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REVIEWS

Diversity and conservation of coral reef fishes in the Malaysian South China Sea

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Abstract Marine biological diversity in the South China Sea is immensely rich, with at least 3,365 species of marine fishes, more than one-third of these are coral reef fish. Understanding the present status of coral reef fishes in the South China Sea in terms of their biodiversity and abundance is therefore important for the sustainable use of coral reef resources in the future. This paper is an overview of the diversity, species composition and species richness of coral reef fishes in the Malaysian South China Sea. A number of coral reef fishes consisting of 35 families and 86 species have been categorised as extinct or threatened. Natural and anthropogenic factors are affecting coral reefs and their ecosystems, with overfishing, blast fishing, poison fishing and trawling considered the major threats in Malaysia. In the Malaysian South China Sea, blast fishing is still practiced in Sabah, East Malaysia (Borneo), and the activity is considered a serious issue. A number of coral reefs are protected as national marine parks, especially in West Malaysia (Peninsular Malaysia), which could help maintain the biomass of coral reef fishes. Strict enforcement of fishery regulations and management, and more national marine parks are needed to conserve and enhance coral reef fishes, especially in the Sabah area of East Malaysia.

Keywords Coral reef fish · Destructive fishing · Enhancement · Malaysia · Marine biodiversity · Protection

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Introduction

Coral reefs thrive best in warm tropical waters but extend beyond the tropics to higher latitudes where warm currents push through from the tropical belt. Southeast Asia is recognised as the global centre for coral reefs, both in terms of extent and species diversity. An estimated 34 % of the Earth's coral reefs are located in the seas of Southeast Asia, which occupy only 2.5 % of the Earth's total sea surface (Burke et al. 2002). Furthermore, more than half of Southeast Asia's hard coral species diversity is found in the South China Sea (UNEP 2004). Although coral reefs are widely distributed along the coast of the South China Sea, many areas are currently under threat from coastal development, marine pollution, overexploitation of marine resources and land pollution and erosion. Corals in the Philippines, Malaysia and Vietnam are at a particularly high risk of extinction. In contrast, relatively healthy corals are found off the Spratly Islands (Fig. 1). Among reef building corals, for example, the region in which the

Spratly Islands reside includes at least 70 genera (Veron 1986, 1993), and more than 400 species of corals (Veron and Hodgson 1989) with a high degree of genetic diversity (Ablan et al. 2002) and 1,500 species of reef fishes are found in this area (McManus 1994). The exact number of all marine species in the South China Sea is difficult to estimate given the inadequate state of taxonomy (Dai and Fan 1996), but the total number of species to be found at all depths in the Spratly Islands certainly ranges to the tens of thousands (McManus 1992).

Marine biological diversity in the South China Sea is immensely rich. A preliminary assessment of the sea's biological diversity, which is not confined to coral reefs, indicates that it contains more than 8,600 species of plants and animals (Ng and Tan 2000). Randall and Lim (2000) listed at least 3,365 species of marine fishes in the South China Sea. Ecologically, the coral reefs of the South China Sea are sources of larvae and juveniles for many commercially important reef fish. Furthermore, coral reefs are important breeding and nursery grounds for many pelagic and demersal fish species found in the open sea (Oakley and Pilcher 1996; UNEP 2004). These reefs are the source of larvae and juveniles of the fish and invertebrates that support the capture fisheries in the surrounding ocean. In fact, the future of the coral live-fish trade in the region is still dependent on wild sources of larvae and

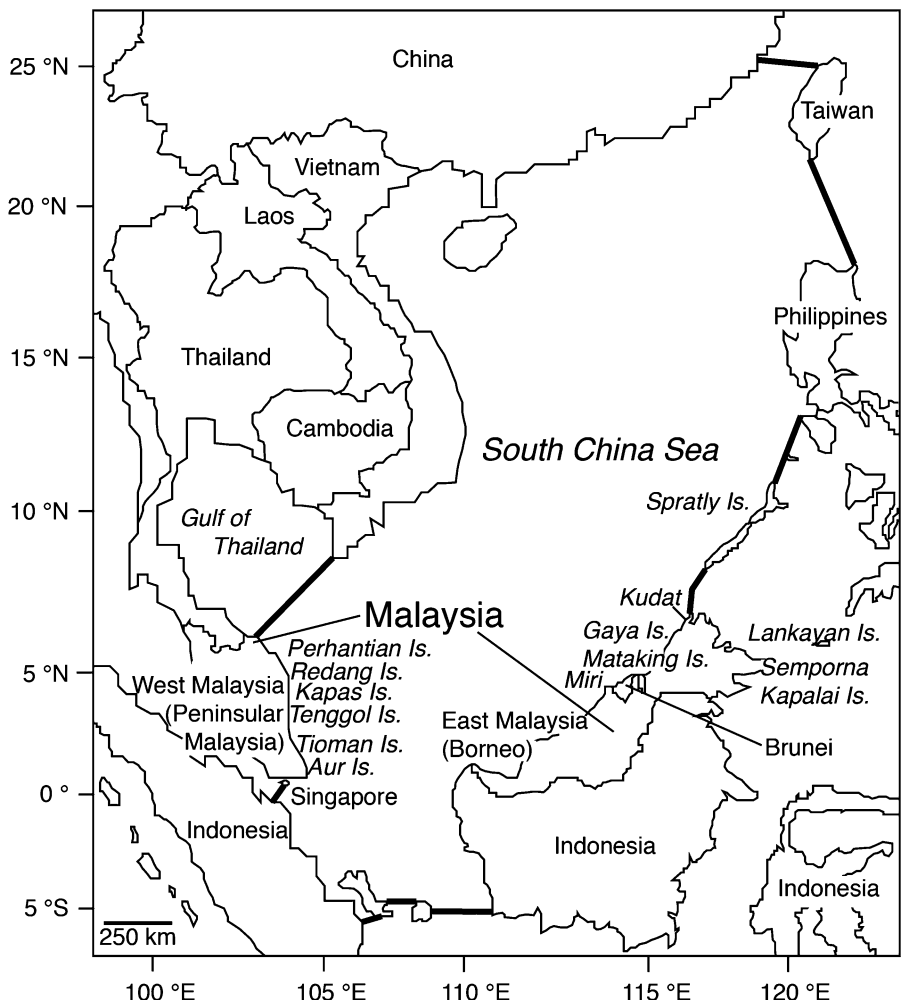

Fig. 1 Map of the South China Sea with special reference to the Malaysian region. Each island and site in Malaysia (eastern coast of West and East Malaysia) corresponds to the annual research site of Reef Check Malaysia as shown in Fig. 2. *Bold lines* indicate the boundary of the South China Sea

juveniles from the reefs. Food derived from reef fisheries remains one of the most basic and essential commodities for the impoverished but growing coastal populations. Furthermore, approximately one-quarter of the diet of pelagic and transboundary migratory fish such as yellowfin tuna comes from reef-associated organisms (Grandperrin 1978). In addition to trophic dependence on reef-associated organisms, other pelagic species are dependent on the reef habitat to complete their life cycle, visiting and using coral reefs as spawning, breeding and nursery grounds.

