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Ecological Impacts of Fishing Gears in Thailand: Knowledge and Gaps

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Abstract

Around the world, knowledge about ecological impacts of fishing, especially in the small-scale sector, is generally poor, impeding thus the implementation of an ecosystem approach to fisheries (EAF). The same condition exists in Thailand where fisheries sustainability is a major concern. As a first step towards EAF, we conducted a comprehensive literature review to assess current knowledge and gaps about ecological impacts of common fishing gears used in Thailand. Of the 134 documents found on the topic, about 70 % were technical reports produced by the Department of Fisheries of Thailand, focusing largely on trawl fisheries, particularly otter board trawls. Impacts from trawling are mostly reported in terms of amount of trash fish and undersized/juvenile economic fish. Impacts of fishing gears on marine mammals (such as dolphins and dugongs) and sea turtles are reported, but only qualitatively. Very little is known about discards. Information about habitat damage is generally limited although a few studies qualitatively describe impacts of seine nets, trawls, dredges, and push nets on seagrass beds, coral reefs and benthic community. Our study reveals that a major gap exists in the understanding of ecological impacts of fishing gears in Thailand, particularly in relation to discards and habitat damage, which needs to be addressed in order to implement EAF.

Keywords: bycatch, ecological impacts, fishing gears, habitat damage, knowledge gap

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Introduction

Degradation of marine ecosystems has been observed worldwide (Millennium Ecosystem Assessment 2005). The causes of such degradation are attributed to natural disturbances and human activities, including unsustainable fishing practices (Swan and Gréboval 2004; FAO 2014). Along with other societal concerns about fisheries, such as food security, livelihoods and social justice, addressing issues affecting ecosystem health is a priority in fisheries governance (Chuenpagdee et al. 2005).

Several studies show that fishing impacts on ecosystems can include habitat destruction, mortality of non-target species, and change in population dynamics, function and structure of ecosystem (Chuenpagdee et al. 2003; Garcia et al. 2003; Pikitch et al. 2004; Pauly et al. 2005). These impacts need to be considered as an integral part of an ecosystem approach to fisheries management (Garcia et al. 2003), and also in accordance with the code of conduct for responsible fisheries which provides a framework for national and international efforts to mitigate fishing impacts on marine ecosystems (FAO 1995). In 2002, the ecosystem approach to fisheries" (EAF) concept was articulated (FAO 2003; Garcia et al. 2003), as follows: "an ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries." Ecosystem approach to fisheries is also one of the basic principles found in the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines), which consider the linkage between ecosystem health and associate biodiversity with livelihoods and well-being of the small-scale fisheries sector (FAO 2015).

Incorporating ecosystem considerations in EAF is challenging due to a limited understanding of how the fisheries systems work (Garcia and Charles 2008). In cases where fisheries are highly diverse, complex and dynamic, like in tropical areas, and where research funding is not abundant, alternative approaches to acquiring knowledge are required. As a first step, it is sensible to make use of available scientific data, evaluate their utility, and assess knowledge gaps, before embarking on new research (Szaro et al. 1998). It is under this premise that the current paper aims to make its contribution, especially with respect to existing knowledge and gaps in the understanding of ecological impacts of fishing in Thailand.

Like many countries around the world, Thailand endorses several international fisheries instruments, such as the FAO Code of Conduct for Responsible Fisheries, Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species (CITES), and SSF Guidelines. Hence, the Department of Fisheries (DOF), the main institution responsible for fisheries management in Thailand, has set rules and regulations, including conservation measures, and incorporated them into the fishery national plans.

For instance, the DOF Strategic Plan for 2013–2016 illustrates strong efforts to contribute to sustaining fisheries resources and biodiversity (DOF 2014a), while the Marine Fisheries Management Plan 2015–2019 has been drawn up to ensure sustainable management of marine fisheries in Thailand, by focusing on reducing fishing effort and mitigating illegal, unreported and unregulated fishing (IUU) (DOF 2015d). As part of the latter plan, efforts to reduce catch of juveniles, restore critical habitats, and improve fisheries data information management are also mentioned (DOF 2015d). In accordance with EAF, implementing these plans requires a broad set of supporting data, including those related to ecological impacts of fishing.

While numerous studies have been conducted to investigate various aspects of fisheries in Thailand, it is not clear what is currently known about fishing impacts. As such, this study is the first of its kind to examine available data, collate the information and identify existing knowledge about ecological impacts of fishing in Thailand. Following Morgan and Chuenpagdee (2003), the study emphasises two main types of impacts, i.e. bycatch and habitat damage, which are considered most relevant for EAF.

The paper consists of three main sections. After the introduction, the method used in the study is presented. Next, it describes the results of the study, detailing in particular ecological impacts of different gear types. This is followed by a discussion about knowledge gaps and some recommendations about how to fill these gaps and move towards EAF.

Materials and Methods

The study involves a comprehensive review of existing literature, including scientific articles, technical papers, newsletters, theses and dissertations, project reports, government reports and unpublished documents, based primarily on information available on websites, coupled by personal contacts. The web search was conducted during January to April 2016, using international and national research databases such as Web of Science, Scopus, and Thai Library Integrated System (ThaiLIS). The main search words were 'impacts', 'fisheries', 'fishing gear', 'bycatch, 'habitat' and 'trash fish.' The search was done in English and Thai language. Known fisheries experts were contacted by email and telephone to inquire about additional data, especially those that can only be found in unpublished reports and other gray literature. Finally, visits to relevant organisations were made to obtain information not available online.

Internet search results were checked for relevance and to eliminate duplication. The final set of data was then categorised into bycatch and habitat damage based on fishing gears, before performing content analysis. For the purpose of the study, we use habitat and bycatch definitions provided by Morgan and Chuenpagdee (2003). Bycatch includes non-target catch, consisting of catch of low-value species and discards. Habitat damage refers to damage to the living sea floor as well as alteration to geological structures including coral reefs, seagrass beds, and soft and hard bottom.

