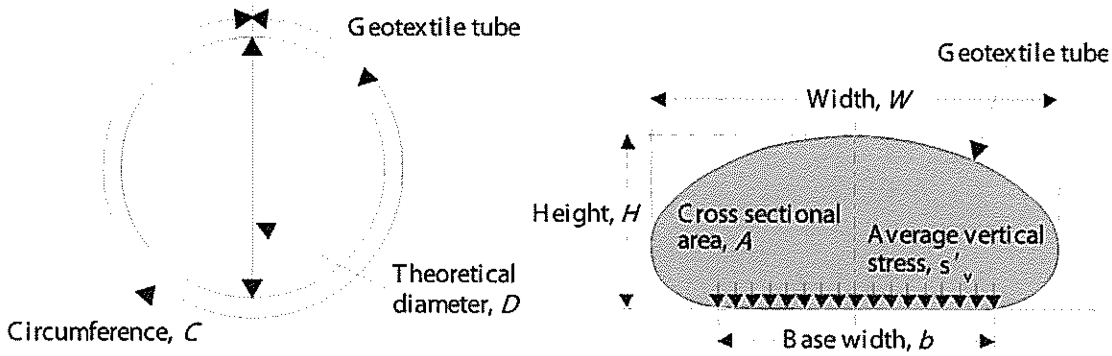


Figure 2. Typical features of geotextile tubes.



a) Fundamental geotextile tube parameters

b) Engineering parameters of importance for filled geotextile tubes

Figure 3. Various parameters associated with geotextile tubes.

required durability to remain intact over the design life of the units.

Geotextile tubes are normally described in terms of either a theoretical diameter, D (in Europe, Middle East and Asia) or a circumference, C (in North and South America) (Fig. 3a). While these two properties represent the fundamental parameters of geotextile tubes they are not of direct interest when it comes to the engineering parameters for hydraulic and coastal applications where the geotextile tube in its filled condition is of prime importance. The various engineering parameters of importance are shown in Figure 3b.

Table 1 lists approximate relationships between the fundamental geotextile tube parameters of theoretical diameter and circumference (Fig. 3a) and the engineering parameters of importance depicted in Figure 3b. The relationships are applicable to geotextile tubes that have a maximum strain £15%, low unconfined creep, and are filled to maximum capacity with sand-type fill. Furthermore, it is also assumed that the foundation beneath the tube is a flat, solid surface.

Applications for geotextile tubes

Geotextile tubes are used for a range of hydraulic and coastal applications where mass-gravity barrier-type structures are required. These applications are shown in Figure 4 and described briefly below.

Geotextile tubes are used for revetment structures where their contained fill is used to provide mass-gravity stability (Fig. 4a). They are used for both submerged as well as exposed revetments. For submerged revetments the geotextile tube is covered by local soil and is only required to provide protection when the soil cover has been eroded during periods of intermittent storm activity. Once the storm is over the revetment is covered by soil again either naturally or by maintenance filling. For exposed revetments the geotextile tube is exposed throughout its required design life.

Table 1. Approximate relationships between fundamental and engineering parameters of geotextile tubes (After Lawson [1])

Engineering parameter	In terms of theoretical diameter, D	In terms of circumference, C
Maximum filled height, H	$H \approx 0.55\ D$	$H \approx 0.18\ C$
Filled width, W	$W \approx 1.5\ D$	$W \approx 0.5\ C$
Base contact width, b	$b \approx D$	$b \approx 0.3\ C$
Cross sectional area, A	$A \approx 0.6\ D^2$	$A \approx 0.06\ C^2$
Average vertical stress at base, σ'_v	$\sigma'_v \approx 0.7\ \gamma\ D$	$\sigma'_v \approx 0.22\ \gamma\ C$

Note: γ = bulk density of the geotextile tube fill.

To prevent erosion of the foundation soil in the vicinity of the geotextile tube it is common practice to install a scour apron (see Fig. 4a). This scour apron usually consists of a geotextile filter layer that passes beneath the geotextile tube and is anchored at the extremity by a smaller, filled, geotextile tube.

Revetments are also constructed using multiple-height geotextile tubes. Here the geotextile tubes are staggered horizontally to achieve required stability. Considerable care should be exercised during construction of these types of revetments to ensure the water emanating from the hydraulic filling of the upper geotextile tubes does not erode the soil and undermine the lower geotextile tubes in the multiple-height revetment structure. Examples of use are given by Nickels and Heerten [2] and Artières [3].

Geotextile tubes are used for offshore breakwaters to prevent the erosion of shoreline developments (Fig. 4b). Here the filled geotextile tube is located a certain distance offshore in order to dissipate wave forces before they can reach the shoreline. Again, scour aprons are used beneath the geotextile tube breakwater to ensure local erosion does not undermine the breakwater structure.

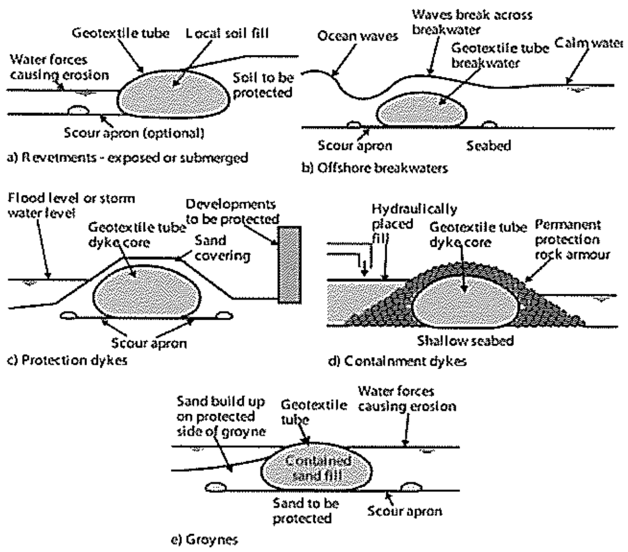


Figure 4. Hydraulic and coastal applications for geotextile tubes.

In many instances the geotextile tube is left exposed which consequently affects its design life. Additional techniques or treatments may be applied to the geotextile tube breakwater to increase its exposed design life. These are discussed in more detail later in this paper. Examples of use are given by Townsend [4] and Oh *et al.* [5].

Geotextile tubes are used for protection dykes where they prevent flood and storm damage to valuable structures and real estate (Fig. 4c). Protection dykes also may be used for river, lake or stream training works.

Where geotextile tube protection dykes are constructed it is common to cover the geotextile tube with local soil. The geotextile tube is only required to function intermittently during storm or flood periods when the soil cover is eroded. The use of the soil cover provides a number of advantages to the geotextile tube core. First, the soil cover hides the geotextile tube core thereby providing an aesthetic environment and ensuring no damage due to vandalism. Second, the soil cover protects the geotextile tube from long-term exposure to the atmosphere (UV degradation).

Where geotextile tubes are used for river, lake or stream training works it is common to leave the tube exposed except for major structures where rock armour layers may be placed over the geotextile tube to dissipate hydraulic forces. Where the tubes are left exposed a geotextile shroud may be used across the top of the tube, or a coating applied, to enhance its longevity in an exposed environment. Examples of use are given by Austin [6], Fowler [7] and Ghazali *et al.* [8].

Geotextile tubes are used for the cores of containment dykes where water depths are relatively shallow, Figure 4d. Here, the tube structure contains a filled reclamation area - the reclamation fill being dry dumped or placed hydraulically. The advantage of this approach is that the same hydraulic fill used in the reclamation can also be used inside the geotextile tubes for the containment dykes thus avoiding the need to import rock fill for the dykes. Where water forces dictate, and where longevity is required, rock armouring can be placed around the geotextile tube core (e.g. Fig. 4d). Examples of use are given by de Bruin and Loos [9], Spelt [10], Fowler *et al.* [11] and Yee [12].

Geotextile tubes can be used as groynes to prevent the littoral movement of sediment (Fig. 4e). In most cases the geotextile tubes are left exposed, but coatings or a rock covering may be applied depending on the circumstances and the required life expectancy. Examples of use are given by Jackson [13] and Fowler *et al.* [11].

Design procedure for geotextile tubes

Since geotextile tubes behave as mass-gravity units the conventional approach to design follows a standard procedure of assessing the possible modes of failure or deformation in order to arrive at a safe design solution. Figure 5 lists the various limit state modes that should be assessed and these are divided into external modes (those modes affecting the performance of the geotextile tube structure overall) and internal modes (those modes affecting the performance of the internal structure of individual geotextile tubes). Either a global factor of safety or a partial factor of safety approach can be applied when assessing the various limit state modes.

There are six external limit state modes to be assessed (Fig. 5a). These are sliding resistance, overturning resistance, bearing resistance, global stability, scour resistance and foundation settlement. Geotextile tubes are very stable units with high base contact width to height ratios, e.g. $b/H = 1.5$ (Table 1). Geotextile tubes should be checked for sliding and overturning stability, especially if the tubes are of small theoretical diameter, $D \leq 2$ m. Bearing stability (e.g. Fig. 5a(iii)) may be of importance if the foundation is very soft and the geotextile tube is very large. However, experience has shown that the distribution of weight of geotextile tubes on soft foundation soils is very efficient.

Global stability only needs to be taken into account when multiple geotextile tubes are used

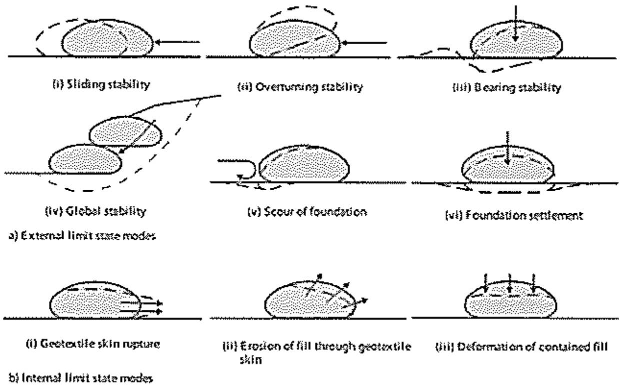


Figure 5. Limit state modes for the design of geotextile tubes.

(e.g. Fig. 5a(iv)). Here, the stability analysis should take into account changes in both the external water level and the groundwater level within the geotextile tube structure. Also, potential weak planes between adjacent geotextile tubes should be assessed.

Scour of the foundation around the edges of geotextile tubes (e.g. Fig. 5a(v)) can lead to undermining, and the geotextile tube overturning. Scour may occur either during the filling process or during the life of the tube. During filling, a large amount of water is expelled through the geotextile skin and this can cause erosion and undermining of the geotextile tube if measures are not taken to prevent this. To prevent scouring of the foundation during filling it is common practice to first install a geotextile or geomembrane layer beneath the geotextile tube prior to tube placement and filling. This procedure is very important where multiple-height geotextile tubes are installed in order to prevent the filling water of the upper tubes causing erosion and instability of the lower tubes in the structure.

Where there is potential for foundation scour during the life of the geotextile tube structure it is common practice to install a scour apron during construction (see Fig. 4). The scour apron consists of a geotextile filter anchored at the extremities by means of a small diameter geotextile tube manufactured as an integral part of the geotextile filter base.

Where geotextile tubes are constructed on compressible foundations, and where they are required to meet specific height requirements for hydraulic structures (e.g. breakwaters), an assessment of the effect of foundation settlement should be performed (Fig. 5a(vi)).

There are three internal stability modes to be assessed (Fig. 5b). These are geotextile skin rupture resistance, geotextile skin hydraulic resistance and deformation of the contained fill. Geotextile skin rupture resistance is discussed in more detail below.

Required tensile properties of geotextile tubes

During the filling process and throughout the life of filled geotextile tubes tensions are generated in the tube unit. These locations are around the circumference of the geotextile tube, along the length, or axis, of the geotextile tube, and at the connection of the filling ports with the geotextile tube.

The analysis of tensions generated in geotextile tubes is complicated due to the effect of geotextile tube geometry. Further, the fill contained within geotextile tubes starts as a liquid, i.e. with zero shear strength, and then fairly quickly reverts to a solid, i.e. with internal shear strength. This change in phase of the contained fill, the amount of filling and pumping pressure applied, and the time over which the contained fill changes in phase all affect the magnitudes of the tensions generated in geotextile tubes. For hydraulic and coastal structures where the contained fill consists of sand, the time it takes to change to a solid material is very short (unlike finer fills) and thus analysis methods based on the assumption of a shear resistant fill are more appropriate for this type of application.

The procedure normally used to determine the tensions in geotextile tubes is to first determine the circumferential tension, then the axial tension, and finally the port connection tension. Figure 6 shows the maximum circumferential tension $[T_{max}]_c$ for filled geotextile tubes having theoretical diameters D = 3.0 m, 4.0 m and 5.0 m using the procedure of Palmerton [14]. As noted in Table 1 the maximum filling height is $H \approx 0.55D$, which results in maximum circumferential tensions $[T_{max}]_c$ of 18 kN/m, 30 kN/m and 50 kN/m respectively for the three geotextile tube sizes.

From modelling analyses the maximum axial tension generated is around 63% of the maximum circumferential tension. The magnitude of the port connection tension is a function of the filling pressure,

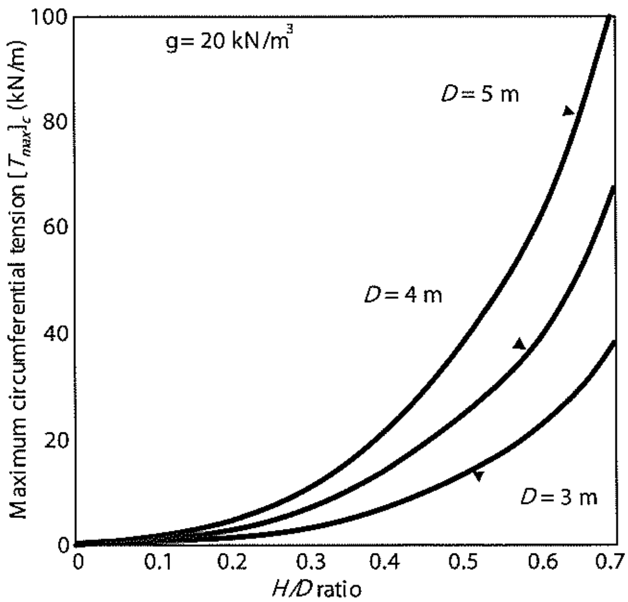


Figure 6. Maximum circumferential tensions in geotextile tubes according to Palmerton [14].

the height of the geotextile tube and the shape of the filling port. Yuan *et al.* [15] have analysed the stress concentrations present in the filling ports during the filling of geotextile tubes and have estimated that these can be 2 to 3 times the circumferential stresses at the top of geotextile tubes. Techniques of reducing the magnitudes of these stress concentrations are given by Yuan *et al.* [15].

The geotextile tube skin and its component parts must have adequate tensile strengths to resist the tensions generated during the filling process and throughout the life of the filled geotextile tube. This tensile strength requirement must account for the tensions generated in the geotextile fabric itself as well as any seams used to join the geotextile fabric together. To arrive at safe tensile strengths a suitable factor of safety must be applied to the magnitude of the tensions generated at the various locations in the filled geotextile tube. Unless a specific analysis is undertaken of the various factors that comprise the overall factor of safety a default value of 4.0 to 5.0 is normally applied.

Protection measures applied to geotextile tubes

External protection measures are applied to geotextile tubes for a variety of reasons, namely;

- to reduce the impact of the hydraulic forces acting directly on the geotextile tube;
- to enhance the design life of the geotextile tube in an exposed environment;
- to protect from extreme natural occurrences, e.g. ice and debris flows, etc;
- to protect from vandalism.

In many instances geotextile tubes are required to perform over a relatively long design life in an exposed environment. In this environment ultra-violet light (UV) degradation can occur, with the geotextile tube design life dependent on the level of UV radiation and the resistance of the geotextile tube skin to this radiation. If the geotextile tube is located in a marine environment, marine growth generally occurs quickly on the outer surface and this tends to mask the geotextile skin somewhat from the effects of UV radiation. However, for good long term performance in an exposed environment additional protection measures are normally required for the geotextile tube skin. These measures are listed below in order of providing longer term performance.

- Additional stabilizer packages in the geotextile tube skin – where the enhanced performance of the stabilizer package improves the performance of the geotextile tube skin over time.
- More robust, or multi-layer geotextile skin – where extra design life is achieved by the use of more robust or multi-layer geotextile skins that degrade over a longer period of time.
- Geotextile shrouds - where the outer geotextile shroud provides protection for the inner geotextile tube skin. The geotextile shroud becomes sacrificial over the design life of the geotextile tube structure. These are used where the geotextile tube structure is continually exposed to the environment and where the hydraulic forces are not severe.
- Geotextile coating – where a robust coating is applied to the geotextile tube to protect it. Coatings can be applied in a variety of colours.
- Soil covering – where the geotextile tube is covered by soil or sand to prevent long term UV exposure. Here the geotextile tube structure performs intermittently during periods of storm activity and is then covered over again by soil or sand.
- Armour covering – where a flexible armour covering is used around the geotextile tube structure to prevent long term exposure to UV light. This is normally used in hydraulic and marine applications where severe hydraulic forces occur.

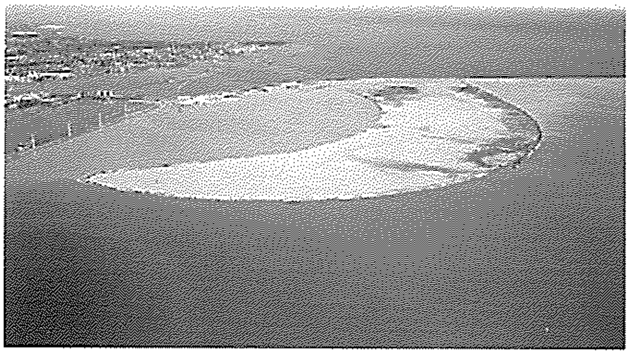
Extreme natural occurrences can also affect the long term performance of exposed geotextile tubes. Examples include the damaging effects of ice flows, and debris carried in water during floods, on the exposed surface of geotextile tubes. Where this is known to be a problem then the geotextile tube structure must be protected. The form of protection from this type of exposure is normally armour covering.

Vandalism can also affect the long term performance of geotextile tubes. This type of damage is normally in the form of localised cuts and tears. The best way of protecting against this likelihood is to cover the geotextile tube so it is out of sight. Alternatively, robust coatings can be applied which prevent vandalism. Failing this, a good maintenance scheme should be put in place to correct any acts of vandalism.

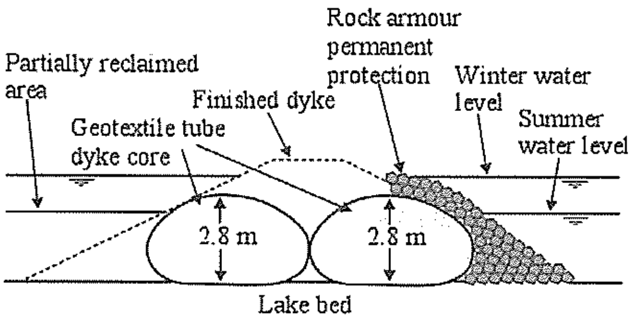
Geotextile tubes for Naviduct Project, Enkhuizen, The Netherlands

This project, originally reported on by Spelt [10] and Lawson [1], is an example where geotextile tubes were used for containment dykes in an environmentally sensitive lake in The Netherlands.

The Krabbersgat Lock at Enkhuizen is an important bottleneck in the main network of waterways in The Netherlands. Due to an increase in shipping and road traffic at the lock significant time delays were occurring for both shipping and road transport. To ensure smooth movement of shipping and road traffic it was decided to construct a combination of an aqueduct and a lock below which a tunnel for road traffic could pass (this structure is known as a "Naviduct").



a) Crescent-shaped containment area



b) Section through containment dyke

c) Filling of geotextile tubes

Figure 7. Use of geotextile tubes to construct containment dyke, Naviduct project, Enkhuizen, The Netherlands.

For cost and environmental reasons a crescent-shaped containment area was constructed in the lake adjacent to the Naviduct site (Fig. 7a). This containment area acted as a local disposal for the spoil material from the adjacent construction site. Once finished, the partially filled containment area will be vegetated and will act as a bird sanctuary. Further, the crescent-shape of the containment area is to act as a barrier to drifting ice during winter.

The construction of the containment dykes was carried out using a double layer of geotextile tubes of filled height 2.8 m (Fig. 7b). The reason why geotextile tubes were used for the containment dykes was because the locally available sand fill from the Naviduct site was too fine and uniform to be used by itself as the structural component of the containment dykes. Instead, the geotextile tubes were filled with the local fine sand, and this provided the structural basis for the containment dykes.

The crescent-shaped containment area utilized 7.5 km of geotextile tubes, two abreast, in the containment dyke. Before placement of the geotextile tubes a geotextile filter layer was placed on the lake bed at the base of the containment dykes for erosion control purposes. The geotextile tubes were laid out in the water, anchored in place, and then filled by connecting the exit pipe of the dredger directly into the inlets of the geotextile tubes, Figure 7c.

Once filled, the geotextile tubes were covered with a geotextile shroud to protect the tube from long-term UV exposure. On the outside of the containment dyke the tubes were covered with rock armour for the final, long term, protection (Fig. 7b). Finally, the dyke was raised to its finished height by using the local fine sand fill, and vegetated.

CONCLUSION

Geotextile containment utilizing geotextile tubes can provide interesting solutions to hydraulic and coastal engineering applications. By containing sand and other similar materials geotextile tubes act as mass-gravity structures in hydraulic and coastal applications. Sand, or like fill, is used for these applications because it does not undergo consolidation once installed and the units can maintain their existing shape and height. Geotextile tubes provide environmentally friendly solutions as they utilize local materials, and in many cases, avoid the use of more costly rock and concrete solutions.

When installed in hydraulic and coastal environments care is required especially if the geotextile containment structures are continually exposed over long periods of time. In these situations, aspects such as UV resistance, abrasion resistance and liquefaction of the sand fill may need to be taken into account.

REFERENCES

1. Lawson C.R. (2003) Geotextile containment – international perspectives. *Proceedings. 17th GRI Conference, Geosynthetic Institute, Philadelphia, USA* pp. 198-221.
2. Nickels H. and Heerten G. (1996) Building elements made of geosynthetics and sand resist the North Sea surf. *Proceedings EuroGeo 1, Maastricht, The Netherlands* pp. 907-910.
3. Artières O., Dunand M. and Durand F. (2005) Coastal protection with filter tube breakwater "Amelie" beach case. *Proceedings EuroGeo 3, Munich, Germany* pp. 367-370.
4. Townsend M. (2005) Semaphore Park offshore breakwater: a trial. *Proceedings 17th Australasian Coastal and Ocean Engineering Conference, Australia* pp. 691-696.
5. Oh Y.I., Shin E.C. and Das B.M. (2006) Application of submerged geotextile tubes for erosion prevention in East coast of Korea. *Proceedings 8th International Conference on Geosynthetics, Yokohama, Japan* **2**: 757-760. Millpress Science Publishers.
6. Austin T. (1995) A second life for dredged material. *Civil Engineering, November* pp. 60-63.
7. Fowler J. (1997) Geotextile tubes and flood control. *Geotechnical Fabrics Report, July* pp 28-37.
8. Ghazali N.H.M, Kam S. and Yee T.W. (2006) Geotextile tubes for protection of mangrove coast at Tanjung Piai Johor National Park, Malaysia. *Proceedings 8th International Conference on Geosynthetics, Yokohama, Japan* **2**: 773-776. Millpress Science Publishers.
9. de Bruin P. and Loos C. (1995) The use of Geotubes as an essential part of an 8.8 m high North Sea dyke and embankment, Leybucht, Germany. *Geosynthetics World, April* pp. 7-10.
10. Spelt K. (2001) Geotubes as the core of guide dams for Naviduct at Enkhuisen, The Netherlands. *Terra et Aqua* **83**: 21-25.
11. Fowler J., Ortiz C., Ruiz N. and Martinez E. (2002) Use of geotubes in Columbia, South America. *Proceedings 7th International Conference on Geosynthetics, Nice, France, Balkema* **3**: 1129-1132.
12. Yee T.W. (2002) Construction of underwater dykes using geotextile containment systems. *Proceedings 7th International Conference on Geosynthetics, Nice, France, Balkema* 3: 1161-1164.
13. Jackson L.A. (1987) Evaluation of sand filled geotextile groynes constructed on the Gold Coast, Australia. *Proceedings 8th Australian Conference on Coastal and Ocean Engineering, Launceston, Australia* pp. 235-238.
14. Palmerton J.B. (2002) Distinct element modelling of geosynthetic fabric containers. *Proceedings 7th International Conference on Geosynthetics, Nice, France, Balkema* **3**: 1021-1024.
15. Yuan Z., Stephens T. and Wilbanks B. (2008) Stress concentration around geotextile tube filling port. *Proceedings 1st Pan American Geosynthetics Conference, Cancun, Mexico, IFAI* pp. 406-413.

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Physical parameters of two mangrove habitats on Carey Island, Peninsular Malaysia

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Abstract This study is an evaluation of different physical parameters of the mangrove habitat in Carey Island. Several parameters were recorded at three stations in the mangrove habitat (Site 1) along the Langat River which contains a good community of mangrove forest. A similar study was also conducted at four stations in a degraded mangrove habitat along eroding sea line (Site 2). In Site 1, the water parameters featured high and almost constant salinity, high water temperature, high conductivity but relatively low dissolved oxygen concentration and high Total Dissolved Solid (TDS). On the other hand, Site 2 recorded high salinity but lower water temperature. Site 2 also featured relatively low dissolved oxygen and high TDS. The water pH for both sites ranged from 6.54-8.16. The light intensity for Site 1, where data were taken under canopy and gap area, ranged from 21,550 to 45,303 Lux. In the degraded mangrove site (Site 2), the light intensity was higher, ranging from 24,000 to 88,375 Lux, as the habitat was more exposed.

Keywords physical parameters – mangrove – Carey Island

INTRODUCTION

Mangroves are defined as woody trees and shrubs which flourish in mangrove habitats, which is almost, but not quite, a tautology [1]. The mangrove trees and the other inhabitants of the mangrove ecosystem are adapted to their unpromising habitat, and can cope with periodic immersion and exposure by the tide, fluctuating salinity, low oxygen concentration in the water, and (being tropical) frequently high temperatures [2].The study was conducted at Carey Island, situated south of Port Klang in the state of Selangor. It is a large island separated from the mainland by the Klang River and is connected by a bridge from Chondoi and Teluk Panglima Garang near Banting. The main objectives for this study were to determine variation in physical parameters at selected mangrove habitats and also to differentiate physical environment between pure mangrove and degraded mangrove habitat.

MATERIALS AND METHODS

Description of study site

The location of the two study areas (Site 1 and Site 2) was recorded by using Global Positioning System (GPS). Site 1 (N 02°54'26.4" and E 101°21'07.2") contains good community mangrove forest (Fig. 1) while Site 2 (N 02° 49'26.4" and E 101°20'26.9") is a mixed sandy-mud degraded mangrove habitat (Fig. 2), facing the Straits of Malacca.

Three stations (1, 2, 3) were laid in Site 1 and four stations (1,2,3,4) were laid in Site 2 for data collections. Data were collected once every month for a total period of six months. The parameters chosen followed Ahmad Shah [3].

In-situ water quality data measurement

Data collected were temperature, pH, salinity, conductivity, dissolved oxygen (DO), total dissolved solid (TDS) and light intensity. Dissolved Oxygen and temperature of seawater were taken and measured by using MI 605 portable dissolved oxygen meter for DO value and temperature of water surface. Unit of dissolved oxygen is expressed as part per million (ppm). pH, conductivity and TDS were measured by using MI805 combined meter. Salinity was determined by using salinity refractometers and the unit is part per thousand (ppt). Light intensity was determined through Digital Light Meter and three measurements taking randomly from each station under the canopy and in the gap.