Recently, several pictorial books about Malaysian fishes have been published. Mohsin and Ambak (1996) reported 710 species of marine fishes from the Malaysian waters and their adjacent seas. Furthermore, Ambak et al. (2010) and Chong et al. (2010) listed 2,243 and 1951 fish species, respectively, in Malaysian waters. Thus, Malaysia has the one of the highest and richest diversity of fish in the world. In fact, Malaysia is identified as one of the world's 12 mega-diversity centres and is one of the six countries of the Coral Triangle, which boasts the most diverse and richest coral reefs in the world with more than 1,000 species of coral reef fishes (Chong et al. 2010). Malaysia consists of West Malaysia (Peninsular Malaysia), Sabah and Sarawak and is located in the Indo-Pacific region (Fig. 1). Sabah and Sarawak are located in the northern part of East Malaysia (Borneo). These two landmasses are separated by the southwestern portion of the South China Sea.

Although the South China Sea has the largest areas of coral reefs of any tropical sea, natural disturbances such as storms and El Niño-related bleaching events have had an impact on these reef systems. In addition, human activities are currently resulting in widespread loss of reef habitats (Arceo et al. 2001). Over the last century, many countries in the region have undergone rapid economic development and population growth, particularly in coastal areas. Consequently, the human pressures on coral reefs have increased. The threats to coral reefs in Southeast Asia, have been estimated by Burke et al. (2002), who consider over 80 % of Southeast Asia's coral reefs to be under threat. Coral reef ecosystems and their associated biota in Malaysia have long been under threat due to a combination of natural hazards and rapid development in coastal areas as in other parts of Southeast Asia. Approximately 35 % of Malaysian coral reefs are reported to have <50 % coral cover (Chou 1998). In West Malaysia, live coral coverage ranged from 17.9 to 68.6 % suggested to the most reefs were in fair condition while some reefs were shown to be in poor condition (Toda et al. 2007). Sabah which contains most of Malaysia's coral reefs, has widespread dead coral cover in 70 % of surveyed sites, indicating a significant degree of reef damage; only 10 % of reefs have <10 % dead coral (Pilcher and Cabanban 2000). According to Burke et al. (2002), 87 % of Malaysia's coral reefs currently face medium to high threat levels from human activities. Malaysian coral reefs are threatened by destructive fishing, overfishing, sedimentation, coastal development and marine pollution. Destructive fishing and reef damage in the 1990s is believed to be the main cause of the decline of Sabah's coral reef fishes (Pilcher and Cabanban 2000). Blast fishing kills all fishes in the area. For example, after a blast >2,500 dead fishes were counted over an area <100 m^2, mostly damsels, small fusiliers and juvenile fishes (Oakley et al. 2000). Formerly pristine coral reefs off Sabah (Semporna) were ruined by blast fishing and cyanide fishing (Chong et al. 2010). These serious issues may lead to habitat loss for a number of coral reef fish species, which would, in turn, lead to the loss of diversity in Malaysian coral reef fishes.

In this paper, the status of the species composition and diversity of coral reef fishes in the Malaysian South China Sea, one of the world's most abundant and richest sites for fish species, is reviewed. I also examined the coral reef fisheries in the Malaysian South China Sea, a major cause of the decline of coral reef fishes. This study informs the protection and conservation of coral reef fishes in the Malaysian South China Sea and could give fundamental clues for understanding sustainable use of coral reef fish resources in the future.

Oceanographic setting and the effects of monsoonal seasons on fish landings

The South China Sea encompasses a portion of the Pacific Ocean, stretching roughly from Singapore in the southwest to the Strait of Taiwan, between Taiwan and China, in the northeast (Fig. 1). The South China Sea is bounded by the coasts of Vietnam, China, the Philippines, Malaysia, Thailand, Brunei and Cambodia. It is separated from the Gulf of Thailand by a shallow sill to the west. It forms a large, semi-enclosed

marine ecosystem. Circulation in the South China Sea is influenced by biannual monsoons. The Northeast monsoon towards the end of the year forces surface currents from north to south, while the Southwest monsoon that occurs mid-year drives currents in the reverse direction. There is also a flow of Pacific water into the basin, which interacts with water from the Indian Ocean. Coral reefs are liberally distributed along most of the coastlines bordering this large marine ecosystem. Approximately 20 % of Southeast Asia's reefs occur in the South China Sea (UNEP 2004).

The weather in Malaysia is characterized by two monsoon regimes, namely, the Southwest (SW) monsoon from late May to September and the Northeast (NE) monsoon from November to March. However, these months do not rigidly define the monsoonal periods due to unexpected changes of the wind system. The months between the monsoons are known as the Inter-Season (IS) period. The NE monsoon brings heavy rainfall, particularly to the east coast states of West Malaysia and western Sarawak, whereas the SW monsoon normally signifies relatively dry weather.

Since the Straits of Malacca are shielded by the Sumatra landmass, the sea is relatively mild, and interruption to fishing activities is minimal during the monsoon periods of the western coast of West Malaysia (Yaakob and Chau 2005). However, the NE monsoon that strikes between the month of November and February brings heavy rain to the eastern coast of West Malaysia, creating rough seas and hindering fishing activity in the South China Sea (Yaakob and Chau 2005). Therefore, the maximum catch occurs in August and September with landings declining after that as a result of monsoon until February (Yaakob and Chau 2005).