Low-value bycatch are catches of fish species that have low economic value, are of low quality, or that have low consumer preference, often referred to as ‘trash fish’. Market price of trash fish in 2013 ranged from 0.1–0.3 USD per kg (DOF 2015b). Another group of bycatch are ‘true’ trash fish, i.e. those that are small in size, even at maturity (Funge-Smith et al. 2005). These low-value bycatch are retained for different uses, including as raw material for livestock/fish feed or fish meal/oil production. Discards, on the other hand, refer to fish and animal species which are caught by fishing gear but discarded either at sea or land due to their non-marketability or no economic value.

The list of gear was based on the DOF classification (DOF 1997), but modified to reflect the latest legislation. In total, nine groups of fishing gears are classified: (1) surrounding nets, (2) trawls, (3) lift nets and falling nets, (4) gill nets and entangling nets, (5) push nets, (6) traps and pots, (7) bamboo stake traps and set bagnets, (8) hook and lines, and (9) dredges. Surrounding nets, trawls, king mackerel drift gill nets, Indo-Pacific mackerel encircling gill nets, push nets, and deep-water bamboo stake traps are considered large-scale fishing gear while the rest are small-scale.

Results

The internet search yielded more than 400 publications on seemingly relevant topics during 1995 to 2015. Of these, 134 publications were considered pertinent to the study and thus retained for further analysis. These publications were evenly spread from 1992–2015, with about 1–14 studies per year. An exception was found, however, in 2006 when as many as 14 studies were found, accounting for 10 % of all publications. The majority of publications were technical papers (70 %), written in Thai and mostly produced by the DOF, Thailand.

Content analysis revealed that studies about ecological impacts of fishing gear were highly skewed towards bycatch (93 %), especially in relation to trawl fisheries (43 %), as detailed below. To contextualise the findings, we begin with a brief overview of fishing gear used in Thailand.

Fishing gear in Thailand

Within the nine major gear categories, at least 75 different types of fishing gear are found. Some of them are limited to certain geographical areas while others have been locally modified to target specific species (DOF 1997). According to the recent Thai fishing vessels surveys (DOF 2015d), there were 38,013 registered fishing vessels in Thailand as of August 2015. About 53 % of them were involved in gill net and entangling net fisheries, with another 10 % and 9 % in trap/pot and trawl fisheries, respectively. Among trawl fisheries, otter board trawls dominate (65 %), followed by pair-trawls (32 %). While trawls represent a small portion of total gears used, they contribute almost half of the total landings annually. In 2013, about 1.6 million metric tons of marine capture fisheries landings were reported, 47 % of which were from trawl fisheries, while the other 32 % came from surrounding nets (DOF 2015b, c) (Table 1).

Table 1. Main fishing gear currently operating in Thai waters, with the number of registered fishing vessels and total landings for each gear.

Categories	Fishing gear	Registered fishing vessels[a]		Landings[b,c]	
		Number	%	Quantity (Metric ton)	%
Surrounding nets	Purse seine	1,313	7.9	413,591	25.6
	Anchovy purse seine	235	1.4	109,039	6.8
Trawls	Otter board trawl	2,075	12.5	537,017	33.3
	Pair trawl	1,026	6.2	226,429	14.0
	Beam trawl	91	0.5	3,877	0.2
Lift net	Lift nets	300	1.8	3,891	0.2
Falling nets	Squid falling nets	3,049	18.6	22,784	1.4
	Anchovy falling nets	624	3.8	12,838	0.8
	Cast net	NA	NA	24	<0.1
Gill nets and Entangling nets	King mackerel drift gill net	159	1.0	8,603	0.5
	Mackerel encircling gill net	37	0.2	5,160	0.3
	Mackerel gill nets	888	5.4	27,721	1.7
	Shrimp trammel nets	1,230	7.4	9,996	0.6
	Crab gill nets	2,250	13.6	18,538	1.1
	Pomfret gill nets	2,816	17.0	44	0.1
	Mullet gill nets			4,368	0.3
	Sea bass gill nets			290	<0.1
	Fourfinger threadfin gill nets			1,140	0.1
	Sardine gill nets			3,306	0.2
	Sand whiting gill nets			906	0.1
	Squid trammel nets			424	<0.1
	Other gill nets			19,892	1.2
Push nets	Push nets	347	2.1	17,858	1.1
	Hand push nets	NA	NA	312	<0.1
Traps and pots	Fish traps	NA	NA	1,622	0.1
	Crab traps	NA	NA	5,476	0.3
	Squid traps	NA	NA	2,443	0.2
	Shrimp traps	NA	NA	1,197	0.1
Bamboo stake traps and set bag nets	Deep water bamboo stake trap	NA	NA	2,057	0.1
	Shallow water bamboo stake trap	NA	NA	777	<0.1
	Set bagnets	NA	NA	1,865	0.1
Hook and lines	Tuna longline	NA	NA	344	<0.1
	Longline	55	0.3	514	<0.1
	Handline and Pole & line	NA	NA	2,664	0.2
Miscellaneous gear (bivalve dredging is included)		53	0.3	147,529	9.2
Total		16,548	100.0	1,614,536	100.0

Sources: [a]DOF (2015a), [b]DOF (2015b), [d]DOF (2015c)

Existing knowledge on ecological impacts of fishing

As previously mentioned, only a small fraction of studies was about habitat damage (9 out of 134). Further, about 44 % of the studies were focused on large-scale fishing gear such as otter board trawl (22 %), purse seine (9 %), pair trawl (9 %), pelagic longline (3 %) and encircling net (1 %). Among small-scale fishing gear, fish gillnets, followed by crab traps and crab gillnets, were most documented (9 %, 7 % and 7 %, respectively). The huge proportion of literature on bycatch is due largely to the mandate of DOF in regular stock assessment and catch composition analysis. The number of publications helps one to get an overview of issues at the national level; for example, many publications on otter board trawls and pair trawls can be used to illustrate the general proportion of economic fish, true trash fish, and economic juvenile species from those gears.