RESULTS

Dissolved oxygen (DO) and water temperature

Dissolved oxygen concentration ranged from 2.41 to 5.02 ppm in Site 1 while Site 2 recorded 0.56 to 6.02 ppm. For Site 1, the value of dissolved oxygen dropped slightly from February to April but increased after that period. At Site 2, the concentration of dissolved oxygen was quite high in February but dropped in March and remained low until July (Fig. 3). Water temperature in Site 1 was higher compared to Site 2.The water temperature ranged from 28.18 °C to 33.03 °C in Site 1 and Site 2 ranged from 26.73 °C to 27.9 °C. Water temperature in Site 1 and Site 2 increased from May to July 2008 (Fig. 4).

pH, conductivity and TDS

The range of pH in Site 2 was slightly acidic 6.44 to neutral 7.63 but in Site 1, the pH values were slightly alkaline from 7.11 to 8.05(Fig. 5). The conductivity ranged from 54.51 mS (milliseimens) to 77.02 mS for Site 1 and 22.69 mS to 54.51 mS for Site 2 (Fig. 6). At Site 1, the conductivity increased from February to April, dropped in May and increased again. At Site

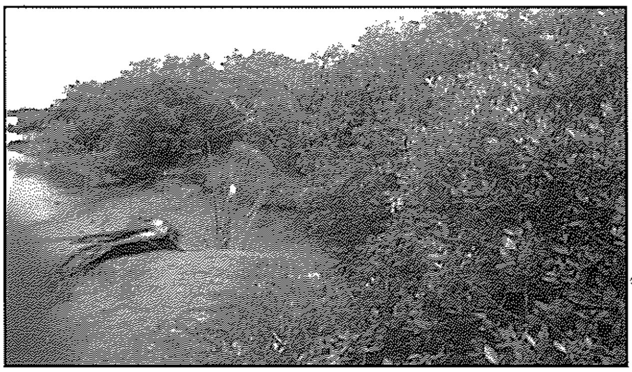

Figure 1. Site 1 with good community of mangrove habitat facing Langat River.

Figure 2. Site 2 with degraded mangrove site at the coastal area facing Straits of Malacca.

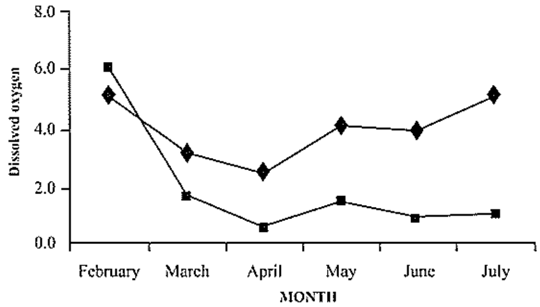

Figure 3. The average monthly dissolved oxygen for February to July 2008 at Site 1 and Site 2. (------◆-----, **site 1**; -----■-----, **site 2**)

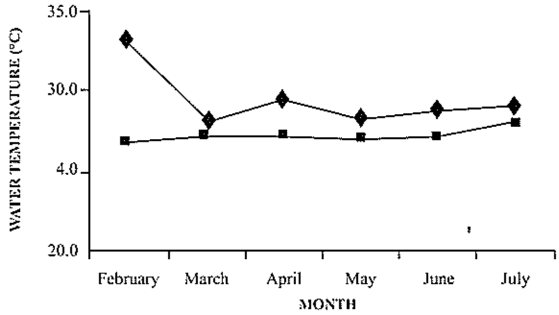

Figure 4. The average monthly water temperature for February to July 2008 at Site 1 and Site 2. (------◆-----, **site 1**; -----■-----, **site 2**).

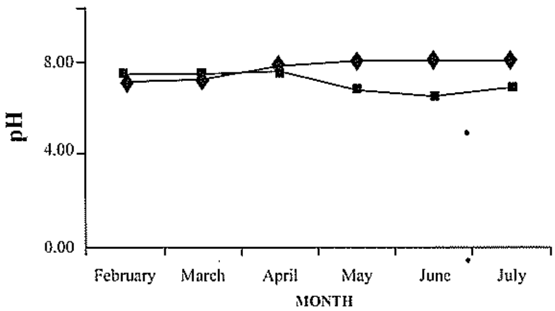

Figure 5. The average monthly pH for February 2008 to July 2008 at Site 1 and Site 2. (------◆-----, **site 1**; -----■-----, **site 2**).

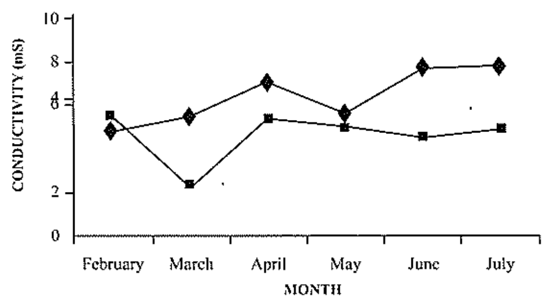

Figure 6. The average monthly conductivity for February to July 2008 at Site 1 and Site 2. (------◆-----, **site 1**; -----■-----, **site 2**).

Marine biotechnology

There are as yet many undiscovered and little known marine organisms (and their metabolites) in our marine waters that could be exploited for the production of useful products, including medicine, nutritional products, novel compounds, biofuel, etc. This is one potential area for collaboration amongst scientists in the South China Sea rim. Malaysia should tap the expertise of our neighbours from Thailand and Vietnam particularly the latter that has made significant headways in DHA biosynthesis from heterotrophic algae. This research area has a high potential for commercialization including biofuel production.

Harmful algal blooms (HAB) is another topic discussed in the conference. It appears that we still do not fully understand the processes involved and the causal factors triggering HAB. Given the occasional happenings of shellfish poisoning in our waters and including SCS, there is a need for further research in collaboration with scientists from outside the SCS rim, in particular China and Japan. An effective networking among HAB scientists and reporting centres (if not in existence) is important to facilitate rapid communication and reporting.

Marine biodiversity

The session on marine biodiversity which made up of both oral and several poster presentations, did illustrate and further substantiate the biodiversity richness of the SCS. Coral reefs are the best known marine habitats, and they indeed attract a lot of attention in terms of ecotourism and research. Ironically, uncontrolled development plans for ecotourism in such areas pose damaging threats to these beautiful marine habitats. This problem similarly appears across the SCS regions. In addition to human-induced elevated turbidity and sedimentation rate, these have taken their toll on coral health resulting in regular episodes of coral bleaching thought to be exacerbated by sea temperature rise as result of global climate change.

Maritime societies and cultures

In this session, the speakers offered various interesting insights and dimensions in the understanding of the marine ecosystem. Instead of the regular scientific analyses of species, taxonomy and biotechnology, the speakers touched on culture and heritage, morals, voice and art. Research discussed here remained largely qualitative and the importance of the human aspect to the marine environment was brought to light.

Fisheries

A total of six oral papers were presented including one invited paper given by Co-Chairperson on marine habitat enhancement using artificial reefs namely Reef-Dome. Artificial reef is one important option given the rapid degradation of coastal habitats lining the SCS. However, it is important to put in more research here to investigate if they are rehabilitating the area or they are just fish aggregating devices. One paper evaluating and forecasting the east coast fisheries scenario has cautioned that the Malaysian side of the SCS may be suffering from serious overfishing, and in particular the possibility of stock collapse of certain small pelagics. Unregulated traditional fisheries may be a cause of concern.

The papers advise against continued government effort to maximize fish landings to increase value, but rather to encourage post-harvest value creation so as to improve food security, income and poverty alleviation. This seems to contradict government effort to increase fisheries production through fish forecasting system, e.g. via satellites, which targets fish stocks and rich fishing ground.

2, the lowest conductivity was recorded in March. For TDS, the content of dissolved solids increased from February to April in Site 1 while in Site 2 there was not much difference in average TDS for the 6 months but high value of TDS was recorded in June 2008 (Fig. 7).

Salinity

The average monthly salinity from February to July 2008 at Site 1 varied from 26.67 to 28.75ppt (Fig. 8). At Site 2, the average monthly salinity ranged from 25.42 to 29.58 ppt. The higher salinity occurred in March for Site 1. At Site 2, the higher salinity occurred from February to April but dropped drastically in May.

Light intensity

At Site 1 which supported a good community of mangrove forest, lower light intensity was recorded. The range of average light intensity was from 21,550 Lux to 45,303 Lux (Table 1). In Site 2, the range of average light intensity was about 24,000 Lux to 88,375 Lux and the higher light intensity was definitely due to direct sunlight.

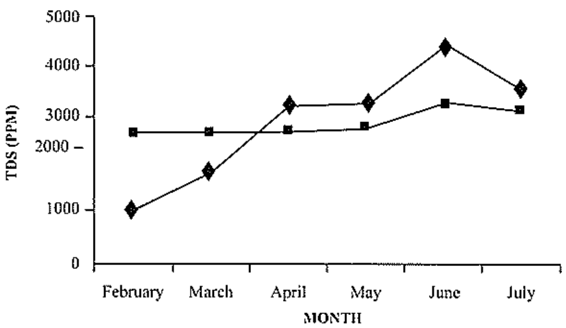

Figure 7. The average monthly TDS for February to July 2008 at Site 1 and Site 2.(------♦-----, **site 1**; -----■-----, **site 2**).

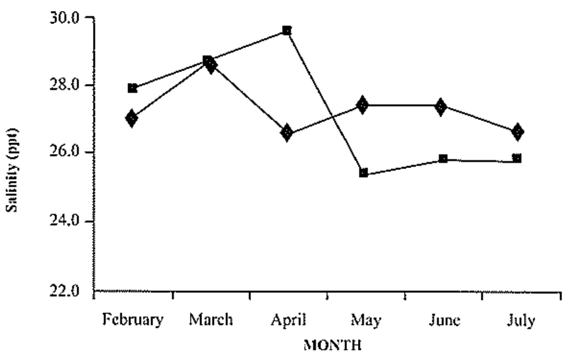

Figure 8. The average monthly salinity for February to July 2008 at Site A and Site B. (------♦-----, **site 1**; -----■-----, **site 2**).

Table 1. Average light intensity of Site 1 and Site 2 for 6 months (February-July 2008).

Month	Light intensity (x 100 Lux)	
	Site 1	Site 2
February	326.83 ± 327	298 ± 73.85
March	215.5 ± 298.63	883.75 ± 828.66
April	222.08 ± 208.08	240 ± 47.47
May	310.46 ±221.49	999.5 ± 127.33
Jun	453.33 ± 294.85	861.5 ± 125.75
July	364.17 ± 318.47	585 ± 249.52

DISCUSSION

Surface water temperature at Site 1 was higher compared to that at Site 2 and between May to July, the surface water temperature at Site 2 had increased to almost similar levels as those at Site 1. This was probably due to the direct sunlight that reached the surface water without shade from degradation of mangrove trees at site 2. Both sites recorded high and almost constant salinity (25.42-29.58 ppt) but became slightly lower during May to July. The low salinity values recorded in May to July were due to seasonal factors. The lower salinity occurred during the beginning of Southwest Monsoon which starts in May and ends in October. Mangroves grow in areas with surface water salinity ranging from 0 to 40 parts per thousand (ppt) [4].

The pH values recorded during this study were quite neutral to alkaline for Site 1 (7.11-8.05) but slightly acidic (6.44-7.63) for Site 2.These values are still within the accepted limits of the pH range for primary contact recreation and agriculture, which is 6.6 to 8.5 [5].Dissolved oxygen concentration in Site 2 was also lower compared to Site 1. Lack of dissolved oxygen at this site may cause solids from dissolved solids in water to decrease the photosynthetic rate in water. The presence of solids 3 could be attributed to the eroded coastline that occurred at Site 2.The concentration of dissolved oxygen in water depends on temperature, salinity, depth and turbulence [6].

Both sites have high total dissolved solids (TDS). High contents of TDS in Site 1 could be due to wave-energy transport of soil and suspended particles in seawater while in Site 2, it could be due to erosion of the coastline. The range of conductivity value for both sites was high (22.69-77.02 mS) compared to the normal range of conductivity. The normal range of conductivity level in full strength of seawater (35 ppt) has a conductivity of 53 miliSeimens [7].

CONCLUSION

The coastal water of Site 1 featured high and almost constant salinity, high surface temperature, high conductivity, high TDS but relatively low dissolved oxygen concentration. On the other hand, lower surface temperature, lower conductivity and relatively low dissolved oxygen were recorded at Site 2 but the TDS and salinity values were still high.

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REFERENCES

1. Hogarth P.J. (2007) *The Biology of Mangroves and Seagrasses*, Oxford University Press.
2. Spalding M. (1997) *The International Society for Mangrove Ecosystems*. Tresaith, Cardigan.
3. Ahmad-Shah A. (1991) Edaphic factors associated with different mangrove communities in Peninsular Malaysia. In Alcala A.C. (ed.) *Proceeding Regional Symposium on Living Resources in Coastal Areas* pp. 433-440. University of the Philippines, Manila.
4. Hutchings P. and Saenger P. (1987) *Ecology of Mangroves*. University of Queensland Press, St.Lucia, Australia.
5. USEPA (1976) *Quality Criteria for Water EPA -44019-76/023*. Office of water planning and standards, Washington.
6. Ong H.C. (2008) *Initial assessment of mangrove habitat along eroding coastline near Sungai. Besar, Selangor*. Master of Technology thesis, University of Malaya, Kuala Lumpur.
7. Smith B.G. (2002) Using oceanography examples to teach chemical principles, A sea of connections. *The Michigan Science Teachers Association* Vol. **47**, no.1.

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Distribution and concentration of organochlorine pesticides in Sungai Merchang, Marang, Terengganu, Peninsular Malaysia

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Abstract Concentration of organochlorine pesticides (OCPs) in the tissues of oyster (*Crassostrea iredalei*) and sediment in Merchang River, Marang were investigated. The distribution of OCPs in the Merchang River involved seven sampling stations. Oyster, a filter feeder and sedentary organisms, was used to test the OCP pollution level in the area. Samples were extracted using soxhlet and analyzed using GC-ECD. OCP compounds were widely distributed in Merchang river environment, with BHC, cyclodiene and DDT group being particularly prevalent. The results showed that OCPs widely existed in the sediment samples compared to the oyster samples. During the first sampling, the concentration of total BHC in sediment samples ranged from 3.67 to 136.78 ng/g, followed by total cyclodiene (6.32 to 42.72 ng/g) and total DDT (5.32 to 35.71 ng/g). The concentration of total BHC in oyster samples varied from 0.0344 to 0.6154 ng/g, followed by total cyclodiene (0.1731 to 83.9308 ng/g) and total DDT (5.519 to 8.6939 ng/g). However, OCPs were detected in oyster only at three stations during the second sampling, with concentration of total BHC from 4.7566 to 31.7238 ng/g, total cyclodiene 26.3713 to 82.8942 ng/g, and total DDT 17.7318 to 80.1095 ng/g. The concentration of total BHC in sediments at different stations varied from 0.0008 to 151.994 ng/g, followed by total cyclodiene (0.17 to 83.93 ng/g) and total DDT (5.52 to 8.69 ng/g). The occurrence of these residual pesticides in the Merchang River could be attributed to the intense agriculture, aquaculture and urban activity around the area.

Keywords organochlorine – sediment – oyster – Merchang Rive

INTRODUCTION

Over the last decades aquatic ecosystems have been contaminated by persistent pollutants of agricultural and industrial origin [1]. Agriculture contributes to a wide range of water quality problems and several kinds of pesticides used over the decades associated with contamination of the water. The impact of food consumption on the agriculture activities had led to the increasing usage of synthetic pesticides such as organochlorine pesticides (OCPs). These pesticides have been used for controlling or destroying any pest on the crops. OCPs are usually divided into three main families which are DDT, BHC and cyclodiene groups such as aldrin, dieldrin, endrin and heptachlor.

OCPs can enter into the aquatic ecosystem in a variety of ways including run-off from non-point sources, discharge of industrial wastewater and wet or dry deposition [2]. Accumulation in biological tissues is due to their lipophilic nature, hydrophobocity and low chemical and biological degradation rates [3]. Therefore, the production and use of these chemicals were banned in the early 1970s in developed countries because of their persistence in the environment, bioaccumulation and adverse effects on wildlife and human [4].

Merchang River is located in the district of Marang, Terengganu, Peninsular Malaysia. Aquaculture activities like oyster cultivation and cage culture are the main economic activities. The present study aims to evaluate the distribution of the organochlorine compounds namely DDTs, BHCs and cyclodiene groups in the oyster and sediments of Merchang River.

MATERIALS AND METHODS

Sampling

The locations of the sampling sites are shown in Figure 1. Seven sampling stations along the

Merchang River (Table 1) were chosen based on strategic points of pollution along the river such as agriculture and aquaculture activities. The samplings were conducted during pre-monsoon and monsoon seasons. Sediment samples were collected by using Van Veen grab and biota samples (oyster) were collected by hand. Locations of the sampling stations were determined by using global positioning system (GPS 315, MAGELLAN). *In-situ* hydrological parameters such as depth, temperature, pH and salinity were recorded by using Hydrolab Datasounde 4a. All the samples were wrapped with aluminium foils and covered with plastic bags and stored at -20°C prior to analysis.

Sample analysis

Organochlorine insecticides such as DDT and its metabolites, hexachlorobenzene isomers (BHCs) and cyclodiene groups were analyzed using the method described by Geochemical and Environmental Research Group [5].

Briefly, sediment samples were freeze-dried and then sieved with 2.5 mm mesh. A subsample of 10 g was Soxhlet extracted with 200 mL dichloromethane and spiked with internal standard (PCB 198, AccuStandard, Inc.) prior to extraction. After the extraction, the solvent extracts were concentrated to about 1 mL by rotary evaporation and blowed down under gentle nitrogen flow. Clean-up procedures and fractionating using copper column and silica/alumina column were carried out. The biota samples were analyzed with the same procedure but the cleaned-up procedures were by using florisil column.

Sample extracts were analyzed using a Hewlett Packard HP-6890 Series II gas chromatograph, equipped with an electron detector capture detector (ECD) and a DB-5 fused silica capillary column (30 m length x 0.200 mm i.d. x 0.25 μm film thickness). The column temperature was programmed at 100°C, held for 1 min, increased to 150°C at the rate of 10°C/min, ramped to 230°C at 7°C/min and the rate of oven temperature held for 10 minutes. The injector and detector temperatures were maintained at 275°C and 325°C, respectively.

RESULTS AND DISCUSSION

Organochlorine distribution

Organochlorine pesticides such as DDT groups, cyclodiene groups and BHC groups were all detected in the sediments and oyster (*Crassostrea iredalei*) samples in the Merchang River. The concentration and distribution of OCs in the sediment and oyster from seven sampling sites are summarized in Tables 2-5. The concentration of the OCs in the sediment ranged from 0.03 to 94.19 ng/g dry weight for pre-monsoon season and 0.002 to 139.78 ng/g dry weight in monsoon season.

The residual levels of OCs in oyster were dominated by cyclodiene groups, followed by BHCs groups and lastly DDTs groups for both sampling times. The ranges of these OCs were 0.0126 to 40.2566 ng/g dry weight for the pre-monsoon and

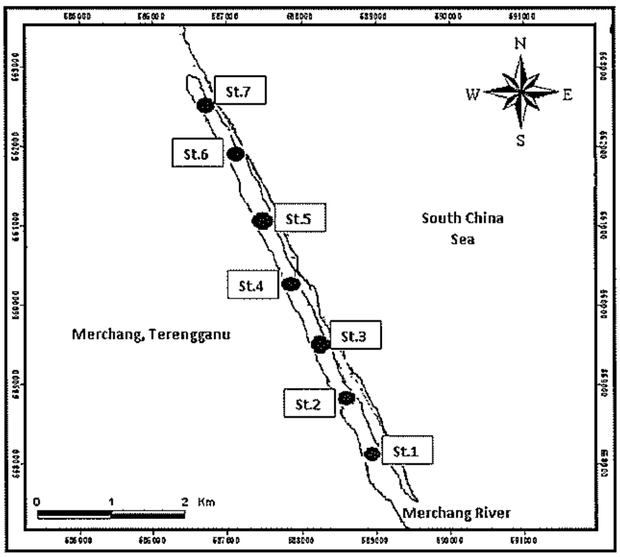

Figure 1. Sampling site at Merchang River with sampling location.

Table 1. Locations for the samples collection.

Station	Latitude	Longitude
1	05°02.703 N	103°17.538 E
2	05°03.623 N	103°17.088 E
3	05°03.521 N	103°17.196 E
4	05°04.179 N	103°16.843 E
5	05°04.743 N	103°16.501 E
6	05°05.150 N	103°16.348 E
7	05°05. 861N	103°15.969 E

0.5087 to 56.7046 ng/g dry weight for the monsoon season. Cyclodiene groups and DDTs groups were highly detected in St. 1 during the pre-monsoon season. However, all compounds were detected in all stations during the monsoon season with high levels in St. 2.

BHC (hexachlorobenzene) group

BHC concentrations (sum of α-, β-, γ- and δ- isomers) in the sediments for both sampling seasons ranged from 0.03 to 94.19 ng/g dry weight and 0.002 to 139.78ng/g dry weight, respectively (Tables 2, 3). In general β-BHC and α-BHC were highly present compared to γ-BHC (lindane) and δ-BHC during pre-monsoon season (Table 2). Lindane was highly present in St. 6 with the highest value 44.77 ng/gdry weight (Table 2). BHCs were mostly abundant in St. 6 and St.7 but low concentrations were found in

Table 2. Total OCPs in sediment samples of Merchang River during pre-monsoon (ng/g dry weights).

Compound	St 1	St 2	St 3	St 4	St 5	St 6	St 7	ΣOCPs
α- BHC	38.86	1.48	43.36	0.83	nd	4.23	20.69	109.45
β- BHC	94.19	0.91	60.52	0.4	0.66	2.78	1.2	160.66
γ- BHC	3.7	3.92	nd	2.14	0.98	44.77	nd	55.51
δ- BHC	0.03	3.74	0.68	6.78	2.03	nd	2.85	16.11
Aldrin	1.22	5.84	3.72	7.09	nd	23.44	33.57	74.88
Dieldrin	0.42	0.15	4.07	2.22	nd	nd	4.18	11.04
Endrin	2.33	1.54	1.27	0.82	2.62	0.62	nd	9.2
α- Endosulfan	0.2	2.24	0.84	0.16	nd	3.25	1.81	8.5
β- Endosulfan	0.73	2.26	1.04	1.25	1.8	nd	0.14	7.22
Endrin aldehyde	0.27	2.07	2.77	5.58	2.36	2.63	nd	15.68
Endosulfan sulfate	0.33	0.16	2.39	0.19	nd	3.8	3.02	9.89
Heptachlor	0.27	2.04	2.56	0.94	nd	3.78	nd	9.59
Heptachlor epoxide	0.55	0.74	0.08	0.43	nd	nd	nd	1.8
4, 4 - DDD	3.02	20.49	7.79	8.52	10.74	22.54	nd	73.1
4, 4 - DDE	0.64	2.02	2.29	2.45	7.03	7.48	1.85	23.76
4, 4 - DDT	1.66	0.19	4.64	2.2	2.44	5.69	5.06	21.88
ΣOCPs	148.42	49.79	138.02	42	30.66	125.01	74.37	

Table 3. Total OCPs in sediment samples of Merchang River in monsoon season (ng/g dry weights).

Compound	St 1	St 2	St 3	St 4	St 5	St 6	St 7	ΣOCPs
α- BHC	0.7	nd	0.01	1.97	0.53	7.34	9.24	19.79
β- BHC	1.17	nd	0.01	2.19	0.71	3.39	16.04	23.51
γ- BHC	0.91	nd	0.01	0.32	1.33	1.47	1.81	5.85
δ- BHC	2.68	0.0008	0.002	4.54	1.45	139.78	nd	148.4528
Aldrin	nd	0.96	nd	nd	nd	nd	22.01	22.97
Dieldrin	nd	0.0005	0.005	nd	2.49	14.09	53.96	70.5455
Endrin	3.29	5.01	nd	nd	0.79	1.09	0.69	10.87
α- Endosulfan	nd	0.21	0.007	nd	nd	nd	63.01	63.227
β- Endosulfan	0.78	0.003	0.002	1.23	3.41	0.78	2.29	8.495
Endrin aldehyde	nd	nd	nd	2.45	4.41	nd	nd	6.86
Endosulfan sulfate	nd	0.017	0.006	nd	nd	2.38	nd	2.403
Heptachlor	7.3	nd	0.089	2.32	1.26	2.07	27.26	40.299
Heptachlor epoxide	nd	0.09	nd	4.54	nd	nd	11.62	16.25
4, 4 - DDD	5.19	nd	nd	5.87	2.96	nd	3.97	17.99
4, 4 - DDE	5.03	0.0132	0.013	5.69	1.25	nd	nd	11.9962
4, 4 - DDT	nd	24.5241	nd	nd	23.47	21.02	13.99	83.0041
ΣOCPs	27.05	30.8286	0.154	31.12	44.06	193.41	225.89	

other stations (Table 3). Furthermore, St. 7 showed the highest concentration of β-BHC while δ-BHC was highly detected in St. 6 (139.78 ng/g dry weight). Low concentrations of BHCs were detected in St. 3 during the monsoon season.

The BHCs concentrations in the oyster samples for both seasons (Tables 4, 5) ranged from 0.0438 to 1.3961 ng/gdry weight and 0.7007 to 14.4077 ng/g dry weight, respectively. Oyster samples were not available in St. 7 during the pre-monsoon season and St. 4 to St. 7 in the monsoon season. δ-BHC was the highest detected in St. 1 which was 1.3961 ng/g dry weight during the pre-monsoon season. However only one compound was detected in St. 3 and St. 6 which were δ-BHC and β-BHC (Table 4). The concentrations of BHCs were greater in St. 2 and St. 3 during the monsoon season. β-BHC was the dominant compound in St. 3 while α- BHC was dominant in St. 2 but not detected in St. 1 (Table 5).

The levels of all the detected BHCs in the

Table 4. Total OCPs in oyster samples of Merchang River during pre-monsoon (ng/g dry weights).

Compound	St 1	St 2	St 3	St 4	St 5	St 6	St 7	ΣOCPs
α- BHC	0.6388	nd	nd	nd	0.3802	nd	n.a	1.019
β- BHC	1.0188	nd	nd	nd	0.1197	0.0572	n.a	1.1957
γ- BHC	0.2573	nd	nd	nd	0.0717	nd	n.a	0.329
δ- BHC	1.3961	nd	0.0344	nd	0.0438	nd	n.a	1.4743
Aldrin	8.8916	nd	nd	0.266	0.0848	0.0629	n.a	9.3053
Dieldrin	16.4509	nd	nd	0.0308	0.1184	0.0181	n.a	16.6182
Endrin	40.2566	0.0481	nd	0.0659	0.6043	0.0126	n.a	40.9875
α- Endosulfan	1.2954	nd	nd	nd	1.2954	0.028	n.a	2.6188
β- Endosulfan	3.4421	nd	nd	nd	0.1408	nd	n.a	3.5829
Endrin aldehyde	4.0322	10.8117	nd	nd	nd	nd	n.a	14.8439
Endosulfan sulfate	nd	0.2248	0.1731	nd	nd	0.5622	n.a	0.9601
Heptachlor	0.9983	nd	nd	nd	0.1101	0.0232	n.a	1.1316
Heptachlor epoxide	8.5637	nd	nd	nd	0.8442	nd	n.a	9.4079
4, 4 - DDD	4.8587	nd	nd	nd	nd	nd	n.a	4.8587
4, 4 - DDE	0.6603	nd	nd	nd	0.2872	nd	n.a	0.9475
4, 4 - DDT	nd	nd	nd	8.6939	6.3589	8.0922	n.a	23.145
ΣOCPs	92.7608	11.0846	0.2075	9.0566	10.4595	8.8564	-	

Table 5. Total OCPs in oyster samples of Merchang River in monsoon season (ng/g dry weights).