In East Malaysia, fish landings in the Kota Kinabalu area are the lowest during the NE monsoon while the other two periods are more favorable for fish landings (Jafar-Sidik et al. 2010). Ho et al. (2013) reported that the highest fish landings was 3,275 tonnes during the SW monsoon in 2009, and the lowest fish landing was during the NE monsoon in 2004 with total landings of only 69 tons in the Kota Kinabalu area. However, in Tawau and Sandakan on the eastern coast of Sabah, fish landings were almost the same for all seasons and the seasonal effect was not clearly noticeable (Jafar-Sidik et al. 2010).

Coral reef fish species

A total of 1,428 coral reef fish species, occupying both mangrove and coral reef areas and belong to 22 orders, 109 families and 504 genera have been recorded in Malaysian waters (Table 1, Chong et al. 2010). Among these fishes, the Serranidae, Apogonidae, Carangidae, Pomacentridae, Labridae and Gobiidae are the most abundant families, containing more than 50 species (Table 1).

To monitor the coral reef ecosystem, reef check surveys were conducted in the Malaysian South China Sea adhering to international standards (Reef Check: www.reefcheck.org). In West Malaysia, the surveys were conducted at sites around the six main islands off the east coast: the Aur, Kapas, Perhentian, Redang, Tenggol and Tioman islands (Fig. 1). In East Malaysia, surveys were conducted at Miri in Sarawak and at Gaya Island, Mataking Island, Kudat, Semporna, Lankayan Island, and Kapalai Island in Sabah (Reef Check Malaysia 2007, 2008, 2009, 2010, 2011, 2012, Fig. 1). Although the study areas changed slightly between years and Semporna, Lankayan Island, and Kapalai Island do not face to the South China Sea, the data sets show fluctuations in the abundance of coral reef fish species in the area. During the survey, coral reef fishes were examined by swimming slowly along the transect line and counting the indicator fishes, namely butterflyfish, sweetlips, snapper, barramundi cod, humphead wrasse, bumphead parrotfish, parrotfish, moray eel and grouper within each of the four 20 × 5 × 5 m corridors. These fish species were chosen because of their suitability for the evaluation of the effects of various types of fishing. Butterflyfish is a target for the aquarium trade; sweetlips, snapper, barramundi cod, parrotfish, moray eel, and grouper are used as food fishes; and humphead wrasse and bumphead parrotfish are targeted for the live-food fish trade. There were few significant changes in the abundances of these fish species between 2007 and 2012 (or between 2008 and 2012 in East Malaysia), and there are few differences between the eastern coasts of West Malaysia and East Malaysia (Fig. 2). Some fish species, such as sweetlips, barramundi cod, humphead wrasse, bumphead parrotfish, moray eel and grouper, were fundamentally very low in abundance in the Malaysian South China Sea. However, it is possible the data is biased as a function of the Reef Check methodology as the effectiveness of sampling methods would differ depending on the species.

Table 1 Diversity of coral reef fishes in Malaysian waters

Taxa			
Order	Family	Number of genera	Number of species
Orectolobiformes	Orectolobidae	1	1
	Hemiscyllidae	1	5
	Stegostomatidae	1	1
	Ginglymostomatidae	1	1
Carcharhiniformes	Scyliorhinidae	3	4
	Carcharhinidae	7	23
	Sphyrnidae	2	3
Torpediniformes	Narcinidae	2	6
	Torpedinidae	1	1
Rajiformes	Rhinobatidae	3	7
	Dasyatidae	7	25
	Myliobatidae	5	9
	Gymnuridae	2	3
Elopiformes	Elopidae	1	1
	Magalopidae	1	1
Anguilliformes	Moringuidae	1	1
	Muraenidae	5	16
	Ophichthidae	5	6
	Congridae	3	3
Clupeiformes	Clupeidae	13	22
	Engraulidae	5	19
Gonorynchiformes	Chanidae	1	1
Siluriformes	Arridae	11	19
	Plotosidae	2	3
Aulopiformes	Synodontidae	4	10
Ophidiiformes	Carapidae	1	1
Batrachoidiformes	Batrachodidae	1	2
Lophiiformes	Antennaridae	1	5
Gobiesociformes	Gobiesocidae	1	1
Atheriniformes	Atherinidae	2	4
Beloniformes	Belonidae	5	7
	Hemiramphidae	4	11
Beryciformes	Holocentridae	4	19
	Anomalopidae	2	2
Syngnathiformes	Aulostomidae	1	1
	Fistulariidae	1	2
	Centriscidae	2	2
	Solenostomidae	1	1
	Syngnathidae	8	16
Scorpaeniformes	Scorpaenidae	10	17
	Synanceiidae	3	3
	Aploactinidae	1	1
	Platycephalidae	9	10

Table 1 continued

Taxa			
Order	Family	Number of genera	Number of species
Perciformes	Centropomidae	1	1
	Ambassidae	3	7
	Latidae	1	1
	Serranidae	15	65
	Pseudochromidae	5	7
	Plesiopidae	1	1
	Terapontidae	3	4
	Priacanthidae	3	7
	Apogonidae	11	57
	Sillaginidae	1	5
	Malachantidae	3	3
	Rachycentridae	1	1
	Echeneidae	1	1
	Carangidae	18	53
	Coryphaenida	1	1
	Leiognathidae	7	16
	Lutjanidae	10	38
	Caesionidae	3	10
	Lobotidae	1	1
	Gerreidae	2	5
	Haemulidae	3	24
	Sparidae	3	4
	Lethrinidae	5	23
	Nemipteridae	4	33
	Sciaenidae	12	25
	Mullidae	3	19
	Pempheridae	2	5
	Toxotidae	1	3
	Kyphosidae	1	2
	Drepaneidae	1	2
	Monodactylidae	1	1
	Chaetodontidae	7	45
	Pomacanthidae	6	18
	Cirrhitidae	3	5
	Mugilidae	6	12
	Pomacentridae	10	108
	Labridae	30	85
	Scaridae	7	27
	Uranoscopidae	1	2
	Trichonotidae	1	2
	Pinguipedidae	2	8
	Pholidichthyidae	1	1
	Tripterygiidae	2	4