Bycatch impacts of fishing

Among the literature related to bycatch, the majority of the studies (64 %) concerned catch composition. Specifically, about 38 % of them provided information about the proportion of juvenile economic fish species in catch composition. Few studies (less than 10 %) mentioned fishing impacts on marine mammals and sea turtles, and only in qualitative terms (Fig. 1). Details on bycatch from fishing are provided below for the eight main gear categories except dredge since we found no literature related to bycatch from dredging.

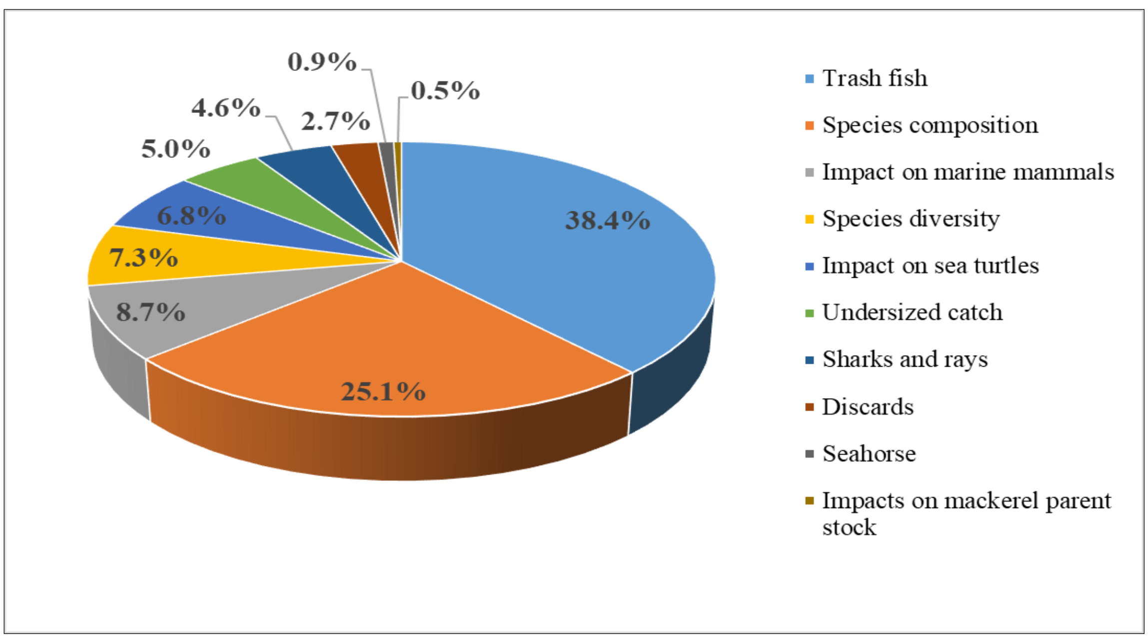

Fig. 1. Proportion of studies related to bycatch in Thai waters (by percentage of all studies)

a) Surrounding nets: Purse seines are mobile gear that target pelagic fish, especially mackerels, anchovies and tunas. Landings from purse seines constitute about 35 % of the total landings in Thai fisheries (Table 1).

According to 2013 landing statistics (DOF 2014b; 2015b, c), 70 % of the purse seine catches were pelagic fish, such as Indo-Pacific and Indian mackerels, sardines, scads and tunas, while anchovy dominated catches in the anchovy purse seine. Only 7 % and 2 % of trash fish were reported from purse seines and anchovy purse seines, respectively (DOF 2014b; 2015b, c).

Light-luring purse seine operating at night produced a higher level of trash fish compared to day-time purse seine fisheries using fish aggregating devices (FADs). In Thailand, FADs are made of bamboo poles with coconut leaves attached to lure schools of fish by floating the FADs on the sea surface and anchoring them with concrete blocks that are placed on the sea floor (Noranarttragoon et al. 2012). An average of close to 10 % of trash fish (with a range of 1 % to 30 %) was found in the light-luring purse seine operating at night (Loychuen et al. 2010; Sanitmajjaro et al. 2012), while the day-time purse seine fisheries using FAD had a lower average of less than 4 % (0.6 % to 8.8% in range) as reported in Noranarttragoon et al. (2006) and Sanitmajjaro et al. (2012). The tuna purse seine is another type of purse seine designed to catch mainly tunas. This gear is very selective with only about 3.5 % to 6.3 % of all catch being non-target species (Siripitrakool and Thapanand-Chaidee 2009; Uttayamakul et al. 2010). A few studies reported that dugongs and sea turtles were accidentally caught in purse seine fisheries, especially when they operate closer to the shore (Hines et al. 2005; Syed and Abe 2009).

b) Trawls: Three types of trawls, i.e. otter board, pair, and beam trawls, are generally found in Thai waters, targeting demersal fish. The majority of them are otter board trawls and together, they contribute almost half of the total annual landings (see Table 1; DOF 2015b). Trawls are mobile gear, which mostly touch the seafloor during operation. Species composition and trash fish from otter board and pair trawls were well documented in several studies, while none of them reported on beam trawls. Information on discards was also scarce. Based on the 2013 catch statistics, at least half of the catches from pair trawls were trash fish. The proportion of trash fish from otter board trawls was lower at 44 %, for vessels of 14–18 metres long (DOF 2014b; 2015b). Some studies indicated that most of the low-value fish or trash fish from trawlers in Thailand are supplied to feed industries (Kaewnern and Wangvoralak 2005; Supongpan and and Boonchuwong 2010; Achavanuntakul et al. 2014). Trash fish composition in trawl catches poses a major ecosystem concern especially when they consist of economic juvenile species, as studies show (Table 2).