Compound	St 1	St 2	St 3	St 4	St 5	St 6	St 7	ΣOCPs
α- BHC	nd	11.9032	3.4614	n.a	n.a	n.a	n.a	15.3646
β- BHC	0.7007	2.1914	14.4077	n.a	n.a	n.a	n.a	17.2998
γ- BHC	3.0444	9.0478	4.3206	n.a	n.a	n.a	n.a	16.4128
δ- BHC	1.0115	8.5814	1.3929	n.a	n.a	n.a	n.a	10.9858
Aldrin	nd	55.994	12.1014	n.a	n.a	n.a	n.a	68.0954
Dieldrin	nd	12.7775	nd	n.a	n.a	n.a	n.a	12.7775
Endrin	nd	3.006	nd	n.a	n.a	n.a	n.a	3.006
α- Endosulfan	1.7939	4.5962	2.3411	n.a	n.a	n.a	n.a	8.7312
β- Endosulfan	1.7493	nd	nd	n.a	n.a	n.a	n.a	1.7493
Endrin aldehyde	22.1377	nd	9.2201	n.a	n.a	n.a	n.a	31.3578
Endosulfan sulfate	nd	3.7358	2.7087	n.a	n.a	n.a	n.a	6.4445
Heptachlor	0.5087	nd	nd	n.a	n.a	n.a	n.a	0.5087
Heptachlor epoxide	56.7046	nd	nd	n.a	n.a	n.a	n.a	56.7046
4, 4 - DDD	6.6002	nd	11.6049	n.a	n.a	n.a	n.a	18.2051
4, 4 - DDE	9.0796	55.6562	14.0651	n.a	n.a	n.a	n.a	78.8009
4, 4 - DDT	2.052	6.9245	2.8194	n.a	n.a	n.a	n.a	11.7959
ΣOCPs	105.3826	174.414	78.4433	-	-	-	-	

Merchang River were above the USEPA maximum contaminants level (MCL) which was 1 ng/L in drinking water [8]. γ-BHC levels in this study was also above the USEPA MCL value (0.2 ng/L). It indicated that this river was contaminated with this compound. BHCs concentrations in the monsoon season were lower than pre-monsoon season due to precipitation and run-off from rainfall. However, δ-BHC was highly detected during the monsoon season because it could exist in the environment for several years because of its stability and resistance to microbial degradation [2].

Cyclodiene group

The most commonly detected cyclodiene group in the sediment samples, at high concentrations were aldrin during pre-monsoon and dieldrin during monsoon season. The ranges of cyclodiene group in the sediment were 0.08 to 33.57 ng/g dry weight and 0.002 to 63.01 ng/g dry weight, respectively. It is surprising to note that at St. 6 and St.7 which were located in the upstream of the river where there were no agricultural activities, various compounds were detected during the monsoon season. The highest concentration of aldrin was 33.57 ng/g dry weight (St.7) and the lowest concentration was heptachlor epoxide which was 0.08 ng/g dry weight (St. 3) during pre-monsoon (Table 2). However α-endosulfan was highly present in St. 7 (63.01 ng/g dry weight) followed by dieldrin (53.96 ng/g dry weight) and heptachlor (27.26 ng/g dry weights) (Table 3).

Overall, the concentration of cyclodiene group in oyster samples was highly detected in down stream area compared with sediments level. The range of cyclodiene group for both sampling seasons were 0.0126 to 40.2566 ng/gdry weight and 0.7007 to 14.4077 ng/g dry weight, respectively. All the compounds were detected in St.1 except endosulfan sulfate during pre-monsoon (Table 4). The highest concentration was endrin (40.2566 ng/g dry weight) followed by dieldrin (14.4509 ng/g dry weight) and aldrin (8.8916 ng/g dry weight) (Table 4). Endrin aldehyde was highly detected in St. 2 (10.8117 ng/g dry weight) during pre-monsoon. High concentration of heptachlor epoxide was found in St.1 (56.7046ng/g dry weight) followed by aldrin and endrin aldehyde, respectively (Table 5). However, β-endosulfan was only detected in St. 1 (Table 5).

According to USEPA maximum contaminants level (MCL), the endrin, heptachlor and heptachlor epoxide values should be less than 2 ng/L, 0.4 ng/L and 0.2 ng/L, respectively in drinking water [8]. Concentrations of endrin, heptachlor and its epoxide in sediments were generally higher than MCL value for drinking water. High concentration of dieldrin present during the monsoon season may be due to run-off and erosion from agricultural sites. Erosion can be an important transport of pesticides residues from the sites [3] and these residues were brought to the river basin and then sank to the sediment. Besides that, dieldrin and endosulfan were used in agriculture in order to control pests in vegetable, tea and cotton plantations while heptachlor was used as seed and soil treatment against soil insects.

DDT group

DDTs were found to range from 0.19 to 22.54ng/g dry weight and 0.0132 to 24.5241 ng/g dry weight (Table 2) for sediment samples. 4, 4' DDD was the most abundant followed by 4, 4' DDE and 4, 4' DDT, respectively (Table 2). 4, 4' DDD was highly detected in agricultural and aquaculture sites (St. 2 to St. 6) during pre-monsoon. The highest concentration of 4, 4' DDD was found in St.6 (22.54 ng/g dry weight) near the cage culture area and the lowest was 4, 4' DDT (0.19 ng/g dry weight) (Table 2). However, 4, 4' DDT was the dominant compound during the monsoon season and low concentration was found for other residues (Table 3).

The 4, 4' DDT residues were the most abundant residues in oyster as it was detected in St.4 to St.6 at relatively higher concentration compared to other residues (Table 4). The DDTs ranges for both sampling seasons were 0.2872 to 8.6939 ng/g dry weight and 2.052 to 55.6562 ng/g dry weight, respectively. 4, 4' DDD was only present in St. 1 (4.8587 ng/g dry weight) during pre-monsoon (Table 4). In contrast, 4, 4' DDE was the most prevalent during monsoon season (Table 5) compared to the other residues. The highest concentration of 4, 4' DDE was found in St. 2 (55.6562 ng/g dry weight) followed by 4, 4' DDD (11.6049 ng/g dry weight) and 4, 4' DDT (6.9245 ng/g dry weight) (Table 5).

The DDTs values were comparable with USEPA guideline and was lower than the critical value for DDT (1000 ng/L) levels in drinking water [8]. It indicated that Merchang River was not contaminated with DDTs and the river water is safe for drinking usage. High concentration of DDT found in the sediment and oyster samples was due to agricultural applications and it clearly indicated that it has continuous input of DDTs in Merchang River. Low concentration of 4, 4' DDE was due to slow degradables of DDTs in the environment [6] because DDT is a persistent pesticide that can remain in the soil for up to 30 years with half-life of 15 years [7].

CONCLUSION

This study determined the OCPs concentration in sediment and oyster samples from Merchang River during pre-monsoon and monsoon seasons. Sixteen compounds were detected – α- BHC, β-BHC, γ-BHC, δ-BHC, aldrin, dieldrin, endrin, α-endosulfan, β-endosulfan, endrin aldehyde, endosulfan sulfate, heptachlor, heptachlor epoxide, 4,4'DDD, 4,4'DDE and 4,4'-DDT. Cyclodiene group (aldrin, dieldrin, endrin, α-endosulfan, β-endosulfan, endrin aldehyde, endosulfan sulfate, heptachlor and heptachlor epoxide) was the main contaminant in Merchang river for both the sampling seasons. It indicated that this river was highly polluted with these compounds. Generally, St. 1 to St. 3 (agricultural sites) were more contaminated compared to the other stations. It suggests that there has been recent input of pesticides whether in agricultural or aquaculture application into this river. The concentration of OCPs during monsoon season were lower than pre-monsoon season due to precipitation and dilution of rainfall. In conclusion, sediments and oyster can be useful indicator for assessing and understanding these pollutants.

REFERENCES

1. Best G. and Ruthen D. (1995) *Pesticides Developments, Impact and Controls*. The Royal Society of Chemistry.
2. Zhou R., Zhu L., Chen Y. and Kong Q. (2008) Concentration and characteristic of organochlorine pesticides in aquatic biota from Qiantang River in China. *Environmental Pollution* **151**: 190-199.
3. Mwevura H., Othman O.C. and Mhehe G.L. (2002) Organochlorine pesticides residues in sediments and biota from the coastal area of Dar es Salaam city, Tanzania. *Marine Pollution Buletin* **45**: 262-267.
4. Yang N., Matsuda M., Kawano M. and Wakimoto T. (2005) PCBs and organochlorine pesticides (OCPs) in edible fish and shellfish from China. *Chemosphere* **63**: 1342-1352.
5. Wade T.L., Brooks J.M., Kennicult II M.A., McDonald T.J., Sericano J.L. and Jackson T.J. (1986) *Trace OrganicsContaminant Analytical Techniques*. GERG Trace Organics Contaminant Analytical Techniques. Geochemical and Environmental Research Group. Texas A & M University, College Station, TX.
6. Kurt P.B. and Ozkoc H.B. (2004) A survey to determine levels of chlorinated pesticides and PCBs in mussels and sea water from Mid Black Sea Coast of Turkey. *MarinePollution Bulletin* **48**: 1076-1083.
7. Sapozhnikova Y., Bawardi O. and Schlenk D. (2003) Pesticides and PCBs in sediments and fish from the Salton Sea, California, USA. *Chemosphere* **55**: 797-809.
8. USEPA, US Environmental Protection Agency (1997) *National Sediment Quality Survey*. App. D. Washington DC, USA.

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Biodiversity and ecological conservation of mangroves in Indonesian South China Sea Areas: a botanical exploration of mangrove ecosystems

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Abstract A recent botanical exploration to collect specimens of Indonesian mangroves has revealed new records of true and associated mangrove species. With an estimated area of about 9.7 million ha (3.9 million ha belonging to State Forest Area and 5.8 million ha as Non-state Forest Area), Indonesia's mangroves are the largest in the world. On the basis of occurrence of true mangrove species, it is also the world's most biodiverse. Of the 9.7 million ha, more than 50% are considered to be degraded mangrove forest (partially and heavily damaged). Consequently, invading non-mangrove species are present in the mangrove ecosystem and/or mangrove forests. New records of the non-mangrove species and/or associated mangrove species can be found in different sites in Indonesia. A brief synopsis of major mangrove plant communities and their correlation with various anthropogenic disturbances are provided. A checklist of 204 angiosperm plants and ferns are given. These species regularly occur in Indonesia's mangroves under different levels of disturbance (good, partially and heavily damaged) found in the 13 provinces in the SCS area. If considerations are given to the associated mangrove species that occur in the peripheral sites in the landward areas, 295 angiosperm plants are reported to be found in Indonesia's mangroves, of which 91 species are considered true mangrove species. Indonesia with 17,504 islands is interesting scientifically as the epicentre for mangrove species diversity in the world. Botanical explorations to evaluate its mangrove plant diversity are recommended for global research collaboration.

Keywords biodiversity – conservation – botanical exploration

INTRODUCTION

Indonesia (6° 08 N Lat. to 11° 13'S Lat., and 94° 45' to 141° 05° E. Long), a group of 17,504 islands scattered overa large body of water, is an archipelago of which about 12,000 are inhabited. Indonesia is one of the 17 biologically richest countries in the world [1]. More than half of the biodiversity in Indonesia is found nowhere else on earth. Botanically, Indonesia is a part of the plant unit known as Malesia (comprising Indonesia, Singapore, Malaysia, Philippines, Brunei Darussalam and PNG) [2], and is interesting for their plant geographical divisions, e.g. the origin of geographical centre for mangrove genera and species distribution [3-7]. There are many more species that remain unknown to science.

Indonesia stretches over 5,700 km from the Indian Ocean to the Pacific Ocean. Seventy percent of the total territory of Indonesia is covered by seas, 30% island, and the transition between them is a small to wide flat strip coastal zone. Indonesian coastlines are estimated to be about 96,181 km in length which compose a variety of habitats for many marine ecosystems. Indonesia's marine biodiversity is equally exceptional [8]. The natural vegetation fringing the coastline of Indonesia is mangrove forests, and is dominated in Indonesian South China Sea region (ISCS).

Administratively, mangrove forests consist of State Forest Area (SFA) and Non-State Forest Area (NSFA). SFAs are managed by the Ministry of Forestry (MOF), Government of Indonesia (GOI), and classified according to their function, namely as: *Protected Forest* for the preservation of pristine forest for catchments management, biodiversity and scientific studies; *Production Forest* for the conservation, responsible development (conversion) and management of remaining mangrove areas; and *Nature Reserve* (NR: nature reserve, WS: wildlife sanctuary, HP: hunting park, NP: national park, NRP: nature recreation park, GFP: grand forest park) for research, heritage, ecotourism, wilderness, scenic and beauty. NSFAs are partially managed by Local Government, *adat* rights and/or *hak ulayat* (customary laws), e.g. *hutan adat* (customary forest).

ISCS consists of 13 provinces (or west Malesia) (Table 1) with a total land area of about 759,364 km^2, and more than a thousand small islands, e.g. 3,214 islands are found only in Riau. The small islands of ISCS are less explored botanically, e.g. Bangka-Belitung [9, 10], Pari Island-Jakarta [11], Lampung Bay [12], Mapor Island [13], and Natuna and Anambas islands – Riau Islands Province (RIP) [14, 15]. Over the last 10 years, ISCS coastal ecosystem has been subjected to over-increasing human population and economic pressure, e.g. Batam Island-RIP [16, 17]. In addition, with increasing pressure for land in most ISCS provinces, coastal mangroves are being irreversibly excised and alienated for other land uses such as business area, housing, harbors, settlement, agriculture and aquaculture [18].

The State Ministry of Environment (SMOE) developed a National Biodiversity Strategy in the early 1990s. Also, within the framework of the International Convention on the Conservation of Biological Diversity (agreed during the Earth Summit in Rio de Janeiro, Brazil in 1992), a conference of parties was held on 6-17 November 1995 in Jakarta, Indonesia on the topic of coastal and marine biodiversity. ISCS mangrove forests have become important and support a rich biological community, including a number of endemic and endangered species, e.g. migratory birds (*Limnodromus semipalmatus*) along the east coast of Sumatra [19, 20].

Floristically, ISCS mangroves are interesting for their new record and rediscovery [21, 22], and to updated biogeographic sites as mangrove biodiversity hotspot. ISCS is facing tremendous biodiversity loss [8]. The fundamental cause of mangrove forest loss is the increase in human population living near the coastal zone. Approximately 65% or more of ISCS population, estimated to total at least 145 million by the year 2000 [23], live adjacent or very close to the coastal zone, thereby increasing the complexities for resource management and the likelihood of coastal degradation [24]. Moreover, Indonesia has high expectations of rewards from sustainable integrated coastal zone management (e.g. PEMSEA) for this rapidly developing nation where population in 2020 may exceed 265 million, i.e., population growth rate of 14.91% per year in 1997-1999 [25] and 13.60% in 2002 [23] at Batam Island-RIP.

The impact of human activities in ISCS mangrove forests is variable depending on the site and in terms of their physical forest quality and biological quality. The reduction in mangrove species richness, tree size and tree density therefore, is typical of this activity. Also, human activity can expand the natural range of mangroves by expanding the degree of salinity intrusion in the coastline, e.g., Muara Angke, Jakarta [26]. I consider that burgeoning populations (density of 11.75-12,673/km^2 in 2000) and considerable economic growth are possibly the biggest cause of mangrove destruction and degradation in ISCS, e.g., Lampung [27, 28]. Today, ISCS mangroves are a socio-political trove in Indonesia. This paper presents the result of mangroves surveys and/or botanical exploration and ecological conservation status in the ISCS under the above circumstances.

Table 1. Areas visited for botanical exploration and sample plots for mangrove vegetation analysis in the ISCS region.

Province	Botanical Sites	Number of Plot Size	Remarks
1. Kepulauan Riau	Batam, Bintan and Natuna districts	10 plots of 0.25 ha	2000-2002
2. Riau	Bengkalis district	20 m x 1000 m	2000
3. Jambi	BerbakNational Park (NP)	20 m x 2000 m	2000-2001
4. South Sumatra	Sembilang NP	20 m x 2500 m	2000-2003
5. Bangka Belitung	Belitung, Klabat Bay-Bangka	15 plots of 0.25 ha	2003
6. Lampung	Way Kambas NP, LampunBay	20 m x 750 m	2002
7. Banten	Uiung Kulon NP, northern coast, DuaIsland	25 plots of 0.25 ha	2001
8. DKI Jakarta	Kep. Seribu NP, Rambut and Muara Angke	30 plots of 0.10 ha	2001
9. West Java	Northern coast and BiawakIsland	45 plots of 0.25 ha	2001
10. Central Java	Northern coast, Segara Anakan, Karimun Jawa NP	20 plots of 0.25 ha	2001
11. East Java	Northern coast, Alas Purwo, Meribetiri, Baluran NPs	35 plots of 0.25 ha	2000
12. West Kalimantan	Gn. Palung NP, Batu Ampar district	20 m x 1000 m	2004
13. Central Kalimantan	Tanjung Puting NP	20 m x 1000 m	2003

A paper highlights the importance of featureless near shore waters along the entire coast of Pahang, which apparently function as important feeding/nursery areas even without the obvious benefit of coastal biotopes such as mangroves and coral reefs. This finding indicates that more research is required to investigate such coastal areas in the SCS. Although not of direct fishery importance, the deep waters of Philippines in the SCS reveal spectacular biodiversity of deepwater crab and mollusk species, including some that were unknown to science before.

In summary, this session on fisheries show that the SCS is indeed an area of high biodiversity, in both shallow and deep waters, and that the biodiversity supports the potentially rich fisheries resources that are so valuable to the coastal communities. However, it seems more crucial now that the fast dwindling fisheries resources require a management system that also considers the ecosystem.

Safety of navigation, maritime security and marine pollution co-operation in the South China Sea

A speaker addressed the importance of China's perspective on developing the economic aspects of the South China Sea and looked to national laws for the governance of the various legal issues involved in the South China Sea. China's emphasis is on wealth creation from the seas. A delegate spoke on the overall claims of states in the region and the efforts that Vietnam is making in building regional peace initiatives. A paper addressed the importance of regulating marine scientific research and suggested that such a centre may be set up for the South China Sea.

The current laws offered protection for the fisheries regime in Malaysia, whilst suggestion on the way forward, given the international law obligations and pressures that Malaysia as part of the region faces, in this context. The session was lively and more work needs to be done with regards to marine scientific research and harmonization of laws and policies for various issues in the South China Sea as a regional or semi-enclosed sea were recommended. According to the keynote speaker, Dr Kenneth Sherman, legal work on the South China Sea as a scientific LME would start soon.

Education, awareness and community development in coastal ecosystems

In this session, various illustrations of environmental education at work were presented. Most papers emphasized the importance of involving the local community in environmental conservation. Environmental education helped to increase community awareness about the environment around them and encouraged them to protect it.

The session was a discourse on current approaches in coastal protection in general and the application of eco-engineering technologies for coastal works in particular. Several presenters elaborated on the fundamentals of coastal processes as well as the specifics of conventional engineering and eco-engineering in coastal protection and coastal rehabilitation. Various aspects were discussed on the needs to appropriately analyze, design, build, and monitor coastal works.

Eco-engineering technologies for coastal protection

Eco-engineering, the use of living or dead plant materials in combination with conventional construction materials like cement or steel for engineering works had also been discussed. The use of recent technologies e.g. geo-tubes and Modified L-Block Breakwater, for coastal protection had also been elaborated upon. The Modified L-Block Breakwater, a product developed at the University of Malaya, had been successfully incorporated in a mangroves rehabilitation project to help dissipate wave energies and stabilize coastal habitats. Geo-structures such as brush faschines and bamboo piles had also been incorporated as wave breakers and sediment traps.

MATERIALS AND METHODS

Botanical exploration in the 13 provinces which interact with the South China Sea has been conducted to determine species growth performances in the mangrove forest and/or mangrove ecosystems. Species are categorized into true and associated mangrove species based on the voucher specimens following the Tomlinson's classification [29]. All specimens were deposited at the Laboratory of Marine Botany at the Center for Oceanological Research and Development, Indonesian Institute of Sciences, Jakarta. The identification of specimens and taxonomical nomenclature follows Becking *et al.* [29-37]. Cross reference was conducted at the Herbarium Bogoriense, Bogor. It is noted that not all areas of the 13 provinces have been explored in detail due to time and budget limitations. Areas visited for surveys and/or botanized at ISCS are presented in Table 1. However, three botanical sites have been chosen for the representation of each province; at the three sites, vegetation analysis was conducted using the transect method for structural characteristics, e.g. importance values of species [38] and plant diversity. Secondary information has been obtained from all available reports and/or publications concerned with mangroves from the 13 provinces.

RESULTS

State of the art of ISCS mangroves

ISCS mangrove wetlands include forests, waterways, mudflat, and saltpans that play significant roles in the economic growth and as coastal barrier for the land-ward side. ISCS mangrove forests have provided vital protection and livelihood support to community in the region since ancient time. The largest and most extensive of ISCS mangrove forest, with the largest sizes of commercial trees (*Rhizophora* and *Bruguiera*), was found in Sumatra and Kalimantan, e.g., Riau [39], South Sumatra [40] and West Kalimantan [41]. Man uses ISCS mangrove forest areas for the establishment of brackish water ponds (tambak) for culture of fish and prawn, e.g., Lampung [42], Java [43, 44] and for forestry purposes for example in Riau [45]. Tambak fish farming in Indonesia is a centuries-old technique [24].

Mangrove exploitation for timber, construction materials, tannin bark extraction, charcoal and firewood are common in ISCS since the colonial era, e.g., Riau Lingga archipelago [46-48]. Consequently, ISCS mangrove forests (e.g. Sumatra and some inKalimantan) have been subjected to over-cutting for a long period of years and became degraded. The common management practices, therefore, correspond to the most favorable girth only. For the mangrove forests in Riau-Lingga archipelago, 15 years of rotation yielding trees on the 10.6 cm in girth average [47], and their annual yield per ha can be estimated being well over 5m^3 [48].

Sustainable production of mangrove logs and chips for the mangrove forests in Tembilahan, Riau under exploitation licenses of PT. Bina Lestari was 873,575 m^3 of logs from 11,310 ha mangrove forests logged between1978-1994 and potentially 1,498,518 m^3 of logs from 12,250 ha [39]. Logs production during the period 1994-1998 (PELITA VI) in Riau province was 769,036 m^3 from concession of the mangrove forests of 7,980 ha [49]. Today, 229,150 ha of mangrove forests are under the concession area for four forestry companies [49]. In 2000-2005, the mangrove forests in Bengkalis district produced log of 14.54 m^3/ha and 2.96 m^3/ha for commercial and non-commercial species, respectively. Also, the TEV of mangrove ecosystems are estimated to be Rp 11,055,324,117/ha/year (NPV 10% in 2004) [50].

ISCS mangrove forests have also been subjected to conversion. Conversion of ISCS mangrove areas for tambak (e.g. Lampung, Java: Banten, Jakarta, West, Central and East Java), housing and settlement (e.g. Banten, Jakarta, Jambi, South Sumatra, Way Sekampung Lampung), agriculture (e.g. Riau, Jambi), industrial facilities (e.g. Kepulauan Riau: Batam island, Jakarta) and other infrastructure for human being (e.g. Tanjung Api-Api, South Sumatra) are rapidly increasing and according to the national and/or provincial economic developments are considered as threats.

The common phenomena of conversions and exploitations at ISCS are those with mangrove forests which resulted in degradation or deforestation (e.g. Central Java: 2,848.03 ha mangroves are degraded), erosion/abrasion (e.g. northern coast of Central Java: 4,755.08 ha are eroded), changes of coastline (703.06 ha of coastal lands are lost) [54], pollution (e.g. Jakarta, Banten) and lost of mangrove forest (e.g. during 2001-2007 in Batam island-RIP 8,448.35 ha mangrove forest are lost) [17].

The degraded mangrove forests and/or overlogged, eroded coastline areas, abandoned tambak areas at ISCS are being rehabilitated [27, 39]. The principles underlying these planting developments are already being put into practice in a man-made mangrove forest since 1990 in Bengkalis Island, Riau (in 1995: 64 ha) by Mr. Sakdullah (who in 1995 received Kalpataru Environmental Award from GOI), in Curah Sawo, Probolinggo East Java (in 1982: 60.5 ha) by local people in conjunction with the Army and State Forestry Corporation. Planting activities follow biophysical criteria, e.g., suitable species (*Choice procedure*: undesirable – acceptable – preferable – desirable species), sites and seasons, to avoid high mortality rates [cf. 51]. Planting activities require the full cooperation of local communities with sufficient motivation and incentives to participate. Priority isgiven to the preservation of critical mangrove areas (e.g. Berbak NP, Jambi) including coastal and estuarine strips (e.g. beachfront, riverfront) for shoreline protection, and in sensitive coastal areas where mangrove would be difficult to replant due to existing wave action or thin soil. Fire effects may also favor the perpetuation of the mangrove species – *Avicennia*, *Excoecaria agallocha*, *Lumnitzera* which are capable of re-growing in coppiced form from the root base.

Recently, GOI has initiated a national rehabilitation program with the participation of local communities called GNRHL (National Movement for the Land and Forests Rehabilitation; MOF Decree No.20/Kpts-II/2001: General design, Standard and Criteria for GNRHL) and lead by the MOF. ISCS mangrove areas are being included in the GNRHL. The GNRHL activity is intended both to improve the quality of life of people living in mangrove environment and to rehabilitate a mangrove forest ecosystem and its original biodiversity [52, 53]. The basic concepts include a task of income generating activity, employment opportunity, strengthening capacity building (both central and local governments), empowering local community (LCOs, NGOs, WID-Women in Development, FWM-Family Welfare Movement), cultural institution development (e.g. Lembaga Adat, Extension and Community Organizing, Village Deliberation Council, Village Self-reliance Organization), and market-oriented development (e.g. private sectors). Due to the national development commitment (e.g. PROPENAS) and public awareness, GOI legalized the GNRHL to rehabilitate 900,000 ha up to the year 2009, and 94,077 ha degraded mangroves in SFA have been approved for rehabilitation during 2005/07 (Government Regulation No.89/2007). The implementation by MOF in 2005/06 was 17,400 ha including Lampung (7.880 ha) [27].

The GNRHL program is expanded into the NSFA for a different objective. The main objectives for both SFA and NSFA are for improving the ecological role (e.g. fisheries, biodiversity) and the function of mangrove ecosystem (e.g. coastal protection: tsunami, typhoon, erosion; timber/charcoal; multi-objectives) with special reference for income-generating activities of the local people as the lower level of the stakeholders – e.g. in Central Java: 3,825 ha mangrove rehabilitation includes Japara Fish Sanctuary [54]. During the period 2002/04, 2,115 ha of degraded mangrove area in NSFA have been rehabilitated with the total budget of Rp 48,885.4 million for the fisheries objectives. Recently, 306,333.22 ha mangrove areas at NSFA in 24 provinces (ISCS: Lampung, Banten, Jakarta, West, Central and East Java) have been set-up for rehabilitation plan by the Annual National Budget (APBN) 2006 of the Ministry of Marine Affair and Fisheries (MOMAF).

Rehabilitation of abandoned tambak and other damaged sites in both SFA and NSFA has been carried out by silvofisheries and naturally by restoring tidal flow to allow entry of propagules and mangrove hydrodynamic [cf. 55] e.g. Margasari village, East coast of Lampung. Silvofisheries alone is not the solution to the problem of co-existence between mangrove and tambak. Silvofisheries or mangrove-friendly aquaculture or tambak tumpang-sari can be useful for sustained forestry and fisheries yields, which integrate the rearing of aquatic organisms and the maintenance of healthy mangrove trees [24, 56]. Mangrove commodities (e.g. trees species, mud crabs) and silvofishery technologies are also being developed and socialized for people who need them (e.g. Batu Ampar West Kalimantan) [41]. Replanting mangroves in abandoned tambak with commercial mangrove tree species has multiple functions ecologically e.g. in Lampung. Weinstock [57] reported that mono-cultural plantings of *Rhizophora mucronata* in blocks along the coast have mitigated erosion and reduced flooding, and protected fish and shrimp ponds located inland. Important areas of research included the development of silvofisheries at the local sites, e.g. West Java. Data from rapid environmental and socio-economic assessments at the ISCS provides a base for identifying priority sites, e.g. Banten, Jakarta, West, Central and East Java.