Table 1 continued

Taxa			
Order	Family	Number of genera	Number of species
	Blenniidae	17	36
	Callionymidae	6	11
	Gobiidae	52	133
	Microdesmidae	1	3
	Ptereleotridae	4	7
	Ephippidae	2	6
	Scatophagidae	1	1
	Siganidae	1	17
	Zanclidae	1	1
	Acanthuridae	5	29
	Sphyraenidae	1	8
	Scombridae	9	19
Pleuronectiformes	Psettodidae	1	1
	Paralichthyidae	1	6
	Bothidae	4	4
	Cynoglossidae	2	9
	Soleidae	7	12
Tetraodontiformes	Triacanthidae	2	3
	Balistidae	9	14
	Monacanthidae	14	23
	Ostraciidae	3	8
	Tetraodontidae	11	34
	Diodontidae	2	5

The data and taxa followed by Chong et al. (2010)

Nevertheless, it is clear that the abundances of these coral fish including butterflyfish, snapper and parrotfish did not change significantly during the last 5–6 years (Fig. 2). The abundance of butterflyfish, snapper and parrotfish in West Malaysia ranged from 4.2 ± 1.4–6.5 ± 3.2, 3.4 ± 5.2–27.2 ± 23.3 and 2.3 ± 0.2–10.5 ± 9.9 fish/500 m^2, respectively. In East Malaysia, they ranged from 4.4 ± 0.6 to 6.6 ± 4.5, 8–18.6 ± 16.0 and 0.05–3.1 ± 2.1 fish/500 m^2, respectively.

The diversity of fish observed during the surveys was similar in both West Malaysia and East Malaysia (Fig. 2). In both regions, some indicator species, i.e., sweetlips, barramundi cod, humphead wrasse and bumphead parrotfish were infrequently recorded during the surveys. These fishes might be heavily fished by a variety of methods in the waters around Malaysia due to their high commercial values (Mazlan et al. 2005). Sweetlips and barramundi cod are target food species for human consumption, as is grouper, which was also found in low numbers in the Malaysian South China Sea. The bumphead parrotfish is categorised as 'vulnerable' on the World Conservation Union (IUCN 2013) 'Red List of Threatened Species' and as a Management Unit Species (MUS) in the Coral Reef Ecosystems Fishery Management Plan for the Western Pacific (NOAA 2010). The slow growth and delayed reproduction of the humphead results in slow replenishment of the species, making them very vulnerable to overfishing. Major pressure comes from the commercial fishing industry. Parrotfish was also low in abundance in East Malaysia compared to West Malaysia. This suggests that current or historical fishing pressure for these species is quite high in Malaysia. However, butterflyfish and snapper showed relatively healthy populations in both areas having higher abundances than the other coral fish species (Fig. 2).

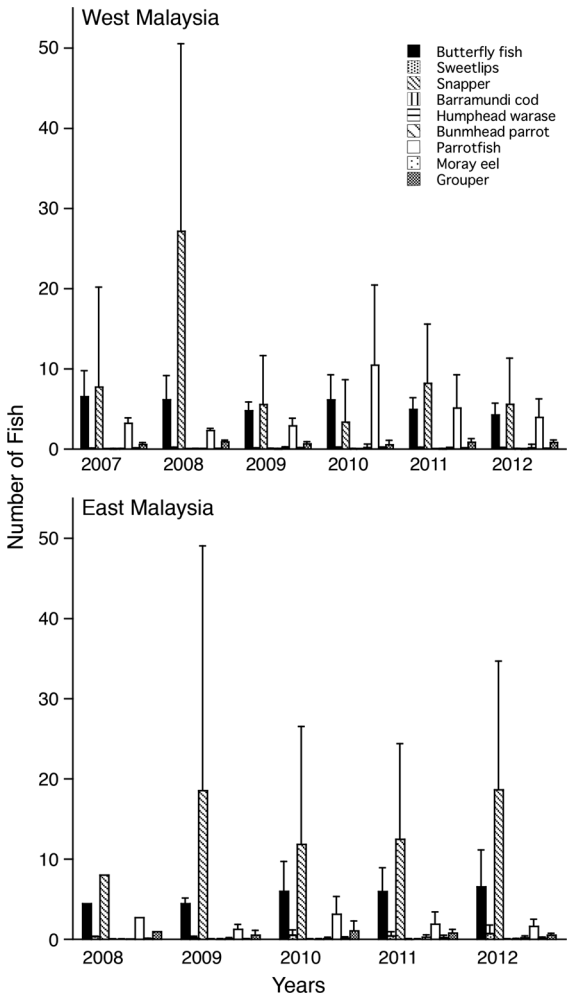

Fig. 2 Yearly fluctuations in the abundance of target species in the Malaysian South China Sea by Reef Check Malaysia (2007, 2008, 2009, 2010, 2011, 2012). The surveys were conducted between 2007 and 2012 in West Malaysia and between 2008 and 2012 in East Malaysia (Borneo). The metric used was the overall average number of target coral reef fish species observed in 500 m^3 during the survey in each site. *Error bars* indicate standard deviations that were calculated from study sites for each fish species

Threats to coral reef fisheries

Despite fluctuations in product supply caused by the changing state of fisheries resources and environmental conditions, fisheries and aquaculture remain very important as a source of food in many countries and communities. In Malaysia, total fish landings in 2010 were recorded at 1,428,881 tons, representing approximately 70.93 % of the total national fish production (Coral Triangle Report 2012). These data suggest that Malaysia depends on fishing operations more than on aquaculture operations in the surrounding waters. The fish landings consisted of pelagic fish (37.28 %); demersal fish (20.38 %); and molluscs, crustaceans, and others (42.34 %) (Coral Triangle Report 2012). The offshore fisheries (beyond 30 nautical miles from the coast) are still relatively small compared to the coastal fisheries (Coral Triangle Report 2012). In Sabah, landings primarily come from coastal fisheries (Daw 2004), and coral reef fisheries are also important for the people's livelihoods throughout Malaysian coastal areas generally (Daw 2004). As a function of the coral reef structures common to coastal fishery activities, trawling and purse seine net fishing are not necessarily effective. In general, traps, fish pots and spear fishing are used to target particular fish species. While these fishing methods do not necessarily exert high fishing pressure on the target coral reef species, blast fishing and poison fishing are still practiced in certain areas of the Malaysian South China Sea (Pilcher and Cabanban 2000). These destructive fishing methods lead to depletions of both target and non-target coral reef fish species and to reef damage.