These data illustrate differences in bycatch based on the type of trawls, size of fishing vessels, and fishing locations. In general, higher percentages of economic juvenile species are found in otter-board trawls and pair trawls operating in the Andaman Sea compared to those in the Gulf of Thailand (Supongpan and Boonchuwong 2010). In addition, sharks and rays have been reported as bycatch in trawl fisheries (Krajangdara 2005; Deechum 2009), with other studies mentioning that sea turtles and marine mammals are at risk in areas where trawls operate (Kittiwattanawong 2004; Hines et al. 2005; Syed and Abe 2009; Adulyanukosol 2010; Chanrachkij et al. 2010). For instance, Adulyanukosol (2010) reported four incidents of dugong being caught in trawlers operating within 3 km from the shore. These mammals later died even as fishers tried to release them from the nets.

Table 2. The average percentages of economic fish, trash fish, and economic juvenile species from otter board trawls and pair trawls, by size of vessels (in metres).

% of catch	Gulf of Thailand				Andaman Sea		
	Otter board trawls		Pair trawls		Otter board trawls		Pair trawls
	<14 m	14-18 m	<=18 m	>18 m	<14 m	14–18 m	All sizes
% Economic fish	45.7	50.3	64.6	56.0	31.6	39.7	29.6
% True trash fish	30.6	32.2	17.0	13.1	31.9	28.5	18.0
% Economic juvenile species	23.7	17.5	18.4	30.9	36.5	31.8	52.4

Note: Data used for analysis are from publications related to trawl fisheries in Thai waters and listed in references.

c) Lift nets and falling nets are mobile gear, operating from vessels of about 14–18 metres in length, equipped with large nets or castnets, targetting mostly pelagic fish. Fishing is generally operated in coastal waters with no more than 45 metres depth or 3–40 nautical miles from the shore (Loychuen et al. 2010; Sinanun et al. 2012). Similar to large-scale surronding net fisheries, lights may be used during the operation to aggregate fish before catching.

However, light-luring liftnets and light-luring falling nets for squid and anchovy are prohibited from operating in coastal waters (usually within 3 nautical miles from the shoreline), based on the announcement of the Ministry of Agriculture and Cooperatives on prohibition of the use of fishing gear and methods in fishing areas (Thailand Ministry of Agriculture and Cooperatives 2016a). Some fishers also use echo sounders to find schools of fish. There are various kinds of lift nets but squid lift nets, krill lift nets and anchovy lift nets are common. These gears are highly selective, with squids and krill dominating the catches. Nonetheless, about 13 % of the catches are trash fish (DOF 2015c). Comparative studies of species composition between day-time anchovy purse seine and light-luring anchovy lift net fisheries showed that trash fish was found in higher percentage in the latter (1.2 % vs. 0.3 %) (Boonkerd et al. 2008; Boonkerd and Anugun 2008). No report was found about marine mammals or other bycatch related to these gears.

d) Gill nets and entangling nets can be either mobile or fixed. Drift nets and trammel nets are common mobile gill nets, while bottom nets and fixed nets are semi-stationary. Different mesh sizes are used in gill net fisheries to target a wide range of fish species. The majority of gill net fisheries in Thailand are king mackerel drift gill nets, with about 11 % of the total catch comprising trash fish (DOF 2014b; 2015b, c). Additional research showed that 93 % of catch from king mackerel drift gill net fisheries were fish of economic importance, while 0.5 % and 7.2 % were sharks and other non-target species, respectively (Pramokchutima 1993), and the rest trash fish (Chantawong et al. 1994). Similarly, in mackerel encircling gill nets, less than 1 % of total catches were trash fish (DOF 2014b; 2015b, c). While the trash fish quantity is generally low in net fisheries, the study by Nakrobru and Saikliang (2003) illustrated other ecosystem concerns.

Specifically, they found that 65 % of Indo-Pacific mackerels caught by encircling nets in the western Gulf of Thailand were mature female fish with an estimated 6,360 eggs, which could mean an increase of about 15,000 metric tons of the mackerel stocks. Shrimp trammel nets are another mobile gear in this category. Consisting of three layers of nets, with decreasing mesh sizes from the outer to the inner layers, trammel nets catch shrimps while drifting with the currents. The bottom of the net often touches the sea floor when operating in shallow water.

According to Boutson et al. (2007), about 87 % of catch from shrimp trammel nets is discarded. The dominant discarded species were true trash fish, e.g. silver-biddy (*Gerres* sp.) and pony fish (*Leiognathus* sp.), as well as other species with no commercial value, such as sea urchins, tiny jellyfish, gastropods and starfish. They also suggested that increasing mesh size in the middle layer and reducing net height may reduce the catch of non-target species. A study by Preecha et al. (2011) revealed similar findings, with nine species reported as discards (50 % of total species caught), most of them being true trash fish (pony fish, Family Leiognathidae). Unlike shrimp gill nets, crab gill nets are semi-stationary and are normally set on the sea bottom for 1–2 days before retrieving. According to several studies, 75 % of total catches from this gear, on average, are crabs (see, for instance, Loychuen et al. 2013; Petsalapsri et al. 2013). Another study showed, however, that a total of 55 crab species were caught in crab gill nets, 69 % of which had no commercial value (Jaingam et al. 2007).