The management classification is still practiced today with some areas administratively changed their sizes due to development, e.g. 12.87% (6,269 ha) changes in Bengkalis district, Riau for the period 2000-2002 [50], 44.04% (8,448.35 ha) changes in Batam island for the period 2001-2007 [17]. A total of 9.7 million ha (SFA: 3.9 millionha, NSFA: 5.8 million ha) of mangrove areas in Indonesia represent a recent calculation by MOF (Table 2). Not all of the SFA and NSFA in the 13 provinces (ISCS) are surveyed in detail. Also NSFA has been overlooked. There are many remaining areas in ISCS that have not been surveyed yet (e.g. Bangka Belitung, RIP), and therefore not included for the calculation. Many evidences indicated that ISCS mangrove forests are under stress from the existing level of human activities, e.g. Lampung and Java. The present condition of ISCS mangrove forests (SFA: 1,696,588 ha, NSFA: 3,597,051 ha) has always been influenced by the anthropogenic disturbances in the local sites and changeable or event loss (Table 2). For the period of 1982 to 1999 the extent and loss of ISCS mangrove forests are presented in Table 2. The figures in Table 2 are conservative and debatable but accepted to be clarified; and up-to-date maps of their boundaries

Table 2. Mangroves distribution in 126 Kabupaten (District) at 22 provinces along with their damaged category in Indonesia (Source: DitJen RLPS MOF 2003-2007). Note: Partially damaged – Large branches and stumps from nearby dead trees, household herbage, and small solid materials. Heavy damaged – covered with landfill (e.g. housing, settlement, conversion lands), dead trees, abandoned tambak and tambak, canal water drains, pathways, urban debris, and large pieces of flotsam.

Province (Number of district)	Mangroves (ha)						Total Mangroves (ha)	
	Undamaged/good		Partially damaged		Heavy damaged			
	SFA	NSFA	SFA	NSFA	SFA	NSFA	SFA	NSFA
Aceh (6)	-	31,544	2,443	286,205	-	26,693	2,443	344,402
North Sumatra (3)	-	387	26,640	6,876	-	2,007	26,640	9,270
Riau (5)	36,140	27,814	399,154	524,210	11,646	51,315	446,940	621,339
Bengkulu (3)	239	45	10,230	35,521	-	-	10,469	35,566
Jambi (1)	834	2,462	12,449	-	23,371	224,185	36,654	226,647
West Sumatra (5)	486	425	5,576	12,830	-	-	6,062	13,255
South Sumatra (4)	247,951	14,882	305,459	431,743	34,471	12,393	587,881	469,018
Lampung (2)	-	-	6,180	5,763	4,583	1,846	10,763	7,609
West Java (8)	-	77	4,211	57,136	29,243	37,631	33,453	94,844
Central Java (12)	2,907	-	523	30,715	15,503	45,631	18,933	76,407
East Java (11)	-	-	43	40,388	-	57,303	43	97,691
Bali (6)	492	-	3,051	11,183	3,382	7,338	6,925	18,521
NTB (6)	2,994	6,303	729	8,563	36	1,612	3,759	16,478
NTT (11)	836	3,455	23,897	103,473	-	-	24,733	106,928
East Kalimantan (4)	54,335	315,574	53,606	302,556	9,492	25,370	116,433	643,510
Central Kalimantan (3)	31,975	221,136	151,199	621,327	291,828	908,125	475,002	1,750,588
West Kalimantan (3)	-	2,789	54,473	158,151	32,446	91,968	86,919	252,908
South Kalimantan (4)	-	-	73,879	116,751	2,288	15,703	76,006	132,454
North Sulawesi (5)	8,130	3,581	13,718	23,153	-	-	21,848	26,734
Central Sulawesi (4)	1,360	9,299	4,741	101,680	7	232	6,108	111,211
South-East Sulawesi (3)	-	-	28,601	59,887	-	-	28.60	59,887
South Sulawesi (17)	6,868	8,619	39,710	430,573	18,025	4,401	64,603	443,602
Total 22 (126)	395,547	648,352	1,219,512	3,368,694	476,321	1,513,814	2,091,380	5,530,860
% province	64	73	100	95	64	77	100	100
% district	36.50	44.45	61.90	92.85	23.35	60.30	100	100
Maluku + Irian Jaya	-	-	-	-	-	-	1,808,620	269,140
Indonesia	-	-	-	-	-	-	3,900,000	5,800,000

were needed as a planning tool. Recently, based on the country's National Agenda 21 and Law No.27/2007: 'Coastal Zone and Small Islands Management', it is stated that the focus should be on improving efficiency in spatial and land resources planning (e.g. for tambak), developing, and strengthening related regulations and laws (e.g. Law No.24/2007: Catastrophes Mitigation, Law No.26/2007: Spatial Planning), streamlining institutional arrangements, and developing sound data and information systems. Sharing of information and expertise (e.g. JICA, KOICA and IUCN) will greatly enhance the success of botanical exploration of each province for integrated coastal zone management post tsunami of 26 December 2004.

Conservation ecology of ISCS mangrove in protected areas

A humid tropical climate with more than 1500 mm rainfall annually is quite favorable for the growth of mangrove forest in the ISCS coastal plain. Ground water properties such as salinity and nutrient content are strongly influenced by rainfall. Consequently, ISCS coastal area has diversed geomorphic unit, and creates a variety of habitat for mangrove development. The nature of geomorphic changes is commonly found, and the plants play minimum roles in the modification of habitat conditions. The eco-geomorphology of islands and the geo-physical processes such as river flow, interact with other local scale factors that result in specific patterns in soil conditions, describing the structural and functional characteristics of mangrove forests, and affecting the spatial distribution of mangrove communities at ISCS (Table 3). The east coast of Sumatra, for example, according to Troll and Dragendorf [58], is fringed with an almost unbroken mangrove belt which in many places is several kilometers wide. Also, the area is among the most dynamic in the world [59]. Scientifically therefore, it represents an important area for protection and conservation of mangrove forests. At ISCS, 11 NPs with mangrove forests as their major vegetation element have been set-up by GOI [19]. All of the NPs developed well floristically and faunistically, e.g. Berbak, Sembilang and Way Kambas NPs in Sumatra, and Gunung Palung and Tanjung Puting NPs in Kalimantan. Water flow in tidal creeks fringed by different mangroves types is very different from that in rivers without mangroves. If flooding of fresh water along with their sediment occurs constantly, the coasts along with their estuarine vegetation is very dynamic. The dynamism of the herbaceous pioneer flora on such coasts has not yet been fully studied. However, that in the Cimanuk delta, northern coast of West Java the recent alluvial deposits are colonized by *Cyperus malaccensis* and *Scirpus littoralis* (Cyperaceae), and in the landward edges of the delta the pioneers are other grasses, *Paspalum vaginatum*, *Sporobulus* sp. [60]. Poaceae and Cyperaceae seem to be better adapted to the hydromorphic conditions.

ISCS coasts are meso-tidal (tidal range less than 4 m) or macro-tidal (tidal range over 4 m) and have relatively low wave energies except occasional cyclones and/or tsunami. A wide horizontal tidal range and tropical temperature has been cited as requirement for extensive growth of mangrove in ISCS [3, 40]. The mangroves grow and form a fringe wetland vegetation zone between land and sea or intertidal zone (ITZ), which in many places is referred to as forest. Some of the virgin mangrove forests contain trees of remarkable sizes, with trees reaching up to 55 m in height and DBH over 30 cm [40, 61].

The ITZ is the area that stretches from the lowest point at which the land is exposed at the lowest low water level (LLWL) to the furthest point at which the land is immersed at the highest high water level (HHWL). Mangroves thrive particularly well in sheltered situations on deep accreting mud in the ITZ of many sites in ISCS. They are often prominent features in estuaries and deltas in Sumatra, West and Central Kalimantan, where they grow on sediments deposited by the rivers. In areas along gentle coastal slopes, mangrove forests can extend 10-20 km inland and it is here that the most complex and biologically diversed mangrove ecosystems exist, and develop luxuriantly as mangrove forest types [62] in their proper habitat. All true mangrove genera *Avicennia*, *Bruguiera*, *Ceriops*, *Kandelia*, *Rhizophora* and *Sonneratia* are known to occur frequently in tree forest types (Table 3) [4, 40, 63]. Individual plants in tree mangrove forests frequently exceed 40 m in height (e.g. *R. apiculata* 62.5 m tall) and many trees are single stands with high density. Sukardjo and Kartawinata [40] found that the height of *Avicennia alba* trees (65 m tall) is strongly associated with the degree of drainage of the soil. However, tree height of the same species may range from several meters to over 45 m at maturity. A large number of species in

Table 3. Mangrove community along with their number of species, tree (DBH>10cm) density/ha and basal area/ha in Indonesian South China Sea region.

Province and community type	Number of true tree mangrove species	Tree density/ ha (D), dbh > 10 cm	Basal Area/ha (m2/ha)
Lampung:	-	-	-
1. *Avicennia marina* - *A. marina* (Way Sekampung)	8	197-339	14.30-20.66
2. *Rhizophora apiculata* – *Bruguiera gymnorrhiza* (Way Kambas NP)	10	400-750	25.55-49.10
South Sumatra + Bangka Belitung:	-	-	-
1. *Rhizophora apiculata* – *Avicennia alba*	8	366	14.47
2. *R. apiculata* – *Bruguiera gymnorrhiza*	9	444	14.23
3. *R. apiculata* – *Nypa fruticans*	4-7	380-386	21.24-21.30
4. *A. alba* – *R. apiculata*	6	426	12.89
5. *A. officinalis* – *R. apiculata*	9	425	15.53
6. *N. fruticans* – *R. apiculata*	5	395	22.55
7. Pure stand *R. apiculata* (Sembilang NP)	1	528	52.44
8. Pure stand *R. mucronata* (Sembilang NP)	1	603	42.41
9. Pure stand *B. gymnorrhiza* (Sembilang NP)	1	656	45.88
10. Pure stand *Xylocarpus granatum* (Sembilang NP)	1	501	42.96
11. *B. cylindrica* – *R. apiculata* (Simpang Alang river)	4-8	1000-3100	27.10-55
12. *X. granatum* – *B. cylindrica* (Simpang Alang river)	4	2000	38.10
13. *B. cylindrica* – *B. gymnorrhiza* – *X. granatum* (Simpang Alang river)	4-9	700-1600	71.70-85.40
14. *N. frutican* – *B. gymnorrhiza* (Simpang Alang river)	7	1800	22.20
15. *Oncosperma tigillaria* (Simpang Alang river)	2	5400	25.30
16. *R.apiculata* – *R. mucronata* (Bangka-Belitung)	6-7	750-800	40.25-50.05
Riau + RiauIslands:	-	-	-
1. *R. apiculata* – *A. marina*	5-7	188-524	13.36-15.15.58
2. *Ceriops tagal* – *R. apiculata*	5-7	188-588	22.99-36.80
3. *A. officinalis* – *A. marina*	6	264	17.25
4. *S. alba* – *R. stylosa* (Natuna-RiauIslands)	9	1373	24.30
5. *B. gymnorrhiza* – *R. stylosa* (Natuna-Riau islands)	7	1032	26.33
6. *E. apiculata* – *B. gymnorrhiza* (Natuna-RiauIslands)	5	783	17.65
7. *R. apiculata* – *Terminalia catappa* (Natuna-Riau islands*)*	6	1060	16.61
8. *X. granatum* – *Lumnitzera racemosa* (Batam-Riau islands)	4	104	1.58-4.92
9. *X. granatum* – *R. apiculata* (Batam-Riau islands)	3	276	3.04-4.16
10. *R. apiculata* – *X. granatum* (BatamRiauIslands)	3-5	164-172	
Jambi:	-	-	-
1. *C. tagal* – *B. gymnorrhiza* (Berbak NP)	6-8	448-760	23.21-37.25
2. *C. tagal* – *R. apiculata* (Berbak NP)	5	504	19.40
3. *Sonneratia alba* – *S. caseolaris* (Berbak NP)	4	199	17.30
4. *S. caseolaris* – *C. decandra* (Berbak NP)	4	206	20.79
5. *S. obovata* – *R. apiculata* (Berbak NP)	5	262	39.23
6. Pure *S. caseolaris* (Berbak NP)	1	229	31.42
West and Central Kalimantan:	-	-	-
1. *R. apiculata* – *A. marina*	13	308	25.77
2. *R. apiculata* – *B. gymnorrhiza*	10-12	448-551	25.68-76.59
3. *R. apiculata* – *S. obovata*	8-12	276-399	17.17-29.95
4. *R. apiculata* – *Xylocarpus granatum*	12	170	22.84
5. Pure *A. alba*	1	314	20.55
6. Pure *R. apiculata*	1	385	29.39
Central Java + East Java:	-	-	-
1. *R. apiculata* – *C. tagal*	3-6	422-465	8.13-8.66
2. *R. mucronata* – *R. apiculata*	6-8	210-347	3.25-7.39
3. *R. apiculata* – *A. officinalis* (Segoro Anak Alas Purwo NP)	9	160	3.40
Banten + Jakarta DKI + West Java:	-	-	-
1. *A. alba* – *R. apiculata*	7	399	19.97
2. *R. mucronata* – *R. stylosa* (Pulau Rambut)	13	533	6.35
3. *Rhizophora* (P.Dua)	12	75	1.555
4. *R. apiculata* – *R. stylosa* (Ujung Kulon NP)	20	382-4346	32-45
5. *R. apiculata* – *X. gfranatum* (Ujung Kulon NP)	18	285-1469	13-57

each forest types are found throughout Indonesia and the *seres* are correspondingly the most complex.

The ITZ of ISCS are usually harsh, restrictive and dynamic, e.g. east coast of Sumatra. Also, ITZ are subject to both shorter term rhythms of tides and season, as well as longer term changes of climate and sea level. Therefore, the spatial distribution of the various mangrove forest types (viz. riverine, basin, fringing etc.) in ISCS depends very largely on physiography, e.g. open protected coasts, large estuary or small river.

Elsewhere in the islands of RIP – for example, on reefs, coralline tidal flats or sandy beaches open to the sea – mangrove trees may grow in the tidal zone, but extensive forests are less likely to develop. Twelve true species of the mangal (after Macnae) [64] are present in Natuna islands, and in Bangka-Belitung such mangal occurs primarily on coral reefs [65]. In small islands, mangroves form assemblages containing a few species and/or a single species which dominate the structure, e.g. the mangrove fringing Mapor island-RIP dominated by *Rhizophora stylosa* and *Pemphis acidula* [13], and in small island associated with coral reef ecosystem, the mangrove assemblages are dominated by a single *R. stylosa* stand e.g. Pari island Jakarta Bay [11]. *R. stylosa* is, therefore, the pioneer species in the sandy shores of islands e.g. BangkaIsland [65] and offshore islands of West Kalimantan [66].

Mangrove forests occur in fully saline waters and are associated with estuaries. Mangrove estuaries and creeks usually have significant salinity fluctuations. It is well known also that mangrove plants can be grown outside their habitat in fresh water in greenhouses [4]. Mangrove species can penetrate inlands extensively along the river, e.g. in West Kalimantan mangrove forests which reach up the Kapuas river for 240 km, and their floristic composition includes species of transition zone, e.g. *Heritiera globosa, Combretocarpus rotundatus.* If tidally determined circulation of salt stops altogether and if no more organic material is deposited, the vegetation changes to the gelam, *Melaleuca leucodendron* or characterized by the presence of the nibong, *Oncosperma tigillaria,* e.g. in South Sumatra [67], or some other type of non-maritime vegetation. Nibong stand in south of Ngerawan River, South Sumatra, is the typical ecotone of the transition zone between mangroves and peat swamp forests. Once again they may merge with freshwater swamp forests or to be backed by extensive peat swamp forests and climax rain forests, e.g. in Kalimantan and Irian Jaya. Consequently, other species may mark the transition zone but they differ in various parts of the country, e.g. in Sumatra by an *Alstonia-Campnosperma* community or by certain forest trees (e.g. *Gluta velutina*, *Scolopia macrophylla*, *Ficus* spp). They can also mark the transition to freshwater swamp forests [67]. The precise environmental factors which control the different transition zones or ecotone community, along with their floristic richness, are worthy of further investigation.

The silt that forms the mud, so characteristic of mangrove forest areas in particular sites, has its origin in the load brought down by rivers [40, 68]. Troll and Dragendorff [58] and Postgate [68] considered that the black color of many mangrove mud is produced by aerobic bacteria reducing sulphates to sulphides. Also, occasional influx of fresh water from the river is necessary for the full development of single stand, e.g. *R. mucronata* forests. The quality of the soil in mangrove forests depends ultimately on the source of its alluvium [68, 70], e.g. species of *Avicennia* and *Sonneratia* are consistently the pioneer on coastal deposition shore in Indonesia. In such areas generally, the mangrove species exhibit zonation in a spatial context from shore inland [cf. 71], which has been related to a complex of environmental factors such as salinity [cf. 72], tidal flushing [cf. 73] and soil types [74], e.g. in Segara Anakan Cilacap [75]. In this case locally, the soil may be of considerable importance. For instance, *Lumnitzera littorea* is commonly found associated with creek banks. This species is typical of loamy soil whereas on clay soils it is replaced by *L. racemosa* [71]. Over such a vast area habitat factors and the resulting pattern may vary enormously. Consequently, there are many major types of communities in or associated with the mangrove forests [76] (Table 3), and many single stands of mangrove species along with their variants, *e.g.* in the mangrove forests of Segara Anakan Cilacap, de Haan [75] recognized a *Bruguiera gymnorrhiza* association with their three variants. At the muddy substrates with abundant silt along the sea coast of the lagoon, *R. mucronata* appears to thrive very well in those areas with high salinity. It is asserted that *R. mucronata* is the pioneer colonist, e.g. in Segara Anakan Cilacap [61]. However, it is believed that occasional influx of fresh water from the river is necessary for the full development of *R. mucronata* forest. Another brackish-water community common in the landward edge in Sumatra, Kalimantan and Irian Jaya is represented by a mixture of *Sonneratia caseolaris*, *Nypa fruticans* and *Heritiera littoralis*. Mixed vegetation of *N. fruticans* and many other mangrove species, including abundant *Xylocarpus* are common in Simpangalang River, South Sumatra. Moreover, in Sembilang, an area dissected by a complex of rivers and streams, offers a vista, which is rare in Asia today, the *Rhizophora*, *Bruguiera*, *Xylocarpus* association, as the most widespread community.

Mangrove taxa including *Avicennia marina*, *Osbornia octodonta*, *Excoecaria agallocha*, *Lumnitzera racemosa* and *Ceriops tagal* are also common elements fringing the chenier ridges in small islands of ISCS, and the ecological importance is needed for further discussion, e.g. RIP [16]. *A. marina* in particular occurs in small and discontinued groves at the chenier/mudflat interface on sites which are reacheable by only a few tides each year, but subject to reliable wet season flooding.

Mangrove forests or mangrove ecosystems by their nature include an aquatic element. During high tide, mangrove forests are areas of little wave-action and swell, but variable sediment loads depending on weather conditions. During low tide, organisms living in mangrove forests are shaded by an expansive canopy of leaves and are subjected to great humidity. The Indonesian mangrove forests in most of the 95,181 km coastline are ecologically unique. The unique associations of animals and plants that dwell upon the roots of mangrove in seas have long attracted the attention of naturalists and have not been adequately studied.

At present in Indonesia, 30 marine conservation areas constitute 4.6 million ha, and mostly mangrove forests being a core area. Also, 1.8 million ha are proposed by MOMAF in 2007 to be declared as provincial marine conservation areas. The conservation is a difficult concept implemented locally at ISCS. There are many statements of definitions and aims which cover a wide spectrum of public opinions [77]. However, it attaches considerable importance to the management of natural resources as part of a conservation ethic and the local community has also issued statements that highlight the importance of wise utilization of such resources. The protected ISCS mangrove forest at SFA implies that any exploitation or harvest from an ecosystem, or any interference with the normal evolving processes and feedback mechanisms within the system, and is incompatible with conservation e.g. NPs at Way Kambas Lampung, Sembilang South Sumatra and Berbak Jambi, Tanjung Puting Central Kalimantan and Gunung Palung West Kalimantan [19].

ISCS mangrove flora

The ISCS region or west Malesia has 295 angiosperm plants of mangrove flora and only 91 species are true mangrove species (Tables 4-5). More than two-thirds of the mangrove species in the world exist in ISCS region [29, 37]. Tables 4-5 show the occurrence of ISCS mangrove flora for a range of 13 provinces. East coast of Sumatra has completely the true mangrove species (Table 4) and the list of associated mangrove species recorded in Table 5. This list is compiled from the data (Tables 1, 3) and my personal knowledge of species distributions with additional data from the available literature and herbarium records, e.g. *Avicennia lanata* occurs in RIP, *Brownlowia argentata* (Tiliaceae) are absent in Java to Nusa Tenggara.

The best developed mangroves in terms of stand structure and number of tree (DBH >10 cm) species are found in the east coast of Sumatra (Riau, Jambi, South Sumatra and Lampung) (Table 3). Sumatra is the distinct, floristically rich biogeographic region comprising peat and fresh-water swamp forests and/ or other coastal wetland vegetation. ISCS mangrove forests are three-dimensional, that is, they have a horizontal spatial component from open sea to land, and a vertical component from roots to leaves. This has resulted in the largest number of species in any mangrove community (Table 3), and floristically consist of specific true mangrove species and its associates such as algae [78, 79], diatoms, fungi and lichen [80], epiphytic plants (*Hoya* sp, *Dischidia benghalensis*), mistletoes (*Amyema gravis*, *Viscum orientalis*), marginal and undergrowth species [4, 7].

Generally, ISCS mangrove forests are dominated by two orders, the Myrtales and Rhizophorales, of which their tree species are common and their density in the natural stand vary considerably with the soil characters (Table 3). Heavy loam, for example, affects water movement and same species cannot tolerate water logging viz. *Bruguiera parviflora* usually indicates such a site. The fern, *Acrostichum aureum*, a vegetable pest occurs in the landward fringe of all the mangrove forest types [81]. At the higher levels the fern can form dense undergrowth and so inhibit regeneration, e.g. in Banyuasin mangrove forests

[82]. In Bangka-Belitung islands, this fern community also includes *Xylocarpus granatum* stands. The fern probably has a wide tolerance range in terms of light and soil salinity.

Field data (Table 1) shows a high diversity of associated plant (Table 5) and animal life is also found in the mangrove forest areas [83-87]. Very few lianas are recorded from mangrove forests (e.g. *Derris* spp., *Dalbergia caudenatensis*, *D. menoeides*, *Smythea lanceata*), and epiphytes are generally few, though species of the ant-harboring Rubiaceous genera *Hydnophytum (H. formicarum)* and *Myrmecodia* are regular features of mangrove forests in Sumatra, Kalimantan to Maluku and Irian Jaya. Epiphytic orchids and bromeliads are the only other higher plants present in the mangrove forests with high rainfall and wet season of almost sixmonths. Van Steenis [7] refers to records of epiphytic orchids from Anambas islands in the South China Sea and Java viz *Dendrobium rhizophoreti*, *D. prostratum*, *D. callibotrys* and *Bulbophyllum xylocarpi*. Epiphytic ferns (e.g. *Humata parvulla, Vittaria* sp., *Davalia* sp.) are not common and they appear to be restricted, at least in Sumatra, Kalimantan, Sulawesi and Irian Jaya, to areas where there is no pronounced dry period.

Human activities such as conversion of mangrove forest areas for the construction of tambak and its canals, roads, dredging and filling, greatly destroyed mangrove forest conditions, and facilitate the invasion of native and/or alien species (e.g. *Podocarpus polystachyus*, *Gluta velutina*, *Glochidion littorale*, *Scirpuslittoralis*, *Paspalum vaginatum, Cyperus malaccensis, Pluchea indica*) into those mangrove habitats [43, 44, 88]. Conversion of mangrove forests for human being, i.e. tambak, settlement, road and other developmental facilities, reduces the biodiversity oftrue mangrove species and increases the associated non-mangrove plants, e.g. in Java: *Pithecellobium dulce, Samanea saman*, *Lannea grandis*, *Pluchea indica*, *Zyzyphus mauritianus*, *Moringa oleifera*, *Morinda citrifolia*, *Albizia retusa* [44]. Different islands and/or sites therefore produced specific flora of the mangrove forests, e.g. coastal wetland of the Solo-Brantas, East Java [88]. ISCS mangrove flora is very specialized, consisting of mangrove proper (major and minor, principal and subsidiary mangrove species), associated mangrove species and/or back mangrove species (marginal species, facultative species, epiphytic plants, mistletoes: *Amyema gravis, Viscum orientalis*, fern, fungi, lichens, algal: *Bostrychia rivularis*, *B. radicans*, *Cladiphora* sp., *Muryella* sp., *Polysiphonia* sp.). The mangrove flora is very incompletely known, both owing to the fact that a large part of the existing collections are unidentified and that many parts have never been botanized (Table 1). The enumeration of mangrove flora and their associated plants in ISCS and/or Indonesia is interesting geographically [78]. Intensive plant collection would be most rewarding and international collaboration to undertake this work is much welcome.

DISCUSSION

ISCS are large marine mangrove forest areas in an environment characterized by tidal ranges of 2-5 m, fluctuating salinities of 28-35%, high atmospheric humidity and constant sub-equatorial temperatures. Variation in the degree of inundation of mangrove forests by sea water in particular islands and/or sites also controls soil salinities, which are important in regulating forest structure [40, 61]. ISCS mangroves can grow in different salinity regime from marine to freshwater, e.g. in Danau Sentarum, West Kalimantan [89], and attain their greatest development both with regard to their physical dimensions and to the number of genera and species (Tables 4, 5). Data on the extent of the ISCS mangrove forests are not complete yet (Table 2), but recently a figure has been reported, e.g. Belitung island (19,393 ha) [9]. The data indicated that the mangrove forests have been altered by several processes viz. the effect of deforestation and fragmentation. Deforestation has caused a 22.80% and 27.40% decrease (to heavy damages) of mangrove forests in the SFA and NSFA, respectively. Fragmentation has resulted in much of the current mangrove forests remaining in small parcels with a high edge to area ratio. In many small islands of ISCS mangroves have been inventorized, e.g. Natuna islands [15]. The populations of the small islands represent the new undescribed species. Aerial photographs of the coastal regions of the islands concerned would undoubtedly produce a very important acreage of potentially rich mangrove forests.

In Sumatra, West and Central Kalimantan where rainfall is high and not seasonal, the mangrove forests reach its optimum development, and in exceptional cases, attain a height of 60 m [40]. Thus ISCS mangrove forests cannot be embraced under any single structural form. In structural term mangrove forests range from tall closed form (trees over 50 m tall, 80-100% canopy cover) to more complex structure. The ISCS mangrove forests are a series of integrated communities (Table 3), and the most diverse mangrove flora occurs in many communities of the mangrove forests where trees are usually the dominant life form, e.g. *Rhizophora apiculata* trees 50 cm DBH which are larger, and attain a height of 62.5 m which are common in mature riverine forests in Sumatra [40]. The discontinuous distribution of their tree height at the border between the fringe and riverine or basin mangrove forests suggests that environmental conditions determine their occurrence. These forests are very dynamic locally and their growth and decline often reflect the changing conditions of the coastal environment in which they grow, and are influenced by seasonal changes in climate. Salinity regimes on tidal flats are important in regulating aspects of mangrove recruitment, survivorships, growth and zonation [64, 71-73]. Little or no information is available about the effect of man's manipulations of the hydrology of mangrove forests upon their survival and their ecosystem. Ecologically, ISCS with highest density of mangrove trees, represent an area of new revelation of mangroves distribution and source of their genetic centre (Table 3).