Destructive fishing in West Malaysia is not widespread, due to higher enforcement and less dependence on coastal fisheries (Chou 2000). The major ecological threats to coral reefs in West Malaysia are related to agricultural development and new infrastructure in coastal zones, which result in increased sedimentation and nutrient runoff. In general, the waters surrounding coral reefs in West Malaysia are important fishing grounds. The fishing activities that are carried out around the islands include drift netting, purse seining, longlining and bottom traps (Aikanathan and Wong 1994).

In East Malaysia, however population growth has led to intensified catching of marine resources to support escalating demands (WorldFish Center 2008). Removal of large numbers of fish has caused the reef ecosystems to become unsustainable, allowing the more competitive organisms to dominate. Decreased yields have forced many fishermen to change their fishing methods to catch enough fish to meet their needs. In East Malaysia, even juvenile fish are caught for sale, and 68 % of the coral reefs are threatened by fishing practices that are damaging and unsustainable (Wild Asia 2005). Some of these practices include cyanide fishing, blast fishing and overfishing. Cyanide fishers dive down to reefs and squirt cyanide in coral

crevices and on fish, stunning the fish and making them easy to catch but poisoning coral polyps in the process. Cyanide fishing supplies live reef fish for the tropical aquarium market, but many fish caught using cyanide are also sold in restaurants. Other fishing practices, such as the use of explosives (blast fishing), demolish coral structures that normally function as fish habitat.

Sabah contains more than 75 % of the Malaysian reefs (Burke et al. 2002). Reef fisheries make an important contribution to the fisheries of Sabah and accounted for 10 % of landings between 1980 and 1990 (Cabanban and Biusing 1999). Catches from demersal hook and line fisheries in 1999 amounted to 17,849 tonnes (Biusing 2001). Reef fish landings are highest in Semporna, Tawau, Sandakan, Kudat and Kota Kinabalu (Cabanban and Biusing 1999), in the South China Sea area. Fishing of reef species is conducted on a range of boats, ships and vessels, which are all widely used to catch reef species commercially and for subsistence, while spears are used primarily for subsistence fishing. The lucrative export trade in live reef fish specifically targets reef-dwelling groupers (Serranidae) and certain species of wrasse (Labridae) and snappers (Lutjanidae).

Blast and cyanide fishing are illegal in Malaysia but have been widely reported on schooling species and large piscivorous fishes (Wood 1979; Oakley et al. 1999; Harding et al. 2000; Pilcher and Cabanban 2000; Daw et al. 2002a, b; Daw 2004). These methods have been blamed for the declining reef condition and the loss of coral cover around Sabah (Pilcher and Cabanban 2000) and for the extremely low densities and lack of reproductively mature adults of target species on all unprotected reefs throughout Sabah (Oakley et al. 1999) and in southeastern Banggi (Daw et al. 2002b). An analysis of the catches of coral reef fish families in Sabah by Cabanban and Biusing (1999) indicated a more than 50 % decline in both yield and catch per unit effort (CPUE) from the 1980s until the early 1990s.

Although the present status of the condition of coral reefs in the Malaysian South China Sea are still fair, as the percentage of live coral cover is 18–70 % (Reef Check Malaysia 2007, 2008, 2009, 2010, 2011, 2012, Toda et al. 2007), a number of coral reef fish species are categorised as threatened (Chong et al. 2010). Among coral reef fish species, 130 species are still assigned at the global level by the IUCN Red List (IUCN 2009). According to Chong et al. (2010), 35 families and 86 species are categorised as extinct or threatened (Table 2), although a large number of coral reef fish species in the Malaysian South China Sea have not been properly evaluated as there only a few studies and these have been conducted over a limited geographical area. Illegal fishing around some islands in West Malaysia, particularly Perhentian and Tenggol, often occurs during the monsoon season when visitor numbers drop and enforcement patrols are restricted by the rough seas (Reef Check Malaysia 2007). In Sabah and Sarawak, dynamite fishing is still rampant and has reduced many reefs to rubble, as observed on the islands of Mataking and Pom Pom off Sabah (Wood and Ng 2011). The devastation is long lasting as it will be years before the reefs regenerate. The growing population in Sabah and Sarawak in East Malaysia is also increasing the fishing pressure, with commercial trawlers applying heavy fishing pressure over surround reef areas. Bumphead parrotfish, the last remaining large fish species in Miri, are commonly sold in the local fish market (Reef Check Malaysia 2010). Due to these circumstances, there is still the potential for an increase in extinct and threatened coral fish species in the future, in the absence of comprehensive conservation and protection.

Function of national marine parks in the Malaysian South China Sea to protect and conserve coral reef fishes

Coral reefs conservation has been the subject of global interest since the 1980s (McManus 1988; McClanahan and Muthiga 1988; Sadovy 1989, 1997; Polunin and Roberts 1993). With the declining trend in the fish stocks of the major world fisheries due to overexploitation and the deterioration of coastal habitats (UNEP 2004, 2006), many countries have opted for additional management strategies to support the existing conventional management measures. As a result, more conservation efforts have been implemented to replenish fish populations and to rehabilitate coastal habitats (Roberts and Hawkins 2000). Marine protected areas (MPAs) are increasingly being used for conservation purposes, especially in Southeast Asia, where in 2002 there were over 630 declared and 185 proposed MPAs (Tun et al. 2004). However, many MPAs are not successful in protecting marine life, a failure that can