Thus, Wisespongpand et al. (2013) asserted that this type of fishing gear highly threatens crab biodiversity since as much as 82 % of the total number of species could be "trash". With respect to non-fish bycatch, studies show that sea turtles can be possibly caught indrift nets operating in Southeast Asia (Syed and Abe 2009). However, no official number of sea turtles caught by the drift nets was reported. Most of the entangled turtles die due to drowning while some are injured (Kittiwattanawong 2004; Chanrachkij et al. 2010). Marine mammals such as dugongs and dolphins are also threatened from gillnet fisheries (Marsh et al. 2002; Hines et al. 2005; Whitty 2014). Dugongs, for instance, are easily entangled in fishing nets and can die from drowning in a few minutes (Adulyanukosol 2010; Wongsuryrat et al. 2011). While total landings from this group of gears is low (about 6 % of the total landings in 2013), their impacts on bycatch are well documented and raise concerns on ecosystem health.

e) Push nets are mobile fishing gears, targeting mostly shrimp and krill, and can be either motorised or operated by hand. About 32 % of the catch is trash fish, followed by demersal fish (15 %), shrimps (15 %) and krill (14 %) (DOF 2014b; 2015b). Sompong (2009) found at least 62 species in catches by these gears. Further, several studies (e.g. Thongsila and Sinanun 2013; Suksumran and Thongsila 2015) indicated that close to 30 % of these were economic juvenile species. Additionally, because push nets usually operate in coastal waters with 2–15 metres depth, they can have an impact on young crabs and other juvenile species.

For instance, studies show that about 90 % of blue swimming crabs sampled from push nets, especially in Samut Prakan Province, were young, with carapace width at under-maturity stage (Arunrojprapai et al. 2010; Jindalikit et al. 2010). Hines et al. (2005) also expressed concern that these gears could be risky to dugongs when operating close to shore, especially in seagrass beds. On the other hand, krill push nets or krill scoop nets mainly catch krill (*Acetes* spp.), which comprised about 94.9 % of the total catch (Arunrojprapai et al. 2004).

f) Traps and pots are semi-stationary gears developed to catch a range of species. Crab, fish, and shrimp traps are placed on the sea floor while squid traps are arranged in the water column. Petchkamnerd et al. (2004) reported that about 62 % of female crabs from crab trap fisheries were under-matured. Boutson and Arimoto (2011) highlighted that the discard rate of small-scale crab trap fisheries (using less than 300 traps) and large-scale fisheries (operating with 2,000 traps) was 22 % and 30 %, respectively. Fourteen and 25 species caught respectively from small- and large-scale crab fisheries were discarded although some of them were economically important species, such as Grunters (*Terapon* sp.), cuttlefish (*Sepia* sp.) etc., because there were too few of them in the catch which were also very small in size (Boutson and Arimoto 2011). Putsa et al. (2016) conducted experiments to assess impacts of 'ghost fishing' of 12 crab traps throughout 454 observed days and found that 520 individuals (25 species) were trapped and 25 % of them died. High mortality was found in Japanese flathead fish *Inegocia japonica* (Cuvier 1829)), pony fish (*Leiognathus* spp.), catfish *Plotosus lineatus* (Thunberg 1787), and eel-catfish *Plotosus canius* (Hamilton 1822).

In the case of fish traps, which target demersal fish of high economic value, especially groupers (*Cephalopholis* spp., *Epinephelus* spp.) and red snappers (*Lutjanus* spp.), studies indicated a high level of selectivity of this gear, resulting in very small bycatch (Tunvilai and Suksumran 2012; Kalaya 2007). Similarly, squid trap fisheries show a low proportion of non-target species (Srikum and Binraman 2008). However, the recent introduction of new octopus traps using noble volute shell *Cymbiola nobilis* (Lightfoot 1786) to catch octopus raises ecological concerns, both in terms of the decline of octopus and of the noble volute shell population (Petchkamnerd and Suppanirun, 2004).

g) Bamboo stake traps and set bagnets are stationary fishing gears, located close to shore, especially near river mouths. The majority of landings from bamboo stake traps were pelagic fish (50 %) while trash fish constituted about 16 %. Landings from set bagnets generally include 50 % of shrimp, with 24 % trash fish and 10 % krill (DOF, 2015c). Boonpukdee and Sujittosakul (2004) studied the species composition of bamboo stake traps in Trat province, Gulf of Thailand, and reported that the majority of the catch was adult fish (71 %), followed by juvenile economic fish (20 %), squid (7 %) and true trash fish (2 %). Another study on species composition in bamboo stake traps in the Andaman Sea showed that trash fish constituted as much as 50 % of the total catch and these were used as feed in coastal aquaculture (SEAFDEC, 2005). Some reports showed concerns about the risk of dugongs getting caught in bamboo stake traps.

When the dugongs are trapped, they try to get out of the traps by hitting their bodies against the bamboo, nets and wires, thus causing injuries to themselves. Studies show that about 85 % of trapped dugongs died (Adulyanakosol et al. 2010; Wongsuryrat 2011), after being trapped for less than an hour, especially in shallow water or during low tide. In the case of set bagnets, about 87–157 species are normally caught, the majority of which were fish (Chamason et al. 2015). Other studies show that the proportion of economic juvenile species can be high, ranging for instance, from 36 % to 43 % of total catch, reflecting ecological issues and economic loss of many juvenile species (e.g. Phoonsawat et al. 2009).

h) Hooks and lines can be mobile (such as pelagic longline and trolling line) or semi-stationary (like bottom longline and pole and line). Hooks and lines are usually operated with small-scale vessels, except in tuna longline fisheries, which use larger boats and operate offshore. The main bycatch of tuna longlines and bottom longline are sharks (Bunluedaj et al. 2010). Studies also report sea turtle bycatch in pelagic and bottom longlines (Syed and Abe 2009; Chanrachkij et al. 2010).

Habitat damage from fishing gears

As previously mentioned, there are significantly less studies on habitat damage from fishing gears than on bycatch. Studies on habitat impacts were related to seagrass beds (50 %), impacts on coral reefs (18 %), reduction of seawater quality (18 %), impacts on benthic communities (9 %), and seafloor destruction (5 %) (Fig. 2).