ISCS region has the highest diversity of mangrove species. The exact number is, of course, debatable and also depends on taxonomic classification and the botanical exploration [11, 14, 66, 78, 90-92], and in deciding what is, and what is not, a mangrove – a problem of better defining them. For instance, *Diospyros ferrea*, *Inocarpus fagiler* are species commonly found in the mangrove flora, and well known in Maluku. The taxonomy of the mangrove flora in Central Malesian or western Indonesia is very incompletely known if compared to ISCS and some species are at risk, e.g. mangrove flora in Bali and Lombok includes 32 true mangrove species and 19 mangrove associate species [36]. ISCS mangrove floras currently recorded in the 13 provinces are affected considerably by the extent and the duration of the biotic and anthropogenic factors, e.g. in Java. To give a few examples – *Lumnitzera littorea*, *Scyphyphora hydrophyllacea*, *Sonneratia alba* and *Xylocarpus australasicus* are on the way to rare species in the central Malesian or eastern Indonesia, and have practically disappeared from the Aru islands. At ISCS the species are found to be common. Also, *Rhizophora lamarckii* is centered on the Coral Sea; and *Camptostemon* as a whole is restricted to Central Malesia [93], but its affinities are unclear since the species is found in East Java, Bali, Lombok, Lesser Sunda Islands, and Borneo, respectively [94]. Even floristic enumerations of plants in any Indonesian mangrove forests are scanty [36, 44, 61, 95, 96], the reports of Giesen and Wulffraat [83] and Giesen *et al.* [37] show the presence of native and/or alien species in Indonesian mangroves. It is interesting to note that even the Rhizophoraceae, often referred to as the true mangrove family, has only 4 (*Bruguiera*, *Ceriops*, *Kandelia* and *Rhizophora*) of its 16 genera inhabiting mangroves (*Carallia* are found in mountain forests). All six described *Bruguiera* species are found in ISCS but their spatial distribution is still uncertain. For example, *B. exaristata* and *C. tagal* var *australis* are found in northern Australia and Southern New Guinea [63, 97], but also occurs in East Java to Timor island of NTT province as the dominant stand in the 11,001.46 ha of mangrove forests [98]. Both species are types or paratypes of two key coral/Arafura sea taxa. Another example is *Brownlowia argentata*, a tiliaceous tree that is absent in Java and Nusa Tenggara but common in Sumatra and Kalimantan. *Aegialites annulata* (Plumbaginaceae) is an eastern Indonesia prominent mangrove species with Java as their limit of distribution, but *Aegialites rotundifolia* is missing in Indonesia [99]. *Avicennia rumphiana* is most common in central Malesia or western Indonesia, but according to my field data, it occurs in Kalimatan and/or Borneo to the east coasts of the Malay Peninsula. From the species distribution point of view, there are many gaps to be investigated. Botanically, ISCS is an area of promise for rediscovery and new records of mangrove flora (Tables 1, 4, 5).

There is still very little comprehensive study on the ecosystem of any of the Indonesian mangrove forests [100]. The floral and faunal ecology of mangrove forests in the various parts of Indonesia has not been adequately studied. Numerous factors affect the distribution of mangrove plants [101]. At ISCS, a more complete analysis of the distribution of plants and animals in the mangrove forests and their dispersal mechanisms are information types that once filled, will allow fine-turning of a provincial conservation plan for the mangrove forests. Thus, mangrove conservation education is promoted on the background of sustainability and biodiversity

Table 4. Flora mangroves: true mangrove species recorded during botanical survey (1-13: province as in Table1) (x: present with voucher specimen, very common. ?: present with sterile voucher specimen, occasional to very rare).

Species	Family	Province of the ISCS												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1. *Aegialitis annulata* R. Br.	Plumbaginaceae, Sh, S	x			?	?								
2. *A. rotundifolia* Roxburgh	Plumbaginaceae, Sh, S	x												
3. *Amoora cucullata* Roxb.	Meliaceae. Sh, S	x	x	x	x	x	x						x	x
4. *Aegiceras corniculatum* (L.) Blanco	Myrsinaceae, Sm, P	x	x	x	x	x	x	x	x	x	x	x	x	x
5. *A. floridum* Roem. & Schult.	Myrsinaceae, Sm, P	x												
6. *Avicennia alba* Blume	Avicenniaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
7. *A. integra* N.C. Duke	Avicenniaceae, T, P	x			?									
8. *A. lanata* Ridley	Avicenniaceae, T, P	x												
9. *A. marina* (Forsk.) Vierh.	Avicenniaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
10. *A. marina* var *australasica* (Walp.) Moldenke	Avicenniaceae, T, P	?												
11. *A. marina* var *eucalyptifolia* (Zipp. Ex Miq.) N.C. Duke	Avicenniaceae, T, P	?					?							
12. *A. marina* var *intermedia* (W. Griff.) Bakh.	Avicenniaceae, T, P	x	x	x	x		x				x		?	
13. *A. marina* var *marina*	Avicenniaceae, T, P	x		x	x		x						x	x
14. *A. marina* var *resinifera* (Forst.f.) Bakh.	Avicenniaceae, T, P												?	?
15. *A. officinalis* L.	Avicenniaceae, T, P	x	x	x	x	x	x	x	x	x	X	x	x	x
16. *A. rumphiana* Hall.f	Avicenniaceae, T, P	x										x	?	
17. *Brownlowia argentata* Kurz.	Tiliaceae, T, S	?	x	?	x		x				?	?	x	x
18. *B. lanceolata* Bth.	Tiliaceae, T, S		x	x	x		x						x	x
19. *B. tersa* (L.) Kosterm.	Tiliaceae, Sh, S	x	x	x	x								x	x
20. *Bruguiera cylindrica* Blume	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
21. *B. exaristata* Ding Hou	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
22. *B. gymnorrhiza* (L.) Lamk.	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
23. *B. hainesii* C.G.Rogers	Rhizophoraceae, T, P	x		x	x		x							
24. *B. parviflora* (Roxb.) Wight and Arn. Ex Griff.	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
25. *B. sexangula* (Lour.) Poir.	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
26. *Camptostemon philippinensis* (Vidal) Becc.	Bombacaceae, T, P	?											?	?
27. *C. schultzii* Masters	Bombacaceae, T, P												?	
28. *Ceriops decandra* (Griff.) Ding Hou	Rhizophoraceae, T, P	x	x	x	x	x	x	x			x	x	x	x
29. *C. tagal* (Perr.) C.B.Robinson	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
30. *C. tagal* var *australis*	Rhizophoraceae, T, P	?												
31. *C. tagal* var *tagal*	Rhizophoraceae, T, P	?												
32. *C. zippeliana* Blume	Rhizophoraceae, T, P	x											?	?
32. *Cerbera manghas* L.	Apocynaceae, T, S	x	x	x	x	x	x	x	x	x	x	x	x	x
33. *C. floribunda* K. Schumann	Apocynaceae, T, S												?	?
34. *C. odollam* Gaertner	Apocynaceae, T, S	x	x	x	x		x							
35. *Cynometra ramiflora* L.	Leguminosae, T, S		x	x	x		x						x	x
36. *Dolichandrone spathacea* (L.f.) K. Schumann	Bignoniaceae, T, P	x	x	x	x		x		x			x	x	x
37. *Excoecaria agallocha* L.	Euphorbiaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
38. *Heritiera globosa* Kostermans	Sterculiaceae, Sm, S												x	x
39. *H. littoralis* Dryand. Ex W. Ait	Sterculiaceae, T, P	x	x	x	x		x						x	x
40. *Intsia bijuga* (Colebr.) O. Kuntze	Leguminosae, T, S		x	x	x		x						x	x
41. *Kandelia candel* (L.) Druce	Rhizophoraceae, T, P	x	x	x	x	x	x	x	?	x	x	x	x	x
41a. *K. obovata* Sheue.Liu & Yong	Rhizophoraceae. T.P.	-												
42. *Lumnitzera littorea* (Jack.) Voigt.	Combretaceae, T, P	x		x	x		x				x	x	x	x
43. *L. lutea* Presl.	Combretaceae, T, P	?											?	?
44. *L. racemosa* Willd.	Combretaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
45. *L. rosea* (Gaud.) Presl.	Combretaceae, T, P	?											?	
46. *L.* (*littorea* x *racemosa*)	Combretaceae, T, P	?											?	
47. *Nypa fruticans* (Thunb.) Wurmb.	Palmae, Tp, P	x	x	x	x	x	x	x	x	x	x	x	x	x
48. *Osbornea octodonta* F. v.Muell.	Myrtaceae, T, P		x	x	x		x	x	x	x	x	x	x	x
49. *Oncosperma tigillaria* (Jack.) Ridl.	Palmae, Tp, P	x	x	x	x		x					?	x	x
50. *Pemphis acidula* J.R. Forsk. & G. Forsk.	Lythraceae, Sm, P	x			x		x	x	x	x	x	x	x	
51. *Paramignya angulata* (Willd.) Kurz.	Rutaceae, Sm, S		x	x	x				x		?	?	x	x
52. *Phoenix paludosa* (Jack.) Ridl.	Palmae, Sh, S		x	x	x		x						x	x
53. *Rhizophora apiculata* Blume	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
54. *R. lamarckii* Montr.	Rhizophoraceae, T, P	?										x		
55. *R. mucronata* Lam.	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
56. *R. stylosa* Griff.	Rhizophoraceae, T, P	x	x	x	x	x	x	x	x	x	x	x		
57. *Scyphyphora hydrophyllacea* Gaertn. f.	Rubiaceae, Sm, P	x	x	x	x	x	x	x	x	x	x	x	x	x
58. *Sonneratia alba* J. Smith	Sonneratiaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
59. *S. apetala* Buck.-Ham	Sonneratiaceae, T, P	x	x			x					?	?	?	?

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Panel discussion

The conference concluded with a Panel Discussion chaired by Prof. Phang Siew Moi to further deliberate on South China Sea Regional Co-operation. The panel comprised members of the countries bordering the South China Sea namely Dr Li Jianwei (China), Dr Fadli Syamsudin (Indonesia), Dr Tan Koh Siang (ASEAN-COST; Singapore), Dr Abdul Kadir Bin Ishak (Malaysia – NOD), Dr Kenneth Sherman (USA – NOAA), Dr Vo Si Tuan (Vietnam), Dr Koch Savath (Cambodia) and Prof Abraham Sakili (Philippines).

Acknoledgements – We wish to extend our heartfelt gratitude and appreciation to the Honorable Chief Minister for his presence to grace the event. Our special thanks for the valuable input given by the distinguished speakers and participants.

Lastly, we would like to congratulate and thank everyone for the support and hard work provided by the teams of the organizers MOSTI, UM and MSMS.

Co-Chairpersons

Professor Dr. Nor Aieni Haji Mokhtar

Director, National Oceanography Directorate

Ministry of Science, Technology and Innovation

and

Professor Dr. Phang Siew Moi

Director, Institute of Ocean and Earth Sciences

University of Malaya

60. *S. caseolaris* (L.) Engl.	Sonneratiaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
61. *S. gulngai* N.C. Duke	Sonneratiaceae, T, P	?				?						x		
62. *S. griffithii* Kurz.	Sonneratiaceae, T, P		?	?	x							?	x	x
63. *S. lanceolata* Bl.	Sonneratiaceae, T, P		x	x	x		x						x	x
64. *S. ovata* Backer	Sonneratiaceae, T, P		x	x	x		x							
65. *S.* (*alba* x *caseolaris*)	Sonneratiaceae, T, P	?										?		
66. *S.* (*alba* x *lanceolata*)	Sonneratiaceae, T, P					?						?		
67. *S.* (*alba* x *gulngai*)	Sonneratiaceae, T, P	?				?								?
68. *S.* species	Sonneratiaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
69. *Xylocarpus australasicus* Ridley.	Meliaceae, T, P	?										?		
70. *X. granatum* Koen.	Meliaceae, T, p	x	x	x	x	x	x	x	x	x	x	x	x	x
71. *X. moluccensis* (Lam.) M. Roem.	Meliaceae, T, P	x	x	x	x	x	x	x	x	x	x	x	x	x
72. *X. rumphii* (Kostel.) Mabb.	Meliaceae, T, P		x	x	x		x						x	?
73. *X.* species	Meliaceae, Sm, P	?	?			?	?				?	?	?	?
74. *Acanthus ebracteatus* Vahl.	Acanthaceae, H, P	x		x			x							
75. *A. ilicifolius* L.	Acanthaceae, H, S	x		x	x		x				x	x	x	x
76. *A. volubilis* Wall.	Acanthaceae, H, S		x	x	x						x	x	x	x
77. *Acrostichum aureum* L.	Pteridaceae, F, Sh, P	x		x	x		x				x	x	x	x
78. *A. speciosum* Willdenow	Pteridaceae, F, Sh, S		x	x	x						?	?	x	x
79. *Clerodendrum inerme* Gaertn.	Verbenaceae, Sh, S	x	x	x	x	x	x	x	x	x	x	x	x	x
80. *Cumingia philippinensis* Vidal	Leguminosae, Sm, S	x											x	x
81. *Derris heptaphylla* (L.) Merr.	Leguminosae, WC, S		?	?	?		?	x	x	x	x	x	?	?
82. *D. heterophylla* (Willd.) Backer	Leguminosae, WC, S						x	x	x	x	x	x		
83. *D. trifoliata* Lour.	Leguminosae, WC, S	x	x	x	x	x	x	x	x	x	x	x	x	x
84. *Dalberrgia caudenatensis* (Dennst.) Prains	Leguminosae, WC, S	x	x	x	x	x	x	x	x	x	x	x	x	x
85. *D. menoeides* Prain.	Leguminosae, WC, S		?	?	?				x	x	x	x	x	x
86. *Finlaysonia obovata* Wall.	Aslepiadaceae, WC, S	x	x	x	x	x	x	x	x	x	x	x	x	x
87. *Caesalpinia crista* L.	Leguminosae, Sh, S	x	x	x	x	x	x	x	x	x	x	x	x	x
88. *Gymnanthera paludosa* (Bl.) K. Schum	Asclepiadaceae, Wc, S	x	x	x	x	x	x	x	x	x	x	x	x	x
89. *Ixora timoriense* Decne.	Rubiaceae, Sm, S	?						x	x	x	x	x	x	x
90. *Pithecellobium umbellatum* (Vahl.) Bth.	Leguminosae, T, S	x							x	x	x	x		
91. *Smythea lanceata* (Tul.) Summerh.	Rhamnaceae, Wc, S	?	?	?	?	?	x	x	x	x	x	x	x	x

as well as including the basic concepts and ideas of modern ecology, e.g. a relevation of genetic source of species. Moreover, to protect the country's tremendous biodiversity, the government instituted Law No.5/1990 on Conservation of Living Resources and Their Ecosystem, as well as Law No.5/1994 which ratifies the Convention on Biological Diversity (CBD). Indonesia has revised the *Biodiversity Action Plan for Indonesia* and has named it as *Indonesian Biodiversity Strategy and Action Plan 2003-2020* [8].

Indonesia belongs to Malesia unit of plant geography [4, 29, 30, 62, 71, 81]. ISCS mangroves are not only exceptionally tall and luxuriant, but also hold the greatest number of tree species (Tables 4, 5). ISCS is thought to be the geographical centre for the mangrove forests and considered being the major centre of origin for mangrove taxa [102], from which these well-adapted tree species, capable of surviving on saline soils that are subjected to tidal inundation, have spread throughout the tropics. For instance *Sonneratia ovata* (Sonneratiaceae), *Avicennia rumphiana* (Avicenniaceae) and *Aegiceras floridum* (Myrsinaceae) are basically from central Malesia [103], but also most common in ISCS [33, 34, 94, 104]. *Aegialitis annulata*, *Bruguiera exaristata*, *Camptostemon schultzii* and *Osbornia octodonta* are characteristic Arafura sea-centered taxa, with western limits in Timor and Maluku, are found in West and Central Kalimantan and Natuna-Anambas Islands of RIP. These need further biogeographical and taxonomical studies on their spatial distribution [93, 94, 104, 105].

In common with Peninsular Malaysia, Thailand and China [106], the east coast of Sumatra contains the richest mangrove flora in the world (Tables 4-5). Not only is there a full range of tidally influenced habitats and an equatorial climate with a short dry season, but there is also a biogeographic intermixture of species which include those from Australasia, Indo-China and the Indian Oceans, e.g. *Kandelia obovata*, a new species of Rhizophoraceae from eastern Asia can be found and/or to occur in the eastern part of Sumatra and Natuna-Anambas Islands in the SCS [21]. Furthermore, the varied uses and the threats on *B. gymnorrhiza* have lead to its IUCN critical endangered status in India in 1997 [107]. To achieve such a good conservation and appropriate management keys, a good overview and to re-recognize the mangrove species is essential. Unfortunately, the current situation throughout

Malesian region is that systematic studies are not prioritized, have poor financial support and offer low career prospects. In sum, Malesian expertise in taxonomy and systematics has fallen to low levels. Thus training and research need to be encouraged.

Tables 4-5 indicate that Indonesia represents a geographic centre for some genera of mangroves [3]. The taxonomy of some genera in Indonesia, especially *Avicennia*, *Sonneratia* and *Xylocarpus* is far from satisfactory, and the list should not be regarded as definitive (Table 4). The actual number of mangrove species in Indonesia therefore, has long been a matter for debate, the range of species accepted differs considerably from Schimper [108] through Becking *et al.* [30] to Sukardjo [95] and Giesen and Wulffrat [83]. However, even taking the term mangrove in a narrow sense [64], the mangrove flora in particular island of Indonesia is still a matter of problem that many characters are distinct between them, and that recognition of a new species is warranted, e.g. the presence of *Lumnitzera littorea*, *L. lutea*, *L. racemosa*, and *L. rosea* or *Lumnitzera* hybrid in ISCS to Seram Island, Kai, Aru and Tanimbar Islands, through Irian Jaya [103, 109, 110]. Clearly further studies in these islands are needed on the supposed ecological separation of the two *Lumnitzera*, i.e. *L. racemosa* and *L. littorea* [103].

Thus, with many islands for botanical exploration, newly identified species can be expected as Indonesia is the centre of unexplored taxon number and phytogeographic ranges (Tables 4, 5). Vast stretches of mangrove forests in many islands of Indonesia (Table 3) still remain to be studied even on a simple floristic level, while several genera widely recognized as a taxonomically difficult genus, still need to be bio-systematically investigated, e.g. *Bruguiera* especially in ISCS, Kalimantan up to Maluku, Aru Islands and Irian Jaya, *Avicennia*, *Sonneratia* and *Lumnitzera rosea* in Sumatra to Irian Jaya. That, along with ecological processes, account for the highest biological and functional diversity of mangrove forests. The botanist's keen attention was, however, attracted mainly on morphology of vegetative and reproductive characters, especially on the new record and the rediscovery of species, e.g. *Bruguiera* [22], *Avicennia* [111] and *Ceriops zippeliana* [112] (from Seram Island) are recorded in Riau Islands. Based on the Tables 4-5, plus additional detailed morphological comparisons of vegetative and reproductive characters between three geographical populations in Malesia, it

Table 5. Associated mangrove species in the transects of the mangrove forests of Indonesian South China Sea region (Life form: T: Tree, Sm: Small to medium size tree, S: Shrub, H: Herb, G: Grasses/Sedges, WC: Woody climber, Pt: Palm tree, Tf: Tree fern (1-13: province as in Table 1) (x: present with voucher specimen, very common. ?: present with sterile voucher specimen, occasional to very rare).

Species	Family	Province of the ISCS												
		1	2	3	4	5	6	7	8	9	10	11	12	13
1. *Allophyll cobbe* (L.) Bl.	Sapindaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
2. *Ardisia ellipticaus*Thunb.	Myrsinaceae, Sh	x	x	x	x	x	x	x	x	x	x	x	x	x
3. *A. humilis* Vahl.	Myrsinaceae, Sh		x	x	x									
4. *Azadirachta indica* L.	Meliaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
5. *Barringtonia conoidea* Griff.	Lecythidaceae, Sm	x	x	x	x	x	x							
6. *B. racemosa* (L.) Spreng.	Lecythidaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
7. *Caesalpinia bonduc* (L.) Roxb	Leguminosae. Sm	x	x	x	x	x	x						x	x
8. *Calamus erinaceus* (Becc.) Drans.	Palmae, WC		x	x	x		x					?	x	x
9. *Calotropis gigantean* (L.) Dryand. ex W.T.Aiton	Aclepiadaceae, Sh.	x	x	x	x	x	x	x	x	x	x	x	x	x
10. *Cassine viburnifolia* (Juss.) Ding Hou.	Celasteraceae, Sm	x	x	x	x	x	x						x	x
11. *Cayratia trifolia* (L.) Domin	Vitaceae, Cl	x	x	x	x	x	x	x	x	x	x	x	x	x
12. *Coccinia grandis* (L.) Voigt.	Cucurbitaceae, Cl	x	x	x	x	x	x	x	x	x	x	x	x	x
13. *Claoxylon polot* (Burm.f) Merr.	Euphorbiaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
14. *Cryptocoryne ciliate* (Roxb.) Schott.	Araceae, H	x	x	x	x	x	x	x	x	x	x	x	x	x
15. *Cycas rumphii* Miq.	Cycadaceae, Tf	x	x	x	x	x	x	x	x	x	x	x	x	x
16. *Cynanchum carnosum* Schltr.	Asclepiadaceae, WC	x	x	x	x	x	x	x	x	x	x	x	x	x
17. *Cyperus javanicus* Houtt.	Cyperaceae, G	x	x	x	x	?	x	x	x	x	x	x	x	x
18. *C. malaccensis* Lmk.	Cyperaceae, G	x	x	x	x	x	x	x	x	x	x	x	x	x
19. *Desmodium umbellatum* (L.) DC	Leguminosae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
20. *Diospyros ferrea* (Willd.) Bakh.	Ebenaceae, T	x	x	x	x		x						?	?
21. *Diplachne fusca* (L.) Beauv.	Cyperaceae, G	x	x	x	x	x	x	x	x	x	x	x	x	x
22. *Ervatamia sphaerocarpa* (Bl.) Birk.	Apocynaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
23. *Ficus annulata* Blume	Moraceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
24. *F. deltoidea* Jack.	Moraceae, Sm	x	x	x	x	x	x	x	x				x	x
25. *F. microcarpa* L.f.	Moraceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x

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26. *F. trichocarpa* Bl.	Moraceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
27. *Fimbristylis ferruginea* (L.) Vahl.	Cyperaceae, G	x	x	x	x	x	x	x	x	x	x	x	x	x
28. *F. polytrichoides* B.	Cyperaceae, G	x	x	x	x	x	x	x	x	x	x	x	x	x
29. *F. spathacea* Roth.	Cyperaceae, G	x	x	x	x	x	x	x	x	x	x	x	x	x
30. *Finlaysonia maritima* Backer ex Heyne	Asclepiadaceae, WC	x	x	x	x	x	x	x	x	x	x	x	x	x
31. *Flagellaria indica* L.	Flagellariaceae, Sh	x	x	x	x	x	x	x	x	x	x	x	x	x
32. *Glochidion littorale* Bl.	Euphorbiaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
33. *Gluta velutina* Bl.	Anacardiaceae, Sm	?	x	x	x		x						x	x
34. *Guettarda speciosa* L.	Rubiaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
35. *Hibiscus tiliaceus* L.	Malvaceae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
36. *Hippomane mancinella* L.	Euphorbiaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
37. *Hoya obtusifolia* R. Br.	Asclepiadaceae, WC	x	x	x	x	x	x	x	x	x	x	x	x	x
38. *Inocarpus fagiler* (Parkinson) Fosberg	Leguminosae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
39. *Melaleuca leucadendron* L.	Myrtaceae, T	?	x	x	x		x						x	x
40. *Merope angulata* (Willd.) Swingle	Rutaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
41. *Myristica hollrungii* Warb.	Myristicaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
42. *Myrsine umbellulata* (Wall.) Merr.	Myrsinaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
43. *Ochthocharis borneensis* Bl.	Melastomataceae, Sh.	x	x	x	x	x	x	x	x	x	x	x	x	x
44. *Pandanus affinis* Kurz.	Pandanaceae, Sh	x	x	x	x	x	x	x	x	x	x	x	x	x
45. *Planchonella obovata* (R.Br.) Pierre	Sapotaceae, T		x	x	x		x	x				x	x	x
46. *Pluchea indica* (L.) Less.	Compositae. Sh	x	x	x	x	x	x	x	x	x	x	x	x	x
47. *Podocarpus polysrachyus* R.Br. ex Endl.	Podocarpaceae, Sm		x	x	x								x	x
48. *Pongamia pinnata* (L.) Pierre	Leguminosae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
49. *Portulaca quadrifida* L.	Portulacaceae, H	x				x	x	x	x	x	x	x		
50. *Premna obtusifolia* R.B.	Verbenaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
51. *Sapium indicum* Willd.	Euphorbiaceae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
52. *Sarcolobus banksii* R.& S.	Asclepiadaceae, Cl		x	x	x					x			x	x
53. *Scaevola taccada* (Gaertn.) Roxb.	Goodeniaceae. Sh	x	x	x	x	x	x	x	x	x	x	x	x	x
54. *Scirpus littoralis* Schrad.	Cyperaceae, H	x	x	x	x		x	x	x	x	x	x	x	x
55. *Scolopia macrophylla* (W.& A.) Clos.	Flacourtiaceae, T	x	x	x	x	x	x	x					x	x
56. *Sesuvium portulacastrum* (L.) L.	Aizoaceae, H							x	x	x	x	x		
57. *Sophora tomentosa* L.	Leguminosae, Sm	x	x	x	x	x	x	x	x	x	x	x	x	x
58. *Stemonurus secundiflorus* Bl.	Icacinaceae, Sm	x	x	x	x	x	x	x					x	x
59. *Thespesia populnea* (L.) Solander ex Correa	Malvaceae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
60. *Tristania* sp.	Theaceae, Sm	?	x	x	x		x						x	x
61. *Vitex ovata* Thunb.	Verbenaceae, Sh	x	x	x	x	x	x	x	x	x	x	x		
62. *V. pubescens* Vahl.	Verbenaceae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
63. *V. trifoliata* (Thunb.) Makino	Verbenaceae, T	x	x	x	x	x	x	x	x	x	x	x	x	x
64. *Wedelia biflora* (L.) DC.	Compositae, H	x	x	x	x	x	x	x	x	x	x	x	x	x

seems necessary to revise the genus *Ceriops* globally. Also, *Rhizophora lamarckii* occurs in Guinea (Irian Jaya and PNG) but reportedly found as new records in Bali and Lombok Islands [36] and Flores Island [98] and possibly in Natuna-Anambas Islands. My field data indicated that *Soneratia gulngai* is to be found in Bali, Lombok islands and Nusa Tenggara [35, 113], and *Avicennia integra* in Irian Jaya through Aru, Kai and Tanimbar islands[33, 34, 92, 114]. Recently, *Aegialitis rotundifolia* (Plumbaginaceae), *Bruguiera hanesii*, *Heritiera fomes* and *Kandelia candel* were found at small islands in Natuna-Anambas of the South China Sea, and at offshore islands of Aceh in the Indian Ocean [99, 107, 115-118]. Consequently, from present species record and its distribution (Tables 4-5), it appears that Indonesia is the interesting center of dispersal of modern-day mangrove floras. Thus Indonesian mangroves looking for strategic alliances and botanical exploration are the key words [20], GLOMIS-ISME, and World Mangrove Atlas [102] and therefore, should be revised.

My field data (Tables 1, 3) suggested that associate species fail to invade mangrove forests after disturbances, both man-made and natural or under stress. The plant communities (Table 3) which comprise the ISCS's mangroves are a consequence of natural recruitment but also human cultivation. Indonesian mangrove forests are therefore, floristically rich with at least 295 species represented (Tables 4-5) [83]. Most of these are migrant species and considered to be marginal species (Table 5). The presence of marginal species has been speculated, less written, and little experimental effort expanded, on the physiological relationship between the species and salinity. The high number of epiphytic species given by Giesen and Wulffrat [83] was found in Sumatra, Kalimantan and Irian Jaya and is associated with high rainfall (>1500 mm per year). The absence tends to indicate the dry climate in Nusa Tenggara [3].