Table 2 Endangered coral reef fishes in Malaysian waters

Taxa	
Family	Species
Myliobatidae	*Aetomylaeus maculatus*
Acanthuridae	*Acanthurus bariene*
	Naso brachycentron
	Naso lopezi
Anomalopidae	*Anomalops katoptron*
Antennariidae	*Antennaris pictus*
	Antennarius dorehensis
Aploactinidae	*Acanthosphex leurynnis*
Atherinidae	*Stenatherina panatela*
Carangidae	*Alectis ciliaris*
	Caranx lugubris
	Caranx papue
	Decapterus macarellus
	Decapterus macrosoma
	Scomberoides tala
Chaetodontidae	*Chaetodon burgessi*
	Chaetodon decussatus
	Chaetodon plebeius
	Chaetodon triangulum
	Coradion melanopus
	Forcipiger longirostris
	Parachaetodon ocellatus
Dasyatidae	*Himantura granulata*
	Taeniura meyeni
Diodontidae	*Cyclichthys orbicularis*
	Cyclichthys spilostylus
Ephippidae	*Platax batavianus*
Haemulidae	*Plectorhinchus schotaf*
	Plectorhinchus vittatus
Labridae	*Anampses melanurus*
	Cheilinus undulatus
	Cymolutes torquatus
	Hologymnosus annulutas
	Hologymnosus doliatus
	Gymnocranius microdon
	Lethrinus microdon
	Lethrinus miniatus
	Lethrinus rubrioperculatus
	Letrhinus xanthochilus
Lutjanidae	*Aprion virescens*
	Etelis carbunculus
	Lutjanus boutton
	Lutjanus fulvus
	Lutjanus rivulatus
	Lutjanus sebae
	Symphorus nematophorus
Microdesmidae	*Gunnelichthys curiosus*
	Gunnelichthys viridescens
Monacanthidae	*Cantherhines fronticinctus*
Mullidae	*Parupeneus ciliatus*
Myliobatidae	*Manta birostris*
Narcinidae	*Temera hardwickii*
Nemipteridae	*Nemipterus celebicus*
Ophichthidae	*Ophichthus altipennis*
Ostraciidae	*Tetrosomus gibbosus*
Paralichthyidae	*Pseudorhombus diplospilus*
Pomacanthidae	*Pomacanthus semicirculatus*
	Amblyglyphidodon indicu
	Chromis ovatiformes
	Chrysiptera bleekeri
	Chrysiptera brownriggii
	Dascyllus carneus
	Plectroglyphidodon leucozonus
	Pomacentrus pavo
	Pristotis obtusirostris
	Stegates nigricans
Pseudochromidae	*Congrogadus subducens*
	Pictichromis diadema
Rhinobatidae	*Rhinobatos schlegelii*
Scaridae	*Chlorurus bleekeri*
Scombridae	*Euthynnus affinis*
	Scomber japonicus
	Scorpaenopsis venosa
	Taenianotus triacanthus
Serranidae	*Belonoperca chabanaud*
	Epinephelus amblycephalus
	Epinephelus corallicola
	Epinephelus multinotatus
Soleidae	*Pardachirus pavoninus*
Solenostomidae	*Solenostomus cyanopterus*
Sphyrnidae	*Sphyrna lewini*
Stegostomatidae	*Stegostoma fasciatum*
Synanceiidae	*Inimicus didactylus*
	Cosmocampus banneri
	Saurida gracilis
Torpedinidae	*Torpedo fuscomaculata*

The data and taxa followed by Chong et al. (2010)

often be traced to a lack of adequate financing and poor regulatory enforcement (Lundquist and Granek 2005, Edgar et al. 2014). According to the Department of Marine Parks Malaysia, 42 MPAs in the form of

marine parks and fisheries protected areas have been created in Malaysia since 1983 (Hiew 1996, Ramli 2002). Of these MPAs, 38 are located in the Malaysian South China Sea, and most of these (34) are in West Malaysia. MPAs have been suggested as an important tool for fishery management, particularly in a situation where fisheries are overexploited (Alban and Boncoeur 2006). The primary objective of MPAs is to protect coral reef ecosystems from fishing and other potentially harmful activities to ensure sustainable benefits from fisheries and tourism services. In Malaysia, massive tourism development has taken place over the last decades, and this sector accounts for the country's second largest source of foreign exchange earnings (Mosbah and Khuja 2014). Malaysia was ranked 9th tourism in terms of tourist arrivals in 2009 with 23.6 million and 10th in 2012 with over 25 million tourists (Mosbah and Khuja 2014). Tourism contributes at least 8–10 % of the gross domestic product (Mosbah and Khuja 2014). Several studies have highlighted that MPAs allow tourism activities that provide economic benefits while enabling the recovery of overexploited marine resources (Kelleher et al. 1995; Lauck et al. 1998; Guénette and Pitcher 1999; Russ and Alcala 2003; Gaylord et al. 2005).

Perhentian Island is one of the coral reef islands off the east coast of West Malaysia. This island is located in the South China Sea, 21 km off the mainland of Terengganu State on the east coast of West Malaysia. The island was gazetted as a marine park in 1994. Several studies have shown that the coral habitats in Perhentian Island have been damaged due to the expansion of tourism activities (Harborne et al. 2000; Tamblyn et al. 2005). Other studies have also shown that Malaysian coral reefs are under medium to high levels of threat due to human activities (Burke et al. 2002). In Perhentian Island, the live coral cover was the lowest (36.5 %) compared to the other islands of West Malaysia (Reef Check Malaysia 2011). Studies outside Malaysia have shown that increased tourism activity, especially diving and snorkelling in marine parks, is the main reason for deteriorating coral reef health (Ward 1990; Hawkins and Roberts 1993; Davis and Tisdell 1995; Rouphael and Inglis 2001). Although the condition of the coral reef is fair, with a diverse coral reef ecosystem and inter-tidal habitats, this island is a breeding, nursing and feeding ground for a number of fish species. There are 127 coral reef fish species recorded in the surrounding waters (Tamblyn et al. 2005). This island was gazetted as a marine park in 1994 and then established as a no-take MPA where fishing was prohibited within two nautical miles of the lowest water level at the shore. The government has undertaken legal action to protect coral reefs from fishing in the MPA area. However, this legal protection has been less effective in Perhentian Island for several reasons (Islam et al. 2013). First, local residents, who rely primarily on fishing for their livelihoods, are not allowed to fish in the no-take MPA area (Islam et al. 2013). Although tourism activities have provided economic opportunities for the local people, fishers still depend on fishing in the area for their subsistence (Islam et al. 2013). Second, the government has a limited capacity to control illegal fishing due to a lack of enforcement of fishing rules, particularly during the NE monsoon season (October–February) when majority of the households participate in fishing in the MPA area (Islam et al. 2013), and all tourism activities are halted during this period. Most of the local residents in the area were fishers prior to the establishment of the Perhentian MPA. Fishers use artisanal fishing gear, namely hooks and lines, traps, and gill and drift nets (Islam et al. 2013). Trawls with relatively small boats operate at short distances from the coast. Fishers from neighbouring areas are also engaged in fishing in this area during this season (Islam et al. 2013). Such illegal fishing activities also occur in other MPA areas. Although local fishing practices might not be of great concern, stricter fisheries regulation and protection might be needed to conserve the coral reef ecosystem, including the reef fish species. In general, MPAs in the Malaysian South China Sea have higher rates of tourism activity. Thus, fishers are also involved in tourism activities to gain a better income. Although the anthropogenic impacts of tourism activities cannot be ruled out, MPAs might reduce fishery pressure during non-monsoon seasons in the Malaysian South China Sea. This suggests that MPAs might serve to protect and conserve coral reef fishes in West Malaysia.