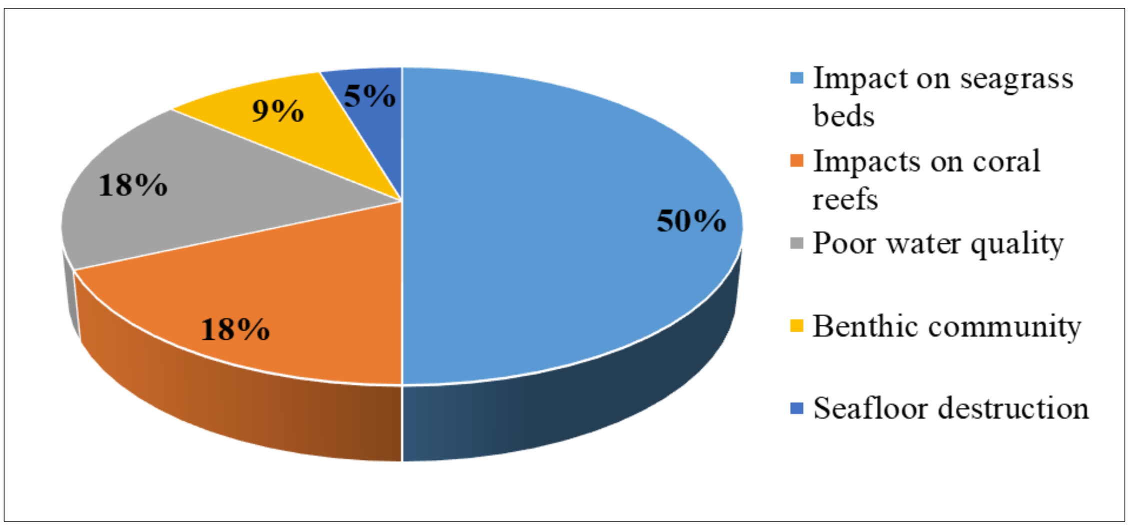

Fig. 2. Proportion of studies related to habitat damage in Thai waters (by percentage)

In the South China Sea and Gulf of Thailand, demersal trawls were identified as threats to coral reefs and seagrass (Vo et al. 2013). Sediments generated during trawling or dredging near coral reefs also contribute to coral reef deterioration (Sudara 1999) and affect coral growth (Chansaeng et al. 1992). Further, push nets have been identified as one of the destructive fishing gears that destroy seagrass beds and benthic organisms (UNEP 2004; Vo et al. 2013).

In the case of beach seine nets, Wungkhahart (1994) found that they operate in a similar manner as trawlers and thus can cause negative effects on seagrass beds and marine benthic species. Several research studies have been conducted on environmental impacts of bivalve dredging fisheries. Dredging causes direct ecological impacts such as seafloor destruction (Chanrachkij 2012), affects water quality by increasing sediments and concentration of hydrogen sulphide (H_2S), as well as raises the level of silicate-silicon in water (see Supongpan and Jindalikit 2005; Jindalikit and Thaochalee 2008; Chanrachkij 2012). In terms of the impacts on benthic communities, the study by Yeemin et al. (2010) revealed that after dredging, less polychaetes and brittle stars were observed in the soft sediment community, while Chanrachkij (2012) noted that the increased sediments and nutrients from dredging may cause temporary hypoxic conditions which further affect marine organisms.

Discussion

Although as many as 134 documents were found related to fishing gears in Thailand, few focused specifically on bycatch and habitat damage. As shown in this study, the data on bycatch are focused on trash fish and juvenile economic fish in trawling, especially otter board trawlers. Little is known about the proportion of juvenile economic species in catch composition, in different sizes of fishing vessels and fishing grounds. Scientific evidence of fishing gear impacts on marine mammals (dugongs and dolphins) and sea turtles is only available in qualitative form. Information about habitat damage from all gears is generally limited although there were a few studies qualitatively describing the impacts of seine nets, trawls, dredges, and push nets on seagrass beds, coral reefs and benthic communities.

Because trash fish are part of retained bycatch and some have commercial value, they are reported in the national fisheries statistics, with landing amount by fishing gear. It is clear, however, that some of them are juvenile economically important fish, which raises concerns in both ecological and economic terms (Nunoo et al. 2009; Pikitch et al. 2012). This study reflects the importance of scientific studies for the implementation of EAF. For example, many publications on otter board trawls and pair trawls help illustrate the general proportion of economically important fish, true trash fish, and economically important juvenile species from those gears at the national level. Spatially, higher percentages of economically important juvenile species found in fisheries operating in the Andaman Sea compared to those in the Gulf of Thailand, could reflect that fisheries resources in the former are more abundant than in the latter, where fishing down the food web occurred because of heavy overfishing as mentioned by Pauly and Chuenpagdee (2003). The authors highlight that trawl fisheries, especially demersal trawlers, are an unselective gear, producing a high quantity of trash fish, resulting in a decline of mean trophic level in the Gulf of Thailand marine food web (Pauly and Chuenpagdee 2003). In addition, only one-fifth of total trawlers in Thai waters are found in the Andaman Sea (DOF 2015b), reflecting the lower fishing effort in the Andaman compared to the Gulf of Thailand (DOF 2015d).

The high number of trawlers is found in the Gulf of Thailand because the seafloor is shallower than the Andaman Sea. In general, true trash fish is composed of many small marine species including finfish, crabs, and shellfish (Hoimuk et al. 2015). Among small fish, 45 species from 21 families were identified as true trash fish caught by trawlers (Siripitrakool et al. 2011), dominated by pony fish (family Leiognathidae), which makes up as high as 27–63 % of the true trash fish (Sanitmajjaro et al. 2012). High species diversity of economic juveniles in trash fish from trawl fisheries has been reported, including 72 species of demersal fish, 23 species of pelagic fish, 12 species of squids, 11 species of shrimps, and 7 species of crabs (Hoimuk et al. 2015). The major component is demersal fish comprising 23–37 % of total economically important juveniles in trash fish (Tossapornpitakkul et al. 2008; Hoimuk et al. 2015). When the proportion of these juvenile trash fish is considerable, as in the case of trawl fisheries (e.g. Supongpan and Boonchuwong 2010; Achavanuntakul et al. 2014), more awareness on the issue is needed.