Due to the unique position at the two continents, Asia and Australia and two oceans, Pacific and Indian, ISCS mangrove forests become a corridor and refuge habitat for migratory birds (e.g. *Limnodromus semipalmatus*, *Tringa guttifer*, *Pelicanus philippensis*), and as habitable forest for a specific fauna including birds (e.g. *Eopsaltria pulverulenta*, *Pachycephala melanura*), reptiles (e.g. *Tomistoma schlegelii*) and other animals of the two continents [119]. Five hundred thousand to one million migratory waders, including Asian Dowitcher (*Limnodromus semipalmatus*), Black-tailed Godwit (*Limosa limosa*), Terek Sandpiper (*Xenus cinereus*) and Common Redshank (*Tringa tetanus*) are dependent on the South Sumatran mangroves for feeding, roosting and wintering. Coastal area of the province ranks as one of the most important stop-over sites in the East Asian Flyway. Mangrove forests provide feeding, nesting, roosting and staging areas for many globally threatened wildlife species, such as Milky Stork (*Mycteria cinerea*), Spot-billed Pelican (*Pelicanus philippensis*), Lesser Adjutant (*Leptoptilos javanicus*), Great-billed Heron (*Ardea sumatrana*), Nordmann's Greenshank (*Tringa guttifer*), *L. semipalmatus*, Sumatran Tiger (*Panthera tigris sumatrana*), otters, Irrawaddi Dolphin (*Orcaella brefirostis*) and Estuarine Crocodile (*Crocodylus porosus*). Thus these are early indications that Indonesian mangrove forests are mega-biodiversity centres and are important for managing the balance of nature for threatened wildlife and the commercial marine and coastal species of both continents and oceans. Changes in the environmental settings regulate the exchange of water, energy and materials across coastal landscapes and can control the levels of biological diversity as well as primary and secondary productivity. However, it is interesting to note that the relationship between changes in biodiversity and ecosystem function is not easily quantified in mangrove ecosystems despite the extensive pool of information [120].

Mangrove habitats in Indonesia have extremely high conservation value, due to their apparent importance for marine and coastal fisheries [121] and usage by migratory wildlife [20]. The presence of large stocks of fishes, particularly juvenile, within Indonesian mangrove forests are important ecological aspects to be described more for their population dynamics such as residence times and growth rates [122]. To preserve and utilize the mangrove environment, it is necessary to quantitatively understand the unique hydrodynamic that constitutes the mangrove environment that supports the mangrove ecosystem. Conversion of mangrove forests destroys the natural nursery grounds of fish and shellfish. This is further aggravated by the conversion of inland freshwater swamp forests that diminished the area of freshwater habitat and affects the supply of water and nutrient to the spawning and nursery areas. There is a direct conflict of interest between MOMAF and MOF over the utilization of the mangrove swamp areas in both SFA and NSFA in terms of area as fisheries resource and forestry value. The conservation of mangrove plants and/or forests therefore, is of social and economic importance to fisheries, e.g. commercial shrimp. A statistically strong correlation between the areas of mangrove and shrimp fishery productivity in different parts of Indonesia was demonstrated by Martosubroto and Naamin [122]. Removal of the rain forests in the uplands and/or river basin or catchment's areas would be disastrous. The ecological basis for economic value of seafood production supported by mangrove ecosystem therefore should be quantified [123].

Mangrove forests are being degraded and removed, as people see little benefit in their continued existence relative to the benefits of short-term exploitation and conversion to other uses, e.g. Pantai Timur-Lampung for tambak [28]. It has always been stated that ISCS mangrove forests have been severely overcut, e.g. Sumatra and Kalimantan up to Sulawesi and Irian Jaya. Ironically, most mangrove forest areas have received very little attention with respect to management [124]. The areas being scattered over many thousands of islands, make it impossible to establish a general working plan, e.g. Riau Lingga archipelago [46, 48, 125]. Currently, large areas of many mangrove forests are getting depleted and degraded at an alarming rate (Table 2). The condition is aggravated by tsunami catastrophes. Also, the losses of mangrove forests (Table 2) are found in many localities along with very diverse flora. Mangrove rehabilitation is therefore needed to restore mangroves to productivity and to repair their important ecological function.

ISCS mangrove forests degradation (Table 2) and its environmental problems at local levels (provincial and district) are major issues not only in mangrove restoration ecology but in overall ecology of the coastal systems [52, 53]. Due to socio-cultural and economic function of mangrove forests at the local level where there are much diversified ethnic groups living in and around the mangrove forests, the relationship between changes in mangrove forest loss and biodiversity benefit is not easy to be quantified. Integration of multiple disciplines for the solution is needed, but this is not an easy task. Moreover, the integration of human use of mangrove environments and mangrove forest management implications through social and economic development required appropriate local community participation. The relation between people and mangrove forests is not always without problems. Different interest groups have different objectives towards the mangrove environment. There are many NGOs in Indonesia promoting nature conservation and conservation education on mangroves. Some organizations are also dedicated to maintaining the wisdom of indigenous natural resource management and raising awareness of local indigenous laws. One form of mangrove management is through the formulation of laws and rules. The GOI recognizes that public participation is essential to the successful implementation of National Strategy for Mangrove Ecosystem Management in Indonesia.

Indonesian mangroves warrant detailed consideration not only because of its commercial importance but also in view of its widespread distribution in all bigger islands, e.g. Sumatra, Borneo, Sulawesi, Irian Jaya, and the far greater amount of useful information now available on a national basis for this sharply differentiated and silviculturally interesting edaphic forest community. Furthermore, many mangrove plants are useful and are valuable in local and national economics [123]. Local people have a good knowledge of the flora. They depend on plants with which they make ample use. A wealth of knowledge awaits recording.

CONCLUSION

It can be concluded generally that the value of the Indonesian mangrove forests is not just of academic interest (e.g. *Kandelia obovata* in NatunaIslands) [21], it is also related to their cultural and commercial values. After the 26 December 2004 tsunami much awareness was generated, and currently, represent an important target for IUCN-MFF (MFF Focal Countries: India, Indonesia, Maldives, Seychelles, Sri Lanka and Thailand). Some Indonesian islands, such as ISCS, Irian Jaya, Sulawesi, and Mentawai, have been found to have very high levels of endemism. Lack of monitoring, due to insufficient funding and equipment, has caused many illegal fishing trips to operate in the country. Foreign fishers also often use unsustainable fishing practices (chemicals and bombs). All may have lead to its IUCN critical endangered status and being lost forever. World Summit on Sustainable Development (WSSD) or Earth Summit 2002 stated that mangrove forests are essential for maintaining global biodiversity in the coastal zone. The Global Environment Facility amounts to US$1,000 million just to initiate biodiversity support [8]. Indonesian mangrove forests are also a physiographic unit, the principal components of which are organisms. The problems therefore are predominantly of a biological nature. Moreover, Indonesia has also ratified the United Nations Framework Convention on Climate Change through Law No.6/1994. The National Action Plan has been formulated with assistance from NGOs. Past global changes encourage paleo-environmental and paleo-climate research efforts directed at securing a quantitative understanding of natural and human-induced variations of the earth system in the past, in order to make informed predictions of future climate, ecosystems and sustainability (IGBP 1991) [126]. Wolanski *et al.* [127] pointed out that each mangrove species has a unique configuration of trunks, prop-roots and pneumatophores that works as a different drag force and therefore results in a different reduction rate of sea waves. Thus, Indonesian mangrove ecosystems reflect the dynamics between climatic variations and localized sea level changes of coastal processes and biological interactions as well as interventions by human activities – past, present/today and tomorrow.

REFERENCES

1. Myers N., Mittermeier R.A., Mittermeier C.B., da Fonseca G.A.B. and Kent J. (2000) Hotspots: Earth's biologically richest and most endangered terrestrial ecoregions. *Nature* **403**:853-858.
2. Jacobs M. (1974) Botanical panorama of the Malesian archipelago (vascular plants). In UNESCO (ed.) *Natural resources of humid tropical Asia* pp. 263-294. Natural resources Research XII.

3. Steenis C.G.G.J.van (1962) The distribution of mangrove plant genera and it's significant for paleo-geography. Verh. K. ned. Akad. Wet. (Ser. C65) **2**: 164-169.
4. Steenis C.G.G.J.van (1958) Ecology (mangrove species). *Flora Malesiana Serie* **1**(5): 431-441.
5. Steenis C.G.G.J.van (1950) The delimitation of Malaysia and its main plant geographical devisions. *Flora Malesiana Serie* **1**(1): ixx-ixxv.
6. Steenis C.G.G.J.van (1941) Kustaanwas en mangrove. *Natuurw*. Tijdschr. Ned. Indie **101**: 82-85.
7. Steenis C.G.G.J.van (1935) Maleische vegetatie schetsen. *Tijdschr. K. Ned. Aardrijksk. Genot*. **52**: 363-398.
8. Bappenas (2003) *Indonesian biodiversity strategy and action plan 2003-2020*. GOI. 3vols.
9. Suyarso (2007) Kondisi dan sebaran geografis mangrove di P. Belitung Propinsi Bangka Belitung. In Ruyitno N. and Azis A. (Eds) *Sumberdaya laut dan lngkungan Bangka Belitung 2003-2007* pp. 103-113. Pusat Penelitian Oseanografi LIPI.
10. Suyarso and Pramudji (2007) Mangrove di kawasan teluk Klabat P. Bangka Propinsi Bangka Belitung. In Ruyitno N. and Azis A. (Eds) *Sumberdaya laut dan lngkungan Bangka Belitung 2003-2007* pp. 115-124. Pusat Penelitian Oseanografi LIPI.
11. Sukardjo S. (2006) Botanical exploration in small islands: 1. Floristic ecology and the vegetation types of Pari island. *South Pacific Studies* **26**(2): 73-100.
12. Suroyo and Suyarso (2000) *Kondisi dan inventarisasi hutan mangrove Teluk Lampung*. In Ruyitmo N., Atmadja W.S., Supangat I and Sudibyo B.S. (Eds) *Aspek oseanografi bagi peruntukan lahan di wilayaj pantai teluk Lampung* pp. 95-102. Pusat Penelitian dan Pengembangan Oseanologi LIPI Jakarta.
13. Suroyo (1997) Mangrove di kawasan laut China Selatan. In Suyarso (Ed.) *Atlas Oseanologi Laut China Selatan* pp. 11-122. Pusat Penelitian dan Pengembangan Oseanologi LIPI Jakarta.
14. Steenis C.G.G.J.van (1932) Botanical results of a trip to the Anambas and Natoena islands. *Bull. Jard. Buitenz*. (Ser.3) **12**: 151-211.
15. Pramudji and Suyarso (2002) Kajian hutan mangrove di beberapa daerah di Kepulauan Natuna Besar. In Ruyitno N and Aziz A. (Eds.) *Perairan Indonesia* pp. 81-88. PusLit Oseanografi LIPI Jakarta.
16. Kartana Y. (Ed.) (2007) *Rencana aksi strategis pengelolaan lingkungan pesisir dan laut secara terpadu Kabupaten Bintan dan Kora Batam*. KLH. 2vols.
17. Bappeda Kota Batam and Bakosurtanal (2007) *Pemetaan neraca dan valuasi ekonomi sumberdaya mangrove Kota batam, Propinsi Kep. Riau*. Skala 1:50,000.
18. Talaue-McManus L. (2000) Transboundary diagnosis analysis for the SCS. *EAS/RCU Technical Report Series* No.**14**: 1-106. UNEP Bangkok Thailand.
19. Rais S., Ruchiat Y., Sartono A. and Hideta T. (2007) *50 Taman Nasional di Indonesia*. MOF-GOI.
20. Sukardjo S. (2008) Safeguarding Indonesian mangroves – critical challenges and strategies. In Tan K.H., Ong J.E and Primavera J.H (Eds) *Proceedings of the International Conference and Exhibition on Mangroves of Indian and Western Pacific Oceans (ICEMAN)* pp.184-215. MIMA Kuala Lumpur Malaysia.
21. Sheue C.R., Liu H.J. and Yong J.W.H. (2003) Kandelia obovata (Rhizophoraceae), a new mangrove species from eastern Asia. *Taxon* **52**: 287-294.
22. Sheue C.R., Yong J.W.H. and Yang Y.P. (2005) The *Bruguiera* (Rhizophoraceae) species in mangroves of Singapore, especially on the new record and the rediscovery. *Taiwania* **50**(4): 251-260.
23. BPS (2003/2005) *Statistik Indonesia*. Biro Pusat Statistik Jakarta. 4vols.
24. Sukardjo S. (2000) Indonesia: mangrove-friendly aquaculture. In Primavera J.H. *et al*. (Eds) *Mangrove-Friendly Aquaculture* pp. 105-140. SEAFDEC, Iloilo, The Philippines.
25. PKSPL-IPB (2001) *Atlas sumberdaya wilayah pesisir dan laut Riau Kepulauan, Propinsi Riau*.
26. Santoso N. (2003) Conservation and rehabilitation of mangrove ecosystem inMuara Angke Wildlife Reserve and Rambut Island Wildlife Reserve as waterbirds habitat. In *Proceedings of the 1st Workshop of Ecotone Phase II and the 3rd Meeting of Southeast Asian Biosphere Reserve Network, Phnom Penh, Cambodia 26 October-1 November 2003* pp. 111-125. MAB UNESCO.
27. BP-DAS Way Seputih Way Sekampung (2005) Pengelolaan ekosistem mangrove pada kawasan pantai timur Propinsi Lampung. Paper presented at the *National Workshop on Mangrove Ecosystem management, Jakarta 17-18 July 2006*. 16 pp.
28. Pribadi R. (2006) Kemitraan dan strategi pengelolaan pesisir dan laut secara terpadu Kabupaten Lampung Selatan. Paper presented at the *Forum Pimpinan Daerah dan Lokakarya Pembangunan Berkelanjutan Wilayah Pesisir dan Laut Indonesia, Jakarta 25-27 April 2006*. 14 pp.
29. Tomlinson P.B. (1986) *The botany of mangroves*. Cambridge University Press.
30. Becking J.H., Berger L.G.den and Meindersma W.H. (1922) Vloed of mangrovebosschen in Ned.-Indie. *Tectona* **15**: 561-611.
31. Ding Hou (1951). cited in Backer, C.A and Bakhuizen R.C. van den Brink Jr. 1963-1968. *Flora of Java* Vol.I-III. Wolters-Noordhoff NV, Groningen, the Netherlands
32. Backer C.A. and Bakhuizen van den Brink Jr. R.C.

(1963-1968) *Flora of Java*. Vol.1-3. Noordhoff Groningen.

33. Duke N.C. (1991) A systematic revision of the mangrove genus Avicennia (Avicenniaceae) in Australia. *Aust. Syst. Bot.* 4: 299-324.
34. Duke N.C. (2006) *Australia's mangroves*. The University of Queensland, Australia.
35. Duke N.C. and Jackes B.R. (1987) A systematic revision of the mangrove genus Sonneratia (Sonneratiaceae) in Australasia. *Blumea* **32**: 277-302.
36. Kitamura S., Anwar C., Chaniago A. and Baba S. (1997) *Handbook of mangroves in Indonesia: Bali and Lombok*. ISME Japan.
37. Giesen W., Wulffraat S., Zieren M. and Scholten L. (2006) *Mangrove fuidebook for Southeast Asia*. FAO Bangkok.
38. Cox G.W. (1967) *Laboratory manual of general ecology*. Dubuque.
39. Soemodihardjo S., Woroatmodjo P., Mulia F. and Harahap M.K. (1996) Restoration of mangroves in Indonesia: a case study of Tembilahan Sumatra. In Field C (Ed.) *Restoration of mangrove ecosystems* pp. 97-110. ISME, Okinawa Japan.
40. Sukardjo S. and Kartawinata K. (1979) Mangrove forests of Banyuasin, Musi rver estuary, South Sumatra. *Biotrop Special Publication No.***10**: 61-68.
41. Kusmana C., Sukardjo S., Santosa N., Hernowo J.B, Priyono A. and Siregar A.F. (2007) *Inventory of flora fauna in the Batu Ampar demo-site, West Kalimantan Province*. LPPM Report, Bogor.
42. PemDa Tk. I Lampung (2005) Propinsi Lampung dalam angka. *Pemerintah Daerah Propinsi Lampung* **1**: 1-250.
43. Schuster W.H. (1949) De visculture in de Kustvijvers op Java. *Depart. Van Landbouw en Visserij Publicatie No.* **2**: 1-167.
44. Sukardjo S. and Akhmad S. (1982) The mangrove forests of Java and Bali, Indonesia. *Biotrop Special Publication No.***17**: 113-126.
45. Wind R. (1924) Mangrovebasten en extrakten and de mangrove. In *Mededeelingen van het proefstation voor het boschwezen* No. 9: 17-25, 53-148. Departement van Landbouw, Nijverheid en Handel in Nederlandsch-Indie.
46. Jonker H.A.J. (1933) De vloedbosschen van den Riouw-Lingga archipel. *Tectona* **26**: 717-741.
47. Danhof G.W. (1946) Over omloop en bedrijf van bakau-bakau in den Rioue-Lingga archipel. *Tectona* **26**: 60-72.
48. Steup F.K.M. (1946) Boschbeheer in de vloedbosschen van Riauw. *Tectona* **36**: 289-298.
49. PemDa Tk. I Riau (1999) Kondisi, permasalahan dan upaya daerah dalam pengelolaan hutan mangrove di Propinsi Riau. In Soemodihardjo S., Romomohtarto K and Suhardjono (Eds) *Prosiding Seminar VI Ekosistem Mangrove* pp. 45-61. LIPI Jakarta.
50. Bapedalda Kabupaten Bengkalis dan LPPM (2004) *Penyusunan pedoman dan pengkajian nilai ekonomi pengelolaan mangrove yang berwawasan lingkungan di Kabupaten Bengkalis, Propinsi Riau*. LPPM.
51. Saenger P. (2002) *Mangrove ecology, silviculture and conservation*. Kluwer Academic Publisher, The Netherlands.
52. Field C.D (Ed.) (1996) *Restoration of mangrove ecosystem*. ISME, Okinawa Japan.
53. Edwards A., Field C.D. and Fortes M. (Eds) (1999) Rehabilitation of coastal ecosystem. *Marine Pollution Bulletin* **37**(8-12): 371-557.
54. Sutrisno D. (2006) Menuju kemitraan dan tata pemerintahan yang lebih baik dalam pengelolaan wilayah pesisir dan laut secara terpadu. Paper presented at the *Forum Pimpinan Daerah dan Lokakarya Pembangunan Berkelanjutan Wilayah Pesisir dan Laut Indonesia, Jakarta 25-27 April 2006*. 9pp.
55. Mazda Y., Wolanski E. and Ridd P.V. (2007) *The role of physical processes in mangrove environment*. TERRAPUB, Tokyo.
56. Sukardjo S. (1989) Tumpang sari ponds as multiple use concept to save the mangrove forests in Java. *Biotrop Special Publication* No. **37**: 129-141.
57. Weinstock J.A. (1994) Rhizophora mangrove agroforestry. *Economic Botany* **48**(2): 210-213.
58. Troll W. and Dragendorf O. (1931) Ueber die Luftwurzeln von Sonneratia Linn.f. und inhere biologische Bedeutung. *Planta* **13**: 311-473.
59. Bemmelen R.W.van. (1949) General Biology. In *The geology of Indonesia Vol. 1a* pp. 298-302. Govt. Print., The Hague.
60. Sukardjo S. (1987) Conservation of the marine life of mangrove forests, estuaries and wetland vegetation in the Cimanuk nature reserve. *Biotrop Special Publication* No. **30**: 35-52.
61. Sukardjo S. (1984) The present status of mangrove forest ecosystem of Segara Anakan Cilacap. In Chadwick A.C. and Sutton S.L. (Eds) *Tropical rainforest - the Leeds Symposium* pp. 50-53. Special Publication of the Leeds Philos. And Lit. Soc., UK.
62. Hogarth P.J. (1999) *The biology of mangroves*. OxfordUniversity Press.
63. Ding Hou (1958) Rhizophoraceae. *Flora Malesiana Ser.* **1**(5): 429-493.
64. Macnae W. (1968) A general account of the fauna and flora of mangrove swamps and forest in the Indo-West Pacific region. *Adv. Mar. Biol.* **6**: 73-270.
65. Kint A. (1934) De luchtfoto en de topographische gesteldheid in de mangrove. *Trop. Natuur.* **23**: 717-741.
66. Steup F.K.M. (1936) Botanische aanteekeningen over Noord Celebes. IV. *Trop. Natuur.* **25**: 29-31.
67. Yamada I. and Sukardjo S. (1979) Ecological studies

of the mangrove and swamp forests in South Sumatra. *Southeast Asian Studies* **17**(3): 425-433.
68. Schuster W.H. (1952) Fish culture in brackish water pond of Java. *Special Publication Indo Pacific Fish Council* No.**1**: 1-143.
69. Postgate J. (1959) Sulphate reduction by bacteria. *Annual Review of Microbiology* **63**: 503-520.
70. Sukardjo S. (1994) Soils in the mangrove forests of the Apar nature reserve, Tanah Grogot, East Kalimantan. *Southeast Asian Studies* **32**(2): 485-398.
71. Chapman V.J. (1976) *Mangrove vegetation*. Vaduz, J. Cramer.
72. Cintron G., Lugo A.E., Pool D.J. and Morris G. (1978) Mangroves of arid environments in Puerto Rico and adjacent islands. *Biotropica* **10**(2): 110-121.
73. Semeniuk V. (1983) Mangroves distribution in northwest Australia in relationship to regional and local freshwater seepage. *Vegetatio* **53**: 11-31.
74. Naidoo G. (1980) Mangrove soils of the Beackwood are, Durban. J. of South *African Botany* **46**: 293-304.
75. Haan J.H.de. (1931) He teen ander over de Tjilatjapsche vloedbosshen. *Tectona* **24**: 39-76.
76. Sukardjo S. (1996) General ecology of mangroves in Indonesia. Paper presented at the *Workshop on National Strategy for the Mangrove Forest Management in Indonesia. Jakarta 26-27 June 1996.* 75 pp.
77. Lynch O.J. and Harwell E. (2002) *Whose natural resoutrces*? *Whose common good?* CIEL-ELSAM.
78. Ogino K. and Chihara M. (1988) *Biological system of mangroves: a report of east Indonesian mangroves expedition 1986*. Ehime University, Japan.
79. Tanaka J. and Chihara M. (1988) Macro-algae in Indonesian mangrove forests. *Bull. Nat. Sci. Muzeum Tokyo Ser. B*.**14**: 93-106.
80. Hyde K.D. (1989) Intertidal mangrove fungi from north Sumatra. *Canadian J. of Botany* **67**: 3078-3082.
81. Watson J.G. (1928) Mangrove forests of the Malay Peninsula. *Malayan Forest Records* **6**: 1-275.
82. Sukardjo S. (1987b) Natural regeneration status of commercial mangrove species, Rhizophora apiculata Bl. and Bruguiera gymnorrhiza (L.) Lmk. in the mangrove forests of Tanjung Bungin, Banyuasin district South Sumatra. *Forest Ecology and Management* **20**: 233-252.
83. Giesen W. and Wulffraat S. (1998) Indonesian mangroves part 1: plant diversity and vegetation. *Tropical Biodiversity* **5**(2): 99-111.
84. Balen S. van (1989) The terrestrial mangrove birds in Java. *Biotrop Special Publication* No.**37**: 193-206.
85. Djohan T.S. (1982) Species diversity of mangrove forest floor fauna in Segara Anakan and the Donan river. In Bird E.C.F. *et al.* (Eds) *Proceeding of the Workshop on Coastal Resources Management in the Cilacap region* pp. 146-159. LIPI and UNU Tokyo.
86. Verwey J. (1930) Einiges uber die biologie Ost-Indische mangrove krabben. *Treubia* **12**: 169-261.
87. Docters van Leeuwen W.M. (1927) Blumen und insekten auf einer kleinen korallen insel. *Ann. Jard. Bot. Buitenzorg* **37**: 1-31.
88. Davie J. and Sumardja E. (1997) The mangrove of East Java: an analysis of the impact of pond aquaculture on biodiversity and coastal ecological processes. *Tropical Biodiversity* **4**(1): 1-33.
89. Steenis C.G.G.J.van (1984) Three more mangrove trees growing locally in nature in freshwater. *Blumea* **29**: 395-397.
90. Bunning E. (1944) Botanische beobachtungen en in Sumatra. *Flora.N.S.* **37**: 334-344.
91. Bunning E. (1947) In die waldern nordsumatrans. *Flora.N.S.* **40**: 148-157.
92. Balgooy M.M.J.van (2001) Aru – a botanical promise. In Saw L.G. *et al.* (Eds), *Taxonomy: the Cornerstone of biodiversity* pp. 225-232. FRIM, Kepong Malaysia.
93. Troll W. (1933) Camptostemon schultzii Mart und *C.* philippensis Becc. Als neue vertreter der australasiatischen mangrove-vegetation. *Flora.N.S* **38**: 348-352.
94. Wells A.G. (1983) *Distribution of mangrove species in Australia*. In Teas H.J. (Ed.) *Biology and ecology of mangroves* pp. 57-76. Dr. W.Junk Publishers, The Hague Netherlands.
95. Sukardjo S. (1994) Conservation strategy of the mangrove forest in Indonesia: a functional consideration. In Well P.G. and Ricketts P.J. (Eds) *Coastal zone Canada '94 – Conference Proceedings Volume* **3**: 1062-1095. Coastal Zone Canada Association.
96. Hayashi S. and Chaniago A. (1995) Distribusi dan identifikasi jenis mangrove, suatu kajian ekosistem hutan mangrove di Pulau Lombok. In Soemodihardjo S., Wiroatmodjo P., Bandiyono S., Sudomo M and Suhardjono (Eds) *Prosiding Seminar V Ekosistem Mangrove* pp. 117-127. LIPI Jakarta.
97. Johnstone I.M. and Frodin D.G. (1982) Mangroves of the Papua sub-region. In Gressitt J.L. (Ed.) *Biogeography and ecology of New Guinea* pp. 513-528. Dr. W. Junk Publisher, The Netherlands.
98. Talu T.D. (2006) Komitmen dan strategi pengelolaan pesisir dan laut terpadu Propinsi Nusa Tengga Timur. Paper presented at the *Forum Pimpinan Daerah dan Lokakarya Pembangunan Berkelanjutan Wilayah Pesisir dan Laut Indonesia, Jakarta 25-27 April 2006.* 22 pp.
99. Steenis C.G.G.J.van (1949) Plumbaginaceae. *Flora Malesiana Serie* **I(4)**: 107-108.
100. Sukardjo S. (1995) Structure, litterfall and net primary production in the mangrove forests in the East Kalimantan. In Box E.O., Peet T.K., Masuzawa T., Yamada I., Fujiwara K and Maycock P.F. (Eds)

Vegetation science in forestry pp. 558-661. Kluwer Academic Publisher, The Netherlands.

101. Duke N.C., Ball M.C. and Ellison J.C. (1998) Factors influencing biodiversity and distributional gradients in mangroves. *Global ecology and Biogeography Letters* **7**: 27-47.

102. Spalding M., Blasco F. and Field C. (Eds) (1997) *World mangrove atlas*. The ISME, Okinawa, Japan.

103. Slooten D.V.van (1937) Die verbreitung von Lumnitzera und anderen mangrovevegewachsen. *Blumea Suppl*. **1**: 162-175.

104. Jones W.T. (1971) The field identification and distribution of mangroves in eastern Australia. Queenlands. *Naturalist* **30** (1-3): 35-51.