In East Malaysia, the four state marine parks in Sabah are managed under the jurisdiction of Sabah Parks, a unit within the Ministry of Tourism, Culture and Environment. Revenue for park management is generated by charging a conservation fee of RM 5 (around US $1.40) to all park visitors, as well as from revenues generated from private companies operating

in the marine parks (Teh et al. 2008). The Malaysian marine police are responsible for enforcing the ban on destructive fishing methods, such as the use of dynamite, which is illegal under the Malaysian Fisheries Act. However, a lack of funds and personnel has hampered the enforcement of marine parks in parts of Sabah (Pilcher and Cabanban 2000). Consequently, illegal fishing with dynamite and cyanide remains common and stricter enforcement and management are needed for conservation of biodiversity in the regions' MPAs.

Coral reefs in relation to fishery management

Although a number of studies on coral reef fish populations have been conducted prior to and after the establishment of the marine parks in Malaysia (De Silva and Rahman 1982; Daw 2004), most of these were not published as scientific reports or in scientific journals, and therefore, the effectiveness of these marine parks to conserve coral ecosystems is still unclear. Most of the surveys were conducted without systematic monitoring to identify the coral reef fish species collected in the national marine parks and so a key question remains about the effectiveness of these parks in enhancing the biomass of exploited species inside the parks. A diversity analysis based on a species list will show how diverse an ecosystem, but without quantitative survey information we cannot make any inference about how abundance may or may not be changing in these areas. While the benefits of marine parks in protecting and enhancing the abundance of exploited species inside and outside of the parks are well documented (Polunin and Roberts 1993; DeMartini 1993; Sladek and Roberts 1999), these outcomes are yet to be demonstrated at national and international levels. In Malaysia, there have been no quantitative assessments of the abundance of coral reef fishes inside and outside of marine reserves, except through reef check survey.

There are regular reports of illegal fishing around some islands off the eastern coast of West Malaysia, particularly at Perhentian and Tenggol (Reef Check Malaysia 2012). However, fishing activity in the coral reef area of eastern West Malaysia is generally lower than that in East Malaysia. In East Malaysia, particularly southern Sabah, high population levels are resulting in significant fishing pressure on reefs (Teh et al. 2011). In Tenggol, for example, the only sheltered bay on the island is used as a mooring point for fishing boats throughout the year (Reef Check Malaysia 2012). Thus, it seems quite difficult to achieve comprehensive fishery enforcement. In Sabah, fish bombing is still commonplace and large areas of reef have been destroyed beyond recovery (Reef Check Malaysia 2012). Not only are target fishes with high commercial value facing a huge challenge in in East Malaysia but the coral reef environment is as well.

The aquarium fish trade continues to export fish from Malaysia to North America, Europe, Japan and China, with growing interest resulting in a steady global increase in the aquarium fish trade. According to the Food and Agriculture Organization (FAO) (2006), export earnings from the ornamental fish trade are US $251 million and more than 60 % of production comes from households in developing countries (Selvarasu and Sankaran 2011). Trade of ornamental fish is growing by 8 % annually and is dependent on wild caught species (Selvarasu and Sankaran 2011). Ornamental fish exports from Malaysia are dominated by wild caught species with increased demand leading to overfishing and illegal fishing practices on a number of coral reef fishes in the area.

Bumphead parrotfish is considered an endangered species in Malaysia, and it is the last remaining large fish species in Miri. However, this fish has been found in the local fish market in Miri (Reef Check Malaysia 2012). Bumphead parrotfish is distributed across the Indo-Pacific and has a persistent abundance in some geographic areas, such as Seychelles, Indonesia, Papua New Guinea, Sudan and Palau, at more than 1.0 fish/1,000 m^2 (Kobayashi et al. 2011). In Malaysia including the Malaysian South China Sea area, the abundance is 0.42 fish/1,000 m^2, which is not as low as in other Asian countries (0.19 in Japan, 0.17 in Philippines, 0.06 in Vietnam, 0.04 in Thailand, and 0 in China, India and Taiwan) (Kobayashi et al. 2011). Protection and conservation are urgently needed for the vulnerable bumphead parrotfish an indicator of coral reef health in Malaysia.

There are over 2,000 fish farmers involved in marine fish aquaculture in Malaysia (Pomeroy 2002). Among the fish species cultured, grouper make up over 16 % by weight and 30 % by value of the total marine fish produced by aquaculture in Malaysia (Subramaniam 1999). Approximately 15 % of fish

larvae and juveniles are collected from the wild and/or produced in government or private hatcheries. The remaining 85 % is imported, primarily from Taiwan and Thailand (Subramaniam 1999). Net cages are the most popular grow-out system. The major grow-out sites for grouper in Malaysia are in Sabah, particularly in Tuaran and Sandakan, and Sarawak (where wild larvae and juveniles are also captured) in East Malaysia (Sadovy 2000). Grouper larvae and juveniles are not allowed to be imported into Sabah to avoid spreading of fish diseases, and thus the importance and need for hatcheries is considerable (Sadovy 2000). Grouper are also cultured in West Malaysia and several species of grouper are grown out in floating net cages, including *E. coioides*, *E. tauvina*, *E. fuscoguttatus*, *E. lanceolatus, Plectropomus leopardus*, and *Cromileptes altivelis* (Pomeroy 2002). Wild larvae and juveniles are the major source of the local supply in West Malaysia. Fish farmers in Malaysia have also been importing large numbers of hatchery-produced fish fry/juveniles from Taiwan in the last few years (Pomeroy 2002). Overharvesting wild individuals in Malaysia and then importing fish to stock farms not only results in changes to the wild population and the community of food species but also reduces the long-term economic viability of the farms themselves. Furthermore, overfishing of wild groupers in the natural environment, especially brood stock, leads to the decline of their wild population (Ottolenghi et al. 2004).