The study on the use of trash fish in fishmeal production is also pertinent, given the increasing concern over aquaculture development, especially shrimp farming in Thailand and elsewhere (Edwards et al. 2004; Funge-Smith et al. 2005). Only a handful of studies provide information about the amount of trash fish found in small-scale fishing gear. While it may be argued that the majority of catches from small-scale fisheries are utilised, lack of information on this topic may lead to inappropriate policies. More research on the ecological impacts and economic losses of catching juvenile economically important fish and the utilisation of trash fish in Thailand is highly desirable. Discard issues have been of global concern as they pertain to a significant proportion of global catches and pose important challenges for sustainable fisheries (Kelleher 2005; Matsuoka 2008). Besides the impacts on the fish population, non-fish species such as benthic organisms, marine mammals, sea turtles, etc. may be threatened as a result of being caught and discarded.

The discarded species may not be valuable to market but they are still key components of marine ecosystems and might be the support for other species. Kelleher (2005) reported the global discard rate at 8 %, giving an estimated average discard of 7.3 million mt per year during 1992–2001. More than 50 % of the estimated discards were from trawl fisheries, especially tropical shrimp trawl fisheries, with discard rate as high as 62 %. He also argued that increased utilisation of bycatch for human and animal food could help reduce the quantity of discards (Kelleher, 2005). Supongpan and Boonchuwong (2010) supported the statement, saying that no marine fisheries discards were found because all landings are utilised. However, Matsuoka (2008) argued that the estimation of global discards is not reliable and factual issues on discards should be more scientifically discussed. Discard rate can vary greatly in different locations and fishing periods as well as between fishers who may have different practices although the same fishing gear is used. For examples, Boutson et al. (2007) reported that the discard rate of shrimp trammel nets in Thailand was 87 %, which is very high compared to that reported by Ean (2000) in Penang, Malaysia. Ean reported that 69 % of total catch was bycatch, consisting of 53 % discards and 16 % retained bycatch, which is either sold or consumed by the household. Discard rates of trammel nets in the Mediterranean countries range from 10 % to 43 % (Tsagarakis et al. 2013).

Finally, even within the same country, some variations are expected. For instance, the study of crab gillnet fisheries bycatch in Pattani Bay, Southern Thailand, reveals that the proportion of discarded species from the Bay (26 %) was lower than that from offshore (47 %) (Fazrul et al. 2015).Based on our analysis, lack of discard information shows a huge gap of knowledge on ecological impacts of fishing gears in Thailand. This is a major concern, especially in the context of IUU fishing, where discards contribute to unreported catches. As illustrated by Teh et al. (2015), about 13 million mt or 5 % of Thailand's reconstructed catch during 1950–2010 is unreported discards. Degraded fish caused by poor storage or handling during transportation, usually kept in buckets, is still valuable and can be sold directly to fishmeal producers. This could be categorised as unreported catch since these fish are not included in fisheries statistics as trash fish (Achavanuntakul et al. 2014). Fishing impacts on marine mammals (dugongs, dolphins) and sea turtles and impacts on habitats are mostly reported in qualitative terms. Trawlers, push nets, gill nets and bamboo stake traps have been reported as the main fishing gears threatening these marine mammals and sea turtles (Hines 2005; Kittiwattanawong 2004; Adulyanakosol 2010). This implies that impacts on marine mammals and sea turtles can be generated from both large-scale and small-scale fishing gears.

Impacts of fisheries on marine mammals and sea turtles have been reported globally (Moore et al. 2010). In the US, impacts of midwater gillnets on both marine mammals and sea turtles are of major concern, while pelagic longlines are also harmful to sea turtles (Chuenpagdee et al. 2003). In Canada, the gear impact study of Fuller et al. (2008) reveals that bottom gillnets cause 'medium-high' impact on marine mammals, while other gears generate 'medium' to 'low' impact. Besides trawlers, these studies emphasised the potential impacts of gillnets on marine mammals and sea turtles. In Thailand, laws have been issued with the aim of protecting marine mammals (dolphins, dugongs, whales) and sea turtles from fishing impacts (Thailand Ministry of Agriculture and Cooperatives 2016b). This measure supports Thailand's efforts related to implementation of the CBD Aichi Targets on sustainable management of marine living resources, especially to mitigate fishing impacts on threatened species and vulnerable ecosystems (CBD undated). In terms of knowledge about habitat damage, large-scale fishing gears, especially demersal trawlers and push nets, have been well studied, particularly in terms of their threats to coral reefs and seagrass beds. However, no in situ research has been conducted to quantify the direct impacts of these gears on seagrass beds and coral reefs (UNEP 2004; Vo et al. 2013).

Some studies mention the indirect effect of trawling on coral reefs through sediment generation, based also on research conducted in other countries. Environmental impacts of dredging, in terms of changes in water quality and the sea floor, are well explained (for example, Chanrajkij 2012), while impacts on benthic communities are less understood. In conclusion, knowledge gaps exist with respect to the understanding of habitat damage caused by many bottom oriented fishing gears, particularly small-scale. The scarcity of research on bycatch and habitat damage could obstruct the implementation of EAF, and to a lesser extent, the efforts to combat IUU fishing.

Conclusion

The huge knowledge gap on bycatch (especially discard information) and habitat damage caused by small-scale fishing gears, illustrated by the study, will certainly pose difficulty in fisheries sustainability, given their importance. This study shows a significant gap in research and knowledge on the ecological impacts of fishing gears in Thailand. In-depth research is required on various topics related to both small- and large-scale fisheries including, but not limited to: (a) a detailed study on catch composition consisting of target species, retained and discarded bycatch, as well as the use of these data as a baseline for gear impact assessment; (b) a study on interactions of fishing gear and natural habitats such as coral reefs, seagrass beds, seafloor etc.; (c) modification of fishing gears and methods to minimise bycatch and damage to the natural habitats by incorporating local knowledge and local fishers in the research; and (d) promoting environmental stewardship by local fishers for sustainable fisheries along with maintaining marine biodiversity. While more research on these topics is required in order to implement EAF in Thailand, public awareness about the ecological impacts of fishing gears should also be raised. As the responsible governing body in fisheries, the DOF should add research strategies and development plans into its implementation strategies and policy planning process.