105. Percival M. and Womersley J.S. (1975) Floristics and ecology of the mangrove vegetation of PNG. *Botany Bulletin* No. 6. Department of Forestry, Division Botany, LAE PNG.

106. Ge X.J. and Sun M. (2001) Population structure of Ceriops tagal (Rhizophoraceae) in Thailand and China. *Wetlands Ecology and Management* **9**: 203-209.

107. Naskar K. and Mandal R. (1999) *Ecology and biodiversity of Indian mangroves*. Daya Publishing House, New Dehli.

108. Schimper A.F.W. (1891) *Die Indo-Malayische strandflora*. Bot/Mitteil. Trop. 3 Fisher Jena.

109. Exell A.W. (1954) *Combretaceae. Flora Malesiana Ser*. **1**(4): 533-589.

110. Tomlinson P.B., Bunt J.S., Primack R.B. and Duke N.C. (1978) *Lumnitzera rosea (*Combretaceae) – its status and floral morphology. *J. of the Arnold Arborectum* **59**(4): 342-351.

111. Duke N.C. (1990) Morphological variation in the mangrove genus Avicennia in Australasia: systematic and ecological consideration. *Aust. Syst. Bot*. **3**:221-239.

112. Blume, C.L. (1849) *Muzeum Botanicum* pp. 126-131

113. Duke N.C. (1984) A mangrove hybrid Sonneratia gulngai (Sonneratiaceae) from north-eastern Australia. *Austrobaileya* **2**(1): 103-105.

114. Duke N.C. (1988) An endemic species, *Avicennia integra* sp. nov. (Avicenniaceae) in northern Australia. *Aust. Syst. Bot*. **1**: 177-180.

115. Santisuk T. (1983) Taxonomy and distribution of terrestrial trees and shrubs in the mangrove formation in Thailand. *Nat. Hist. Bull. Siam Soc*. **31**(1): 63-91.

116. Aksornkoae S., Maxwell G.S., Havanond S. and Panichsuko S. (1992) *Plants in mangroves*. Chalongrat Publ. Bangkok.

117. Singh V.P. and Garge A. (1993) *Ecology of mangrove swamps of the Andaman Islands*. International Book Distributors, Dehradun.

118. Tam N.F.Y. and Wong Y.S. (2000) *Hongkong mangroves*. AFCD-CU of Hongkong.

119. Scott D.A. (1989) *A directory of Asian wetlands*. IUCN Gland Switzerlands.

120. Twilley R.R., Snedaker S.C., Yanes-Aranciba A. and Medina E. (1996) Biodiversity and ecosystem processes in tropical estuaries: perspective from mangrove ecosystem. In Mooney H., Cushman J.H., Medina E., Sala O.E and Schulze E.D. (Eds) *Biodiversity and Ecosystem Function: a global perspective* pp. 327-370. *Wiley*, New York.

121. Sukardjo S. (2004) Fisheries associated with mangrove ecosystem in Indonesia: a view from a mangrove ecologist. *Biotropia* **23**: 13-39.

122. Martosubroto P. and Naamin N. (1977) Relationship between tidal forests (mangroves) and commercial shrimp production in Indonesia. *Mar. Res. Ind*. **18**: 81-86.

123. Ronnback P. (1999) The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecological Economic* **29**: 235-240.

124. Sukardjo S., Affandi R., Mulyadi A.T., Ginting N. and Parry, D.E. (1997) *National strategy for mangroves management in Indonesia*. 2 vols. Ministry of Forestry, Republic of Indonesia. Jakarta.

125. Versteegh F. (1951) Proeve van een bedrijfsregeling voor de vloedbosschen van Bengkalis. *Tectona* **DLXLI**: 202-258.

126. IGBP (1991) *A study of global change*. Stockholm, Sweden.

127. Wolanski E., Mazda Y., Furukawa F., Ridd P., Kitheka J., Spagnolm S. and Stieglitz T. (2001) Water circulation in magroves and its implications for biodiversity. In Wolanski E. (Ed.) *Oceanographic processes of coral reefs* pp. 53-76. CRC Press, London.

Malaysian seaweed resources in the South China Sea and their potential economic and ecological applications

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Abstract The east coast of Peninsular Malaysia and the west coast of Sabah and Sarawak border Malaysia's South China Sea area. Malaysia is rich in marine algae (seaweed) resources. A total of 364 taxa of marine algae (seaweeds) are reported from the South China Sea area of Malaysia. This includes 8 families of Cyanophyta with 17 genera and 26 taxa; 14 families of Chlorophyta with 29 genera and 87 taxa; 26 families of Rhodophyta with 67 genera and 165 taxa and 8 families of Phaeophyta with 18 genera and 86 taxa. Many of the seaweeds have potential for commercialization based on a variety of products and uses. Seaweeds have been utilized in Malaysia for food, animal feed, fertiliser and traditional medicine. The search for novel bioactive compounds from marine algae has revealed tropical seaweeds to be a potentially important source. Seaweeds are useful for environmental management and can be used in integrated multi-trophic aquaculture system for remediation of aquaculture wastes. The seaweed biomass generated is a potential source of biofuel.

Keywords Malaysia – seaweeds – carrageenan – biopharmaceuticals – biofuel – bioremediation

INTRODUCTION

The east coast of Peninsular Malaysia, the west coast of Sabah and Sarawak borders Malaysia's South China Sea area. In the context of the Large Marine Ecosystem (LME), the waters closer to the east coast of Peninsular Malaysia belong to the Gulf of Thailand LME [1], while the open waters all the way to the west coasts of Sabah and Sarawak are included in the South China Sea LME. Both the LMEs are productive (150->300 $gC.m^{-2}.yr^{-1}$) with high marine biodiversity [1, 2]. Many rivers drain into the South China Sea and contribute to the nutrient loads, especially around the estuaries, resulting in high productivities. Marine fisheries provide a major protein source especially for the coastal communities in Malaysia. Seaweeds which have been traditionally used as food, are now cultured for the industrial production of the phycocollod carrageenan [3, 4].

SEAWEED RESOURCES OF MALAYSIA

Malaysia is rich in marine algae (seaweed) resources. Phang et al. (2007) [5] reported 386 taxa of marine algae, comprising Chlorophyta (13 families, 102 taxa), Rhodophyta (27 families, 182 taxa), Phaeophyta (8 families, 85 taxa) and Cyanophyta (8 families, 17 taxa). Many of these seaweeds are found along the coastline and around the many islands of Malaysia, which face the South China Sea. Appendix 1 lists the seaweeds reported for the South China Sea area of Malaysia. There are at least 364 taxa of seaweeds in Malaysia's South China area – 242 taxa (1 blue-green, 60 green, 114 red and 67 brown seaweeds) reported in Phang *et al.* [5]; 15 taxa (4 green and 11 red seaweeds) reported for Pulau Tioman, Pahang in Phang *et al.* [6]; 3 taxa (brown seaweeds) reported in Lim *et al.* [7]; 1 taxa (brown seaweed) in Phang *et al.* [8]; 90 taxa (24 blue-green, 19 green, 35 red and 12 brown seaweeds) reported for Terengganu in Gan *et al.* [9]; 1 taxa (brown seaweed) reported in Lim *et al.* [10]; and 12 taxa (1 blue-green, 4 green, 5 red and 2 brown seaweeds) reported in Phang *et al.* [11].

UTILISATION OF MALAYSIAN SEAWEEDS

Many of the seaweeds have potential for commercialization based on a variety of products and uses. Seaweeds have been utilized in Malaysia for food, animal feed, fertiliser and traditional medicine

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Sustainability of Large Marine Ecosystems of Southeast Asia

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Abstract The Large Marine Ecosystems (LMEs) of Southeast Asia are presently undergoing change under the influence of growing economic development and human population growth. Four of the region's LMEs – South China Sea, Sulu-Celebes Sea, Indonesian Sea, and Gulf of Thailand – are undergoing ecological disturbances from overfishing, loss of coastal habitats (e.g. sea grasses, mangroves, coral reefs) and biodiversity, nutrient over-enrichment, increasing pollution and vulnerability to climate change. These four LMEs produce an average annual marine biomass yield of 10.8 mmt representing 15.6 percent of the world's catch valued at nine billion dollars. Recent analyses indicate that climate change and global warming have not adversely affected the continuing rapid rise of fishery biomass yields in the four Southeast Asian LMEs. However, nutrient over-enrichment, particularly from dissolved inorganic nitrogen from fertilizers, manure, and sewage estimated at 100,000 to 2.5 million tons per year is entering the four coastal ecosystems at unprecedented rates and contributing to the increased frequency and extent of oxygen depletion events leading to dead zones, harmful algal blooms and fish mortalities. In recognition of the need to introduce ecosystem-based assessment and management actions, countries in the region have requested and been granted financial assistance from the Global Environment Facility and World Bank for implementing a five-module (productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance) LME approach for the recovery and sustainability of depleted fish stocks, the mitigation of nutrient over-enrichment, the conservation of biodiversity and adaptation to climate change.

Keywords Large Marine Ecosystems (LMEs) – LME Approach – Southeast Asia – sustainable marine ecosystems

THE LARGE MARINE ECOSYSTEM APPROACH

A global movement that applies an ecosystem based management (EBM) approach to recover and sustain marine goods and services is presently being practiced in a growing number of developing countries. It is known as the Large Marine Ecosystem (LME) approach, and it is being endorsed and supported by governments world-wide, as well as by financial institutions including the Global Environment Facility, the World Bank and by a broad constituency in the scientific community [1].

While we concur with the movement toward an ecosystem-based approach to the management of marine fisheries [2], it is important to recognize that a broader, place-based approach to marine ecosystem assessment and management, focused on clearly delineated ecosystem units, is needed and is presently underway, with the support of financial grants, and donor and UN partnerships, in nations of Africa, Asia, Latin America and eastern Europe.

The LMEs are natural regions of coastal ocean space encompassing waters from river basins and estuaries to the seaward boundaries of continental shelves and offshore margins of coastal currents and water masses. They are relatively large regions characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations [3]. It is within the boundaries of 64 LMEs (Fig. 1), that 80% of mean annual marine fisheries yields is produced, overfishing is most severe, marine

[3, 12]. Seaweeds like *Gracilaria changii, G. edulis, G. salicornia, G. tenuispitata* and *Gelidium* spp. are used as salads and for the preparation of desserts such as *agar-agar*. In Peninsular Malaysia, there is some collection of natural populations of *Gracilaria* and *Caulerpa* for local consumption. During fasting months, fresh *Gracilaria* or *sarer* is sold in the eastern states (Kelantan and Terengganu) of Peninsular Malaysia for use as salads.

In Sabah *Eucheuma*, *Solieria* and *Caulerpa* are collected and eaten either raw or blanched in salads. In the Chinese medicine shops one can buy dried *Sargassum, Turbinaria* and *Ulva* of unknown origin, which are popularly used by the Chinese in a soup considered as a rich source of iodine and which 'cools' the body system. The nutritional value of Malaysian seaweeds is little known except for a few reports. Chu et al. [13] reported on the lipid and fatty-acid content of selected seaweeds. Nine species of seaweeds were analyzed for fatty acid composition, and *Dictyota dichotoma* was found to contain the highest (17.6% ash-free dry wt) amount of lipids. All the seaweeds contained eicosapentaenoic acid ranging from 2.4 to 10.7% total fatty acid, with *Gracilaria edulis* having the highest content. Three species of Malaysian seaweeds *Eucheuma cottonii, Caulerpa lentillifera* and *Sargassum polycystum*, were analyzed for their nutrient content [14]. The seaweeds were high in ash (up to 46%) and dietary fibres (up to 40%) and low in lipids (up to 1.11%) on a dry weight basis. The crude protein content of *Eucheuma* (9.76% DW) and *Caulerpa* (10.41% DW) were higher than *Sargassum* (5.4% DW). All three seaweeds were rich in vitamin C and α-tocopherol (up to 11.3 mg/100g).

Malaysia has a small seaweed industry located in Sabah. There are three companies culturing red seaweeds, mainly *Kappaphycus* and *Eucheuma*, with two factories (Tacara and Omnigel) producing semi-refined carrageenan and chips in Tawau, while the newest factory, Genius Ocean, produces refined carrageenan in Semporna, Sabah. In the period 2000-2003, the seaweed production ranged from 2565 to 4101 metric tonnes bringing a revenue ranging from RM 6 to 14 million per annum [15]. Fishing families around Semporna are involved in the mariculture of the *Eucheuma* using the monofilament techniques in the reefs fringing the islands near Semporna. The monthly production from Semporna is around 60 to 100 tonnes dry wt per month [12]. The harvested seaweed is sun dried on the platforms of houses built on the reefs and sold at RM 1.10 (US$1 = RM3.5) per kg dry wt to the carrageenan producers. The carrageenan is used mainly for jelly and puddings, processed meat and blends for sauces [16]. *Gracilaria changii*, a good source of high quality agar and agarose [3] has also been experimentally cultivated in shrimp ponds, mangrove ponds and irrigation canals [17]. Unlike *Eucheuma*, *Gracilaria* farming has not gone large-scale, probably because there are no large agar factories in the region. A small cottage-scale agar factory was operating in Sungei Buloh, Selangor in the 1990s but closed down after a short period. The *Gracilaria* was imported from Thailand (Shaharuddin Shaffei, personal communication).

The search for novel bioactive compounds from marine algae has revealed tropical seaweeds to be a potentially important source [18-21]. Bioactive properties of seaweeds range from antiviral to antioxidant, immunostimulatory, anti-coagulant, anti-thrombic and anti-inflammatory. Traditionally coralline algae like *Corallina* and *Amphiroa* are crushed and fed to children to expel worms [3]. *Halimeda opuntia, Acanthophora spicifera, Laurencia, Eucheuma spinosum, Gracilaria* sp., *Hypnea musciformis*, *Dictyopteris* sp., and *Sargassum* spp. contain antibiotic compounds. Three species of *Laurencia* collected from Terengganu and Pulau Tioman, Pahang, contain brominated metabolites, tiomanen, acetylmajapoleneB and acetylmajopolene A [22]. Some of these compounds show moderate antibacterial activity against selected marine bacteria. Of eight edible seaweed species from Sabah, *Caulerpa lentillifera*, *C. racemosa* and *Sargassum polycystum* show higher phenolic content and anti-oxidant properties [23]. These tropical seaweed resources have great potential for development as food, feed and sources of biopharmaceutical products in addition to industrial colloids [4].

SEAWEEDS AND THE ENIVIRONMENTAL MANAGEMENT OF THE SOUTH CHINA SEA

Seaweeds as 'nutrient scrubbers'

Seaweeds are good for wastewater treatment because:

1. they can use specific nutrients and combinations of nutrients as well as tolerate the high nutrient levels in wastewaters – e.g. they can take up ammonium, and can take up and accumulate phosphorus even when external phosphorus levels are high;

2. they have high tolerance for environmental conditions like extremes of temperature, light, salinity – e.g. *Enteromorpha* is very tolerant of salinity which can range from >30 to < 3 ppt;
3. they can accumulate heavy metals;
4. they can use multispecies systems with different growth and reproduction periods to treat wastes which may vary with the seasons;
5. they have high productivity potential; and
6. their biomass can be used as manure, fodder, production of biochemicals or bioenergy [24].

An ecologically friendly aquaculture system where seaweeds, herbivores, omnivores and detritivores are cultured in an integrated multi-trophic system, can provide for a sustainable aquaculture industry [25, 26]. The use of two seaweed species, *Gracilaria chilensis* and *Macrocystis pyrifera*, with differing light requirements allow the *Gracilaria* to be cultured in the upper portion of the water column, resulting in increased efficiency and effectivenss as biofilters in an integrated aquaculture system [27]. *Gracilaria* can be cultured in shrimp ponds, where the seaweed removes dissolved nutrients from the excess feed of the shrimps, thereby cleaning up the water, and produce a useful biomass for extraction of agar and agarose or any other useful biochemicals [17]. The seaweeds can also be used to feed aquaculture species like abalone. The young larvae find protection amongst the seaweeds from predators and the seaweeds also produce oxygen and remove carbon dioxide, thereby contributing to reduction in global warming simultaneously.

Seaweeds as carbon sequesters

Marine photosynthesis accounts for 50% (59 $Pg.C.y^{-1}$) of the total primary productivity of the earth, while marine macrophytes like seaweeds and seagrasses in the coastal areas contribute about 1$PgC.y^{-1}$ [28]. Seaweeds have high productivities and can serve as efficient carbon removers from the marine environment [29]. The brown seaweed *Laminaria japonica* is projected to have an annual production of 1300 $t.ha^{-1}$ FW or 6.5 times the maximum yield of a terrestrial crop like the sugar cane. In the tropics, *Eucheuma* have productivities around 1440$g.m^{-2}.y^{-1}C$ [29]. Increased CO_2 concentrations have also been shown to increase nitrogen uptake by two *Gracilaria* species [30]. Net primary productivity in seaweeds ranges from 20 $gC.m^{-2}.d^{-1}$ (*Laminaria solidungula* in the Arctic) to 1900 $gC.m^{-2}.d^{-1}$ (*Laminaria* in the temperate) and 2500 $gC.m^{-2}.d^{-1}$ (*Sargassum* in the tropics). In Sabah, *Eucheuma* and *Kappaphycus* are maricultured to provide biomass for the extraction of carrageenan [4], giving an annual production around 2800 mt and generating a revenue of US$5 million.

In line with Malaysia's National Agriculture Policy, aquaculture including seaweed cultivation, has been identified as a priority development activity. Todate only 800 ha is under seaweed cultivation, mainly around Semporna, Sabah. More than 20,000 ha of coastal areas throughout Sabah have been identified as potential sites for farming seaweeds [15]. The agarophyte *Gracilaria* has also been identified as a potential seaweed for commercialization [4]. With an extensive coastline of 4675 km, numerous islands and extensive continental shelves, the potential for developing seaweed 'forests' is immense and the mitigating effect substantial. However, whether seaweed cultivation can contribute to management of carbon dioxide, will reside to a large extent on the productivities achieved with or without fertilization, and the ultimate fate of the biomass. The carbon budget has to be drawn for a seaweed farm and with respect to each potential use of the seaweed biomass, e.g. as a source of ethanol, food [13] or industrial material [16]. In seaweed cultivation, the use of the seaweed biomass as a source of energy will best serve its role in carbon reduction. The capture of cool, nutrient-rich deep sea water for use in extending the biogeographical range of temperate seaweeds has also been suggested. Tank cultivation of *Ulva prolifera* using deep seawater was found to produce growth rate of 37% daily growth rates [31].

SEAWEEDS AS A SOURCE OF BIOFUEL

Malaysia has invested in the production of biodiesel from plant sources including lipids from palm oil and jatropha. Microalgae are being investigated as an alternative feedstock for biodiesel production. While high lipid microalgal strains are available, their capacity to grow fast and produce high lipid contents depends very much on an optimized bioreactor system. Various designs, ranging from bioreactors floating in the ocean to serpentine and coiled tubular reactors, are available for culture in the sea.

The oil content of microalgae can range from 16 to 68% dry weight [32]. The oil yield from microalgae can reach up to 136,900 L/ha compared to other plant crops, which range from 172 to 5950

L/ha [32]. Microalgae produce a variety of lipids including triglycerides, hydrocarbons, glycolipids and phospholipids [33]. While most algae produce triglycerides as the major lipids, *Botryococcus braunii* contains high amounts of hydrocarbons, which can be converted to gasoline and light and heavy cycle oil after subjected to cracking process [34].

Microalgae appear to be the only source of biodiesel that has the great potential to replace fossil diesel [32]. Unlike other oil crops, microalgae grow very fast, most can double their biomass within 24 h. High productivity of biomass can be attained using photobioreactors, which do not require large land areas compared to other crop plants. High algal biomass production can also be attained at lower costs using high rate algae ponds [35]. Furthermore, using microalgae to produce biodiesel will not compromise production of food, fodder and other products derived from crops.

Microalgae can either be grown on organic carbon through heterotrophic mode or on inorganic carbon (CO_2 or HCO_3^-) through photoautotrophic mode. One of the potential microalgae for biodiesel production is *Chlorella protothecoides* [36]. The microalga produces a crude lipid content of 55.2% dry weight when grown under heterotrophic condition on glucose. The biodiesel produced is of high quality, with high heating value and viscosity [36]. Cheap organic carbon sources such as molasses can be used to substitute glucose or acetate for growing microalgae on heterotrophic mode [35]. A slurry of *Chlorella vulgaris* mixed with transesterified rapeseed oil and a surfactant has been shown to be useful as fuel in a diesel engine [37].

An added advantage of using photoautotrophic microalgae is that they can fix CO_2. Using such system, any CO_2 released on combustion of the biodiesel will have been previously fixed, therefore, the energy supply will be CO_2 neutral [37]. Furthermore, such system has great potential for CO_2 mitigation. Recently, De Morais and Costa [38] demonstrated that microalgae such as *Spirulina* and *Scenedesmus obliquus* are efficient in removing CO_2. An integrated system using microalgae to remove CO_2 emitted from industrial sources and power plants, and for the production of biodiesel will be an attractive approach.

Seaweeds contain biomaterials in their cell walls and as storage products, which are amenable to bioconversion to bioethanol. World ethanol production is about 51,000 million L with 73% used as fuel, 17% as beverage and 10% as industrial ethanol [39]. In Malaysia Renewable Energy (RE) is considered the 5th Fuel after gas, oil, coal and hydro. Investment in biofuels may rise to US$100 billion by 2010. Malaysia with high solar irradiance has potential for converting solar energy into both electricity as well as biomass which in turn can be the sources of both biodiesel and bioethanol. Fuel ethanol is currently produced from corn, sugar cane and other lignocellulosic biomass [40]. Cellulosic and hemicellulosic compounds derived from wood wastes (e.g. from construction activities) can be treated with yeast to produce >5w/v% ethanol. Bioethanol can be a supplement to petrol or gasoline.

Limiting steps in the production of bioethanol from biomass (like algae) include: appropriate species with high quantity and quality of fermentable biomaterials (feedstock) and high photosynthetic efficiency; mass culture and harvest of the biomass; metabolic control of the biomaterials; biorefining techniques to isolate biofuel precursors; and process optimisation of the fermentation.

Advantage of using algae is that they, unlike terrestrial biomass resources, will not result in higher food prices, impact on water use, biodiversity and destruction of rain forest. The production of renewable energy from algae can be carbon neutral, if not carbon-reducing. With use of corn and sugar cane for ethanol production, reduction in carbon emission may be up to 56% but with seaweeds, carbon reduction may be potentially up to 90%. For biofuel production the algal biomass needs to be produced at a cost of around one dollar or less per kilogramme. In order to achieve this ambitious goal there is the need for year-round reliable high productivity algal culture and all factors need to be optimized and efficiently integrated.

Integration of algal biomass production with waste bioremediation is one way of reducing the cost of production while contributing to pollution abatement. Effluent from aquaculture causes eutrophication problems to surrounding waters. The effluent contains nutrients in the form of phosphorus, nitrogen and dissolved organic matter. Pond sludge is also a big problem in shrimp farming. These wastes can be used to provide the substrates for growing the marine algae. The combined roles of the marine algae, that is the bioremediation of aquaculture effluent and the production of a renewable energy source (bioethanol) make the systems an economically viable one. Integrated farming is already being used in some countries and can be easily incorporated into the Malaysian scenario. In addition the growth of the algae will also be removing carbon dioxide from the environment, thereby contributing to the reduction in global warming. In Sabah, the red seaweeds *Eucheuma* and *Kappaphycus* give productivities of up to 46 gDW per m^2 per day, indicting the potential of seaweed biomass production for fuel [4, 41]. Analysis of selected Malaysian seaweeds show that the carbohydrate content can reach 24% DW (unpublished data). This indicates their potential for bioconversion to bioethanol, a potentially important source of renewable energy.

The integration of seaweed culture with bioremediation of wastes like aquaculture effluents and carbon dioxide from industries and oil refineries, will contribute to both economic and ecological enhancement in the South China Sea region. This will bring great benefits to the aquaculture industry, the biofuel industry as well as the global environment.

REFERENCES

1. Heileman S. and Chuenpagdee R. (2008) Gulf of Tahiland. In Sheman K. and Hempel G. (eds) *The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No.182* pp. 255-267. United Nations Environment Programme. Nairobi, Kenya.
2. Heileman S. (2008) South China Sea LME. In Sheman K. and Hempel G. (eds) *The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No.182* pp. 297-308. United Nations Environment Programme. Nairobi, Kenya.
3. Phang S.M. (1984) Seaweed resources of Malaysia. *Wallaceana* **33**: 3-8.
4. Phang S.M. (2006) Seaweed Resources in Malaysia: Current status and future prospects. *Aquatic Ecosystem Health & Management* **9(2)**: 185-202.
5. Phang S.M., Wong C.L., Lim P.E., Ooi J.L.S., Gan S.Y., Ismail M., Yeong H.Y. & Mustafa E.M. (2007). Seaweed Diversity in Malaysia. In: Chua L.S.L., Kirton L.G. & Saw L.G. (eds) *Status of Biological Diversity in Malaysia and Threat Assessment of Plant Species in Malaysia*. Pp 185-210. Forest Research Institute Malaysia.
6. Phang S.M., Wong C.L., Yeong H.Y. and Masuda M. (2008) Marine algae of Pulau Tioman, East Coast Peninsular Malaysia. In Phang S.M., Amri A.Y., Ooi L.S.J. and Mydin H.A.J. (eds.) *Natural history of the Pulau Tioman group of Islands* pp. 19-34. Institute of Ocean and Earth Sciences, University of Malaya Monograph Series 1, Malaysia.
7. Lim P.E., Kawai H., Phang S.M. (2008) Some Ralfsiales from Malaysia. In Phang S.M., Lewmanomont K., Lim P.E. (eds.) *Taxonomy of Southeast Asian Seaweeds* pp. 77-81. Institute of Ocean and Earth Sciences, University of Malaya Monograph Series 2, Malaysia.
8. Phang S.M., Wong C.L., Ng W.S. and Sim M.C. (2008) Checklist of Malaysian Sargassum species. In Phang S.M., Lewmanomont K., Lim P.E. (eds.) *Taxonomy of Southeast Asian Seaweeds* pp. 83-103. Institute of Ocean and Earth Sciences, University of Malaya Monograph Series 2, Malaysia.
9. Gan M.H., Orosco C.A. and Maya Sofia M. K. A. (2008) *Checklist of Terengganu seaweeds: With emphasis on East Coast Peninsular Expedition I 2005*. In Phang S.M., Lewmanomont K. and Lim P.E. (eds.) *Taxonomy of Southeast Asian Seaweeds* pp. 159-178. Institute of Ocean and Earth Sciences, University of Malaya Monograph Series 2, Malaysia.
10. Lim P.E., Sakaguchi M., Hanyuda T., Kogame K., Phang S.M. and Kawai H. (2007) Molecular phylogeny of crustose brown algae (Ralfsiales, Phaeophyceae) inferred from *rbc*L sequences resulting in the proposal for Neoralfsiaceae fam. nov. *Phycologia* **46(4)**: 456-466.
11. Phang S.M., Lim P.E., Yeong H.Y., Ng W.S. and Song S.L. (2010) Marine Algae collected during the Scientific Expedition to Bachok, Kelantan and the Islands of Terengganu with One New Record, Pterocladia for Malaysia. *Malaysian Journal of Science* **29**:31-46.
12. Phang S.M. (1998) The Seaweed Resources of Malaysia. In Critchley A. and Ohno M. (eds). *Seaweed Resources of the World* pp. 79-91. *JICA publication*
13. Chu W.L., Norazmi Mohamed and Phang S.M. (2003) Fatty-acid composition of some Malaysian seaweeds. *Malaysian Journal of Science* **22(2)**: 21-27.
14. Matanjun P., Mohamed S., Mustapha N.M. and Muhammad K. (2009) Nutrient content of tropical edible seaweeds, *Eucheuma cottonii, Caulerpa lentillifera* and *Sargassum polycystum*. *Journal of Applied Phycology* **21(1)**: 75-80.
15. Ahmad S. (2006) Seaweed industry in Sabah, east Malaysia. In Phang S.M., Critchley A.T. and Ang P.O. Jr. (eds.) *Advances in Seaweed Cultivation and Utilisation in Asia* pp. 41-52. University of Malaya Maritime Research Centre Publication, Malaysia.
16. Young D. (2006) TACARA natural carrageenan production. In Phang S.M., Critchley A.T. and Ang P.O. Jr. (eds.) *Advances in Seaweed Cultivation and Utilisation in Asia* pp. 153-160. University of Malaya Maritime Research Centre Publication, Malaysia.
17. Phang S.M., Shafeei Shaharuddin, Hashim Noraishah and Sasekumar A. (1996) Studies on *Gracilaria*

changii (Gracilariales, Rhodophyta) from Malaysian mangroves. *Hydrobiologia* **327**: 347-352.