With the rapidly developing economies of China and Southeast Asia, the 'live fish trade' of the Indo-Pacific has expanded rapidly in recent years, and now targets many species (Pierre et al. 2008). Groupers are the most intensively exploited group in the live fish trade and aquaculture, and the high prices paid by exporters to local fisherman mean that target species may be heavily over-fished (Pierre et al. 2008). Signs of over-exploitation have been reported in numerous regions with reductions in the numbers of fish landed (Sadovy 1999).

Conservation of coral reef fishes in the Malaysian South China Sea

Coral reefs in Southeast Asia are increasingly threatened by overfishing, coastal development, and climate change (Burke et al. 2002). It has been suggested that more than half of the world's coral reefs may be lost in the next 30 years if current degradation continues unabated (Wilkinson 2000). The loss of coral reefs in Southeast Asia, which accounts for 32 % of coral reefs globally, is devastating for the region's marine biodiversity, which is among the richest in the world (Allen and Werner 2002). The reefs of the Malaysian South China Sea contribute to the economic livelihood of coastal communities (UNEP 2004). Reef-related fisheries form a significant part of fish landings, and fish is the major protein source for the Malaysian people (Kawarazuka 2010). Coral reef fisheries are a vital source of protein for coastal communities throughout the tropics. Ecologically, coral reefs are sources of larvae and juveniles for many commercially important reef fish species and other organisms. Coral reefs are important breeding and nursery grounds for many pelagic and demersal fish species found in the open sea. Thus, protecting and conserving coral reef ecosystems is essential for the sustainable use of fish resources in the future.

The South China Sea has the largest areas of coral reefs of any tropical sea. While natural disturbances, such as storms and El Niño related-bleaching events (exacerbated by global changes brought about by human activities), have an impact on reef systems, human activities are currently resulting in the widespread loss of reef habitats (Arceo et al. 2001). Over the last century, many countries in the region have undergone rapid economic development and population growth, particularly in coastal areas. Consequently, human pressures on coral reefs have increased. Coastal infrastructure development to support economic growth and the accompanying pollution of the marine environment have caused degradation of the reefs close to major population centres. Resource exploitation has led to extensive coastal degradation and watershed deforestation and erosion have resulted in the increased sedimentation of coral reefs. All of these stresses affect the overall health of reef systems. The rates of loss of coral reefs are not precisely known due to a lack of detailed data and information on the status of coral reefs over the last few decades. The threats to coral reefs in Southeast Asia have been estimated by Burke et al. (2002). In East Malaysia, overfishing, blast fishing, poison fishing and trawling are the major threats, with over 80 % of Southeast Asia's coral reefs are under threat (Burke et al. 2002). Thus, strict fishery enforcement, prohibition of blast and poison fishings and improvements in fishing gear

for coral reef fisheries are needed. Although bomb fishing is illegal in Malaysia and well-controlled in West Malaysia, in some areas of East Malaysia, especially Sabah, it is still used frequently because it is simply easier and fishermen can make more income using such a method.

Off the eastern coast of West Malaysia, the 38 coral reef protected areas, i.e., national marine parks, are effective for the conservation of coral ecosystems. Recent surveys have shown a substantial recovery, with the level of hard coral cover increasing to the highest level recorded around the Perhentian islands since regular surveys started in 2007 (just under 60 %) (Reef Check Malaysia 2012), suggesting an increase in the breeding and nursery grounds available for many coral reef fish species and other pelagic and demersal fish species found in the open sea. There were no significant changes in coral reef conditions, which have been consistently 'good', with more than 50 % of percentage of live coral cover observed over the last 5 years around Tioman Island (Reef Check Malaysia 2012). In contrast, large areas of coral reefs around the coast of East Malaysia remain unprotected, with only four islands having been designated as national marine parks. Protecting reefs in designated areas can contribute to increasing their resilience to both natural (e.g., storms, disease) and man-made (e.g., dynamite fishing, poison fishing, overfishing) impacts, both of which are significant problems in East Malaysia. There is an urgent need to increase the amount of coral reef within the gazetted marine protected areas and to put in place the necessary resources to ensure effective enforcement.

Conclusion

A rich diversity of species has been observed in Malaysian South China Sea until now with approximately one-third (more than 1,000 species) of all South China Sea fish species recorded as coral reef fishes in the area. The coral reefs of the South China Sea are sources of larvae and juveniles for many commercial and non-commercial reef fish species. In addition, coral reefs are important breeding and nursery grounds for many pelagic and demersal fish species found in the open sea. These reefs provide larvae and juveniles of the fish that support the capture fisheries in the surrounding ocean. Large global data sets across spatial and temporal scales indicate that, as marine biodiversity declines, the ocean's capacity to provide food, maintain water quality and recover from perturbations becomes severely impaired (Worm et al. 2006). The Malaysian South China Sea is not excluded from these issues as coral reef fisheries are a vital source of protein for coastal communities and coastal development is rapidly progressing in the area. A large number of species in the region have been categorized as endangered or threatened [109 families and 1,428 species (Chong et al. 2010, Table 2)], and yet many more species have not been properly evaluated. Although a number of natural and anthropogenic factors are affecting coral reefs and their ecosystems, overfishing, blast fishing, poison fishing and trawling are the major threats in Malaysia. In the Malaysian South China Sea, blast fishing is still practiced in Sabah, East Malaysia, and the activity is considered a serious issue due to its high fishery pressure on target and non-target coral fish species, as well as on the coral reef ecosystem. Strict enforcement of regulations, regular monitoring and appropriate management are needed to protect and enhance the coral reef fishes in the Sabah area. A number of coral reefs are protected as national marine parks, especially in West Malaysia, and could maintain the biomass of coral reef fishes, even though the mainland (peninsula) is continuing to develop. Further systematic and comprehensive monitoring to examine the diversity, species composition and habitat use of coral reef fishes is important for the protection and conservation of fish resources in the South China Sea to ensure the sustainable use of fish diversity and food resources in the future.

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