18. Masuda M., Abe T., Kogame K., Kawaguchi S., Phang S.M., Daitoh M., Sakai T., Takahashi Y. and Suzuki M. (2002) Taxonomic notes on marine algae of Malaysia VIII. Three species of *Laurencia* (Rhodophyceae). *Botanica Marina* **45(6)**: 571-579.
19. Varaippan C.S. (2003) Potent antibacterial activity of halogenated metabolites from Malaysian red algae, *Laurencia majusculea (*Rhodomelaceae, Ceramiales). *Biomolecular Engineering* **20**:255-259.
20. Vairappan C.S., Ang M.Y., Ong C.Y. and Phang S.M. (2004) Biologically active polybrominated indoles in the red alga *Laurencia similis* from the coastal waters of Sabah (Rhodomelaceae, Ceramiales). *Malaysian Journal of Science* **23 (2)**: 119-126.
21. Varaippan C.S. and Phang S.M. (2005) Morphology and Halochamegrene Metabolite Content of *Laurencia majuscule* (Rhodomelaceae, Ceramiales) from the Spratly Islands. *Malaysian Journal of Science* **24(2)**: 29-36.
22. Varaippan C.S., Suzuki M., Ishii T., Okino T., Abe T. and Masuda M. (2008) Antibacterial activity of halogenated sesquiterpenes from Malaysian *Laurencia* spp. *Phytochemistry* **69**: 2490-2494.
23. Matanjun P., Mohamed S., Mustapha N.M., Muhammad K. and Ming C.H. (2008) Antioxidant activities and phenolics content of eight species of seaweeds from north Borneo. *Journal of Applied Phycology* **20(4)**: 367-374.
24. Schramm W. (1991) Seaweeds for wastewater treatment and recycling of nutrients. In Guiry M.D. and Blunden G. (eds.*) Seaweed Resources in Europe: Uses and Potential* pp. 149-168. John Wiley and Sons.
25. Neori A. (2008) Essential role of seaweed cultivation in integrated multi-trophic aquaculture farms for global expansion of mariculture: an analysis. *Journal of Applied Phycology* **20(5)**: 117-120.
26. Robertson-Andersson D.V., Potgieter M., Hansen J., Bolton J.J., Troell M., Anderson R.J., Halling C. and Probyn T. (2008) Integrated seaweed cultivation on an abalone farm in South Africa. *Journal of Applied Phycology* **20(5)**: 129-145.
27. Buschmann A.H., Variela D.A., Hernandez-Gonzalez M.C. and Huovinen P. (2008) Opportunities and challenges for the development of an integrated seaweed-based aquaculture activity in Chile: determining the physiological capabilities of *Macrocystis* and *Gracilaria* as biofilters. *Journal of Applied Phycology* **20(5)**: 121-127.
28. Chung I.K., Beardall J., Mehta S., Sahoo D. and Stojkovic S. (2007) Using marine algae for carbon sequestration: a critical appraisal. In Proceedings *3rd Workshop on Asian Network for Using Algae as Carbon Sinks*. pp. 33-38. UNCCC Side Event, Bali, Indonesia.
29. Gao K. and McKinley K.R. (1994) Use of macroalgae for marine biomass production and CO_2 remediation:a review. *Journal of Applied Phycology* **6(1)**: 45-60.
30. Gao K., Aruga Y., Asada K. and Kiyohara M. (1993). Influence of enhanced CO_2 on growth and photosynthesis of the red algae *Gracilaria* sp. and *G. chilensis. Journal of Applied Phycology* **5**:563-571.
31. Hiraoka M. and Oka N. (2008) Tank cultivation of *Ulva prolifera* in deep seawater using a new "germling cluster" method. *Journal of Applied Phycology* **20(1)**: 97-102.
32. Chistie Y. (2007). Biodiesel from microalgae. *Biotechology Advances* **25**: 294 – 306.
33. Chu W.L., Phang S.M. and Goh S.H. (1992) Microalgal lipids. *Malaysian Oil Science and Technology* **1(2)**: 37-40.
34. Banerjee A., Sharma R., Chisti Y. and Banerjee U.C. (2002) *Botryococcus braunii*: a renewable source of hydrocarbons and other chemicals. *Critical Reviews in Biotechnology* **23(3)**: 245 -279.
35. Phang S.M., Chui Y.Y., Kumaran G., Jeyaratnam S. and Hashim M.A. (2001) High Rate Algal Ponds For Treatment of Wastewater. A Case Study for the Rubber Industry. In Kojima H. and Lee Y.K. (eds.) *Photosynthetic microorganisms in environmental Biotechnology* pp. 51-76. Springer, Hong Kong.
36. Xu H., Miao X. and Wu Q. (2006) High quality biodiesel production from a microalga *Chlorella protothecoides* by heterotrophic growth in fermenters. *Journal of Biotechnology* **126**: 499 – 507.
37. Scragg A.H., Morrison J. and Shales S.W. (2003) The use of a fuel containing *Chlorella vulgaris* in a diesel engine. *Enzyme and Microbial Technology* **33**: 884 – 889.
38. De Morais M.G. and Costa J.A.V. (2007) Biofixation of carbon dioxide by *Spirulina* sp. *Scenedesmus obliquus* cultivated in a three-stage serial tubular photobioreactor. *Journal of Biotechnology* **129(3)**: 435-445.
39. Sanchez O.J. and Cardonna C.A. (2008) Trends in biotechnological production of fuel ethanol from different feedstocks. *Bioresource Technology* **99**: 5270-5295.
40. Pauly M. and Keegstra K. (2008) Cell wall carbohydrates and their modification as a resource for biofuels. *The Plant Journal* **54**: 559-568.
41. Phang S.M., Critchley A.T. and Ang P.O. Jr. (2006) Advances in Seaweed Cultivation and Utilisation in Asia. pp. 177 University of Malaya Maritime Research Centre ISBN 983-9576-30-5

Appendix 1. Checklist of South China Sea marine algae.

Taxa	Location	Reference
Division Cyanophyta		
Order Nostocales		
Family Nostocaceae		
Anabaenopsis sp V.V. Miller	Marine Park, Pulau Pinang, Terengganu	[9]
Trichormus variabilis (Kützing) Komárek & Anagnostidis	Pantai Chandering; Terengganu Pantai Kuala Abang, Terengganu	[9]
Family Rivulariaceae		
Calothrix contarenii (Zanardini) Bornet & Flahault	Pantai Marina, Terengganu Pulau Bidong Laut, Terengganu Chagar Hutang, Pulau Redang, Terengganu	[9]
Calothrix crustacea Thuret	Pulau Tioman, Pahang	[5]
Dichothrix sp Zanardini	Pulau Bidong Laut, Terengganu	[9]
Rivularia atra Roth ex Bornet & Flahault	Pantai Kemasik, Terengganu Teluk Kalong, Terengganu	[9]
Family Scytonemataceae		
Scytonema sp C. Agardh	Pulau Bidong Laut, Terengganu	[9]
Order Oscillatoriales		
Family Oscillatoriaceae		
Blennothrix lyngbyacea (Kützing) Anagnostidis & Komárek	Marine Park, Pulau Pinang, Terengganu	[9]
Lyngbya confervoides C. Agardh	Pantai Chendering, Terengganu	[9]
Lyngbya majuscula (Dillwyn) Harvey	Pantai Bukit Keluang, Terengganu Pantai Chendering, Terengganu Pantai Kuala Abang, Terengganu Tanjung Jara, Terengganu Pulau Bidong Laut, Terengganu Pulau Karah, Terengganu Changar Hutang, Pulau Redang, Terengganu	[9]
Lyngbya meneghiniana (Kützing) Falkenberg ex Gomont	Setiu Wetlands, Terengganu Teluk Kalong, Terengganu	[9]
Lyngbya penicillata (Gomot) Hoffmann	Batu Buruk, Terengganu Pulau Bidong Laut, Terengganu	[9]
Lyngbya semiplena (C. Agardh) J. Agardh	Pantai Kemasik, Terengganu Teluk Kalong, Terengganu	[9]
Lyngbya sordida Gomot	Setiu Wetlands, Terengganu Marine Park, Pulau Pinang, Terengganu	[9]
Oscillatoria subbrevis Schmidle	Pantai Bari Kecik, Terengganu	[9]
Oscillatoria yonedae I. Umezaki	Changar Hutang, Pulau Redang, Terengganu	[9]
Family Phormidiaceae		
Brachytrichia Zanardini ex Bornet et Flahault	Flora Beach Resort, Pulau Perhentian Besar	[11]
Phormidium gracile West & G.S.West	Pulau Bidong Laut	[9]
Phormidiun laetevirens (P.L.Crouan & H.M.Crouan ex Gomont) Anagnostidis & Komárek	Jetty Shahbandar, Estuary of Terengganu River	[9]
Phormidium nigroviride (Thwaites) Anagnostidis & Komárek	Setiu Wetlands	[9]
Planktothrix rubescens (De Candolle ex Gomont) Anagnostidis & Komárek	Marine Park, Pulau Pinang	[9]
Symploca hydnoides (Harvey) Kützing	Changar Hutang, Pulau Pinang	[9]
Symplocastrum coccineum (Gomont) Anagnostidis	Marine Park, Pulau Pinang	[9]
Order Pseudanabaenales		
Family Pseudanabaenaceae		
Leptolyngbya crosbyana (Tilden) Anagnostidis & Komárek	Marine Park, Pulau Pinang, Terengganu	[9]
Family Schizotrichaceae		
Schizothrix calcicola (C. Agardh) Gomont	Marine Park, Pulau Pinang, Terengganu	[9]
Order Stigonematales		
Family Mastigocladaceae		
Brachytrichia quoyi (C. Agardh) Bornet & Flahault	Pantai Chendering, Terengganu Teluk Kalong, Terengganu Changar Hutang, Pulau Redang, Terengganu	[9]

Division Chlorophyta

Order Ulvales		
Family Ulvaceae		
Ulva clathrata (Roth) C.Agardh	Salang Beach, Pulau Tioman, Pahang	[5],[6]
[Syn: *Enteromorpha clathrata* (Roth) Greville]	Pulau Perhentian, Terengganu	
	Pulau Redang, Terengganu	
	Batu Buruk, Terengganu	
	Pantai Chendering, Terengganu	
	Pantai Kuala Abang, Terengganu	
	Tanjung Jara, Terengganu	
	Pantai Kemasik, Terengganu	
	Teluk Kalong, Terengganu	
	Pantai Marina, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Pulau Sibu Tengah, Johor	
Ulva compressa Linnaeus	Kuala Semarak, Bachok, Kelantan	[11]
	Setiu Wetland, Terengganu	
Ulva fasciata Delile	Pulau Tioman, Pahang	[5],[6]
	Pulau Sibu, Johor	
	Pantai Bak-Bak, Kudat, Sabah	
	Pulau Tiga, Kota Kinabalu, Sabah	
Ulva flexuosa Wulfen	Sungai Semarak, Kelantan	[11]
	Setiu Wetland, Terengganu	
	Kuala Besut, Terengganu	
Ulva intestinalis Linnaeus [Syn: *Enteromorpha intestinalis* (Linnaeus) Nees]	Pulau Tioman, Pahang	[5],[6],[11]
	Setiu Wetland, Terengganu	
	Pantai Bari kecik, Terengganu	
	Teluk Kalong, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Pulau Ru, Terengganu	
	Pantai Bari, Setiu, Terengganu	
	Pantai Mersing, Johor	
	Pulau Sibu, Johor	
Ulva reticulata Forsskaal	Kuala Semarak, Bachok, Kelantan	[6]
	Pulau Tioman, Pahang	
Order Acrosiphoniales		
Family Acrosiphoniaceae		
Spongomorpha arcata (Dillwyn) Kützing	Teluk Kalong, Terengganu	[9]
Urospora doliifera (Setchell & N.L.Gardner) Doty	Setiu Wetlands, Terengganu	[9]
Urospora penicilliformis (Roth) Areschoug	Setiu Wetlands, Terengganu	[9]
Order Cladophorales		
Family Anadyomenaceae		
Anadyomene plicata C. Agardh	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Kampung Mukut, Pulau Tioman, Pahang	
	Tangion Datu, Sarawak	
Anadyomene stellata (Wulfen) C. Agardh	Membidai Beach, Pulau Labuan, Sabah	[5]
Valoniopsis pachynema (G. Martens) Børgesen	Pantai Chendering, Terengganu	[9]
	Pantai Kuala Abang, Terengganu	
	Tanjung Jara, Terengganu	
	Pantai Kemasik, Terengganu	
Family Cladophoraceae		
Chaetomorpha aerea (Dillwyn) Kützing	Pulau Redang, Terengganu	[5]
Chaetomorpha antennina (Bory de Saint - Vincent) Kützing	Setiu Wetland, Terengganu	[9]
	Tanjung Jara, Terengganu	
	Pantai Kemasik, Terengganu	
Chaetomorpha crassa (C. Agardh) Kützing	Pantai Bari kecik, Terengganu	[9]
Chaetomorpha linum (O.F. Muller) Kützing	Pulau Sibu, Johor	[5]
	Pulau Kerengga Kecil, Pulau Redang, Terengganu	
Chaetomorpha minima Collins & Hervey	Pulau Tioman, Pahang	[5],[9]
	Pantai Chendering, Terengganu	
	Pulau Sibu, Johor	
Chaetomorpha spiralis (Okamura)	Batu Buruk, Terengganu	[9]
	Pantai Chendering, Terengganu	

Cladophora cf. *aokii* Yamada	Pantai Kuala Abang, Terengganu Pulau Ru, Terengganu	[9]
Cladophora catenata (Linnaeus) Kützing	Pulau Tioman, Pahang Pulau Kerengga Besar, Pulau Redang	[5],[6]
Cladophora coelothrix Kützing [Syn: *Cladophora repens* Harvey]	Pulau Redang, Terengganu	[5]
Cladophora forsskali (Kützing) Bornet ex De Toni [Syn: *Siphonocladus forsskalii* (Kutzing) Bornet ex De Toni]	Tangion Datu, Sarawak	[5]
Cladophora herpestica (Montagne) Kützing	Setiu Wetland, Terengganu Pulau Geluk, Terengganu	[9]
Cladophora prolifera (Roth) Kutzing	Pulau Tioman, Pahang	[5],[6]
Cladophora stimpsonii Harvey	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Cladophora vagabunda (Linnaeus) van den Hoek	Pantai Mersing, Johor Pulau Sibu, Johor	[5]
Cladophora cf. *patentiramea* (Montagne) Kützing	Batu Rusa, Terengganu	[9]
Rhizoclonium hookeri Kutzing [Syn: *Rhizoclonium africanum* Kutzing]	Pulau Redang, Terengganu	[5]
Rhizoclonium Kützing	Kuala Semarak, Bachok, Kelantan	[11]
Ventricaria ventricosa (J. Agardh) Olsen & J. West [Syn: *Valonia ventricosa* J. Agardh]	Kampung Genting, Pulau Tioman, Pahang Pulau Perhentian Besar, Terengganu Pulau Gaya, Kota Kinabalu, Sabah	[5],[6]
Family Siphonocladaceae		
Boergesenia forbesii (Harvey) J. Feldmann	Pulau Tioman, Pahang	[5],[6]
Boodlea coacta (Dickie) G. Murray & De Toni	Pulau Redang, Terengganu	[5]
Boodlea composita (Harvey) Brand [Syn: *Cladophora composita* Harvey]	Teluk Salang, Pulau Tioman, Pahang Pulau Redang, Terengganu Pulau Kerengga Besar, Terengganu Pulau Perhentian Besar, Terengganu Tangion Datu, Sarawak	[5],[6]
Boodlea struveoides Howe	Pulau Tioman, Pahang	[5],[6]
Cladophoropsis membranaceae (Hofman Bang ex C. Agardh) Børgesen	Pulau Sibu, Johor	[5]
Cladophoropsis sundanensis Reinbold	Batu Buruk, Terengganu Pantai Kuala Abang, Terengganu Pantai Kemasik, Terengganu Batu Rakit, Terengganu	[9]
Dictyosphaeria cavernosa (Forsskal) Bøergesen [Syn: *Dictyosphaeria favulosa* (C. Agardh) Decaisne ex Endlicher]	Kampung Genting, Pulau Tioman, Pahang Teluk Tekek, Pulau Tioman, Pahang Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Dictyosphaeria vershuysii Weber-van Bosse	Kampung Mukut, Pulau Tioman, Pahang Kampung Lalang, Pulau Tioman, Pahang Kampung Genting,, Pulau Tioman, Pahang Island of Tanjung Paya, Pulau Tioman, Pahang	[6]
Dictyosphaeria Decaisne ex Endlicher	Teluk Salang, Pulau Tioman, Pahang	[6]
Struvea anastomosans (Harvey) Piccone et Grunow ex Piccone [Syn: *Struvea deliculata* Kutzing]	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Struvea ramosa Dickie	Pulau Tioman, Pahang	[5]
Family Valoniaceae		
Valonia aegagropila C. Agardh	Pulau Tioman, Pahang Pulau Tenggol, Terengganu Pulau Sibu, Johor	[5],[6]
Valonia utricularis (Roth) C. Agardh	Pulau Tioman, Pahang	[5],[6]
Order Bryopsidales		
Family Bryopsidaceae		
Bryopsis corymbosa J. Agardh	Pulau Tioman, Pahang	[5],[6]
Bryopsis hypnoides Lamouroux	Pulau Perhentian, Terengganu	[5]
Bryopsis indica A.Gepp & E. Gepp	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Bryopsis pennata Lamouroux	Pulau Tioman, Pahang Pulau Kerengga Besar, Pulau Redang, Terengganu Pulau Sibu, Johor	[5],[6]
Bryopsis plumosa (Hudson) C. Agardh	Pulau Perhentian Besar, Terengganu Pulau Sibu Tengah, Johor	[5]
Derbesia prolifica W. R. Taylor	Pulau Tioman, Pahang	[5],[6]
Family Caulerpaceae		
Caulerpa lentillifera J. Agardh	Pantai Bak-Bak, Kudat, Sabah Pulau Sibu, Johor Kampung Paya, Pulau Tioman, Pahang	[5],[6]
Caulerpa microphysa (Weber van Bosse) J. Feldmann	Pulau Sibu, Johor	[5]
Caulerpa mexicana	Pulau Bidong Laut, Terengganu	[9]

Caulerpa nummularia	Pulau Bidong Laut, Terengganu	[9]
	Changar Hutang, Pulau Redang, Terengganu	
	Marine Park, Pulau Pinang, Terengganu	
Caulerpa peltata Lamouroux	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Kampung Mukut, Pulau Tioman, Pahang	
	Kampung Ayer Batang, Pulau Tioman, Pahang	
	Kampung Mukut, Pulau Tioman, Pahang	
	Pulau Kerengga Besar, Pulau Redang, Terengganu	
	Pulau Kerengga Kecil, Pulau Redang, Terengganu	
	Pulau Bidong Laut, Terengganu	
Caulerpa peltata Lamouroux [Syn: *Caulerpa racemosa* (Forsskaal) J. Agardh var. *peltata* (Lamouroux) Eubank]	Pulau Bidong Laut, Terengganu	[5]
Caulerpa racemosa (Forsskaal) J. Agardh	Teluk Salang, Pulau Tioman, Pahang	[5],[6]
	Kampung Paya, Pulau Tioman, Pahang	
	Island of Tanjung Paya, Pulau Tioman, Pahang	
	Kampung Genting, Pulau Tioman, Pahang	
	Pulau Redang, Terengganu	
	Pulau Perhentian, Terengganu	
	Pulau Sibu, Johor	
	Pulau Gaya, Kota Kinabalu, Sabah	
Caulerpa racemosa (Forsskaal) J. Agardh var *clavifera*	Pulau Rengis, Pulau Tioman, Pahang	[6]
Caulerpa racemosa (Forsskaal) J. Agardh var. *macrophysa* (Sonder ex Kutzing) W. R. Taylor	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5],[6]
	Pulau Kerengga Kecil, Pulau Redang Terengganu	
	Pulau Tioman, Pahang	
	Pulau Sibu, Johor	
Caulerpa serrulata (Forsskaal) J. Agardh	Teluk Salang, Pulau Tioman, Pahang	[5],[6],[11]
	Kampung Mukut, Pulau Tioman, Pahang	
	Pulau Redang, Terengganu	
	Pulau Perhentian Besar, Terengganu	
	Pulau Perhentian Kecil, Terengganu	
	Pulau Kapas, Terengganu	
	Pulau Bidong Laut, Terengganu	
	Flora Beach Resort, Pulau Perhentian Besar, Terengganu	
	Pulau Sibu, Johor	
	Pantai Bak-Bak, Kudat, Sabah	
	Pulau Tiga, Kota Kinabalu, Sabah	
Caulerpa serrulata f. *lata* (Weber-van Bosse) C.K.Tseng	Pantai Chendering, Terengganu	[9]
	Pulau Bidong Laut, Terengganu	
	Changar Hutang, Pulau Redang, Terengganu	
	Marine Park, Pulau Pinang, Terengganu	
Caulerpa serrulata var *boryana*(J. Agardh) Gilbert	Flora Beach Resort, Pulau Perhentian Besar, Terengganu	[11]
Caulerpa serrulata var. *boryana* f. *occidentalis* (Weber-van Bosse) Yamada & Tanaka C	Pulau Bidong Laut, Terengganu	[9]
	Marine Park, Pulau Pinang, Terengganu	
Caulerpa sertulariodes (S. Gmelin) Howe	Pulau Sulong, Kota Kinabalu, Sabah	[5]
Caulerpa taxifolia (Vahl) C. Agardh	Pulau Tioman, Pahang	[5]
	Pantai Bak-Bak, Kudat, Sabah	
Caulerpa verticillata J. Agardh	Kampung Mukut, Pulau Tioman, Pahang	[5],[6]
	Pulau Sibu, Johor	
	Pantai Bak-Bak, Kudat, Sabah	
Family Codiaceae		
Codium geppiorum O. Schmidt	Pulau Tioman, Pahang	[5],[6]
Codium tomentosum Stackhouse	Pulau Redang, Terengganu	[5]
Family Halimedaceae		
Halimeda discoidea Decaisne	Pantai Bak-Bak, Kudat, Sabah	[5]
Halimeda macroloba Decaisne	Pulau Kapas Terengganu	[5]
	Pulau Sibu, Johor	
Halimeda opuntia (Linnaeus) Lamouroux	Kampung Mukut, Pulau Tioman, Pahang	[5],[6]
	Kampung Genting, Pulau Tioman, Pahang	
	Pulau Redang, Terengganu	
	Pulau Sibu, Johor	
	Pantai Bak-Bak, Kudat, Sabah	
	Pulau Tiga, Kota Kinabalu, Sabah	
	Pulau Sapi, Kota Kinabalu, Sabah	
	Pulau Gaya, Kota Kinabalu, Sabah	
	Beach East of Sungei Kelangan, Pulau Balambangan, Sabah	

Halimeda opuntia (Linnaeus) Lamouroux var. *minor* Vickers	Pulau Tioman, Pahang Pulau Redang, Terengganu Pulau Sibu, Johor	[5],[6]
Halimeda simulans Howe	Pulau Sibu, Johor	[5]
Halimeda tuna (Ellis & Solander) Lamouroux	Pulau Tioman, Pahang Pulau Sibu, Johor Pulau Tiga, Kota Kinabalu, Sabah Pulau Sapi, Kota Kinabalu, Sabah Pantai Bak-Bak, Kudat, Sabah	[5],[6]
Family Udoteaceae		
Avrainvillea erecta (Berkeley) A. Gepp & E. Gepp	Pulau Sibu, Johor	[5]
Avrainvillea longicaulis (Kutzing) G. Murray & Boodle	Pulau Sibu, Johor	[5]
Avrainvillea obscura (C. Agardh) J. Agardh	Teluk Tekek, Pulau Tioman, Pahang Pulau Sibu, Johor Pulau Sibu Tengah, Johor	[5],[6]
Tydemannia expeditionis Weber-van Bosse	Teluk Salang,Pulau Tioman, Pahang Kampung Genting, Pulau Tioman, Pahang Island at Tanjung Paya, Pulau Tioman, Pahang Salang Wreck, Pulau Tioman, Pahang Chebah Island, Pulau Tioman, Pahang Pulau Tulai, Pahang	[5],[6]
Udotea cyathiformis Decaisne [Syn: *Udotea sublittoralis* Taylor]	Pulau Redang, Terengganu	[5]
Rhipidosiphon javensis Montagne [Syn: *Udotea javensis* (Montagne) A. Gepp & E.Gepp]	Teluk Salang,Pulau Tioman, Pahang Pulau Sibu, Johor	[5],[6]
Chlorodesmis sp Harvey & Bailey	Marine Park, Pulau Pinang, Terengganu	[9]
Order Dasycladales		
Family Dasycladaceae		
Neomeris annulata Dickie	Kampung Lalang, Pulau Tioman, Pahang Pulau Sibu Tengah, Johor	[5],[6]
Family Polyphysaceae		
Acetabularia crenulata Lamouroux	Lubok Termiang Beach, Pulau Labuan, Sabah Membidai Beach, Pulau Labuan, Sabah	[5]
Acetabularia parvula Solms-Laubach	Pulau Kerengga Besar, Pulau Redang, Terengganu	[5]
Acetabularia pusilla (Howe) Collins	Pulau Redang, Terengganu	[5]
Parvocaulis exiguus (Solms-Laubach) S.Berger, U.Fettweiss, S.Gleissberg, L.B.Liddle, U.Richter, H.Sawitsky, H.& G.C.Zuccarello	Marine Park, Pulau Pinang, Terengganu	[9]
Parvocaulis parvula (Solms-Laubach) Schnetter & Bula Meyer	Pulau Bidong Laut, Terengganu Pulau Geluk, Terengganu Marine Park, Pulau Pinang, Terengganu	[9]
Order Siphonocladales		
Family Boodleaceae		
Phyllodictyon anastomosans (Harvey) Kraft & M.J.Wynne	Pantai Bari kecik, Terengganu Batu Buruk, Terengganu Pantai Chendering, Terengganu Pantai Kuala Abang, Terengganu Pantai Kemasik, Terengganu Pulau Bidong Laut, Terengganu Changar Hutang, Pulau Redang, Terengganu Batu Rusa, Terengganu	[9]
Division Rhodophyta		
Order Acrochaetiales		
Family Acrochaetiaceae		
Acrochaetium Nageli	Pulau Bidong Laut, Terengganu	[5]
Order Nemaliales		
Family Galaxauraceae		
Actinotrichia fragilis (Forsskal) Borgesen	Tanjung Layar, Pulau Tioman, Pahang Kampung Mukut,Pulau Tioman, Pahang Kampung Genting, Pulau Tioman, Pahang	[6]
Galaxaura Lamouroux	Swallow Cave, Salang,Pulau Tioman, Pahang	[6]
Tricleocarpa cylindrica (Ellis & Solander) Huisman & Borowitzka [Syn: *Galaxaura cylindrica* (Ellis & Solander) Lamouroux]	Pulau Tioman, Pahang Pantai Kuala Abang, Terengganu Pulau Bidong Laut, Terengganu Changar Hutang, Pulau Redang, Terengganu	[5],[9]