Also, a new information system and data collection process could be developed to help obtain systematic and regular data on bycatch and habitat impacts. Lastly, research collaboration among DOF and research and academic institutions, as well as funding agencies, should be promoted to increase capacity and knowledge on these topics.

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References

Achavanuntakul, S., S. Piromwarakorn, D.J. True, P Yamla-Or, S. Khlongakkhara and K. Tanangsnakool. 2014. Mapping shrimp feed supply chain in Songkhla province to facilitate feed dialogue. A report submitted to Oxfam Thailand. 151 pp.

Adulyanukosol, K. 2010. Ecology of the dugong (*Dugong dugong*) in Thailand: Population characteristics, feeding habits and conservation. Marine and Environmental Science Graduate School of Engineering and Science. University of the Ryukyus. 260 pp.

Arunrojprapai, C., K. Loychuen, T. Srikum, T. Kongchai, J. Jindalikit and S. Puteeka. 2010. Catch rate and size composition of blue swimming crab from trawl and push net fisheries in Thai waters. Technical Paper No. 8/2010. Department of Fisheries, Thailand. 31 pp.

Arunrojprapai, C., T. Reungprim and P. Keaw-Khaeiw. 2004. Sergestid push net fishery in the Andaman Sea. Technical Paper No. 17/2004. Department of Fisheries, Thailand. 35 pp.

Boonkerd, S. and T. Anugun. 2008. Anchovy resource survey in the upper Gulf of Thailand in 1997. Extension Paper No. 2/2008. Department of Fisheries, Thailand. 30 p.

Boonkerd, S., T. Anugul and A. Yamrungrueng. 2008. Anchovy resource survey in the Upper Gulf of Thailand. Technical Paper No. 3/2008. Department of Fisheries, Thailand. 17 pp.

Boonpukdee, S. and T. Sujittosakul. 2004. Bamboo stake trap fisheries in Trat Bay. Technical Paper No. 9/2004. Department of Fisheries, Thailand. 41 pp.

Boutson, A. and T. Arimoto. 2011. Catch comparison between small- and commercial scale of collapsible pot fishing targeting blue swimming crab (*Portunus pelagicus*) in the Upper Gulf of Thailand. In 49th Kasetsart University Annual Conference: Fisheries, Bangkok, Thailand. 8 pp.

Boutson, A., C. Mahasawasde, S. Mahasawasde, S. Tunkijjanukij and A. Preecha. 2007. Possibility to modify shrimp trammel net to reduce discard species. Kasetsart Journal (Natural Science) 41: 149–156.

Bunluedaj, C., C. Nuangsang, W. Premkit and P. Lirdwitayaprasit. 2010. Fish resources survey by tuna longline along the continental shelf in the Andaman Sea. Technical Paper No. 10/2010. Department of Fisheries, Thailand. 29 pp.

Chamason, O., N. Kulanujaree and P. Hussadee. 2015. Community structure of aquatic animals caught by stow nets in the Bang Pakong river mouth. Technical Paper No. 3/2015. Department of Fisheries, Thailand. 55 pp.

Chanrachkij, I. 2012. Environmental impacts by undulated surf clam (*Paphia* spp.) dredge fishing: Case study in Paknam Pranburi estuary and adjacent areas, Pranburi district and Sam Roi Yot district, Prachaup Khiri Khan Province. M.Sc. thesis, Faculty of Fisheries, Kasetsart University. Thailand. 354 pp.

Chanrachkij, I., N. Yasook, S. Anantapongsuk, P. Petrasatien and W. Wanchana. 2010. Survey of small-scale fishing gear and practices contributing to sea turtle mortalities along the coast of Rayong province, Eastern Gulf of Thailand. Training Department/Southeast Asian Fisheries Development Center, Samutprakan, Thailand. 55 pp.

Chansaeng, H., N. Phongsuwan and P. Boonyanate. 1992. Growth of corals under effects of sedimentation along the northwest coast of Phuket Island, Thailand. In 7th International Coral Reefs Symposium (ed. R.H. Richmond), pp. 129–136. Guam, USA.

Chantawong, P., T. Chantawong and N. Ubonsuwan. 1994. King mackerel gillnet fishery along the Andaman sea coast of Thailand. Technical Paper No. 29/1994. Department of Fisheries, Thailand. 47 pp.

Chuenpagdee, R., P. Degnbol, M. Bavinck, S. Jentoft, D. Johnson, R. Pullin and S. Williams. 2005. Challenges and concerns in fisheries and aquaculture. In Fish for Life: Interactive Governance for Fisheries (eds. J. Kooiman, S. Jentoft, R. Pullin and M. Bavinck), pp. 25–37. University of Amsterdam Press, The Netherlands.

Chuenpagdee, R., L.E. Morgan, S.M. Maxwell, E.A. Norse and D. Pauly. 2003. Shifting gears: assessing collateral impacts of fishing methods in the U.S. waters. Frontiers in Ecology and the Environment 1: 517–524.

CBD (Convention on Biological Diversity). (undated). Aichi Biodiversity Targets, https://www.cbd.int/sp/targets/. Accessed 15 March 2016.

Deechum, W. 2009. Species compositions and some biological aspects of sharks and rays from the Gulf of Thailand and Andaman landing sites. M.Sc. thesis, Faculty of Aquatic Science, Songkla University, Songkla, Thailand. 145 pp.

DOF (Department of Fisheries). 1997. Definitions and classification of fishing gears in Thailand. Department of Fisheries, Thailand. 198 pp.

DOF (Department of Fisheries) 2014a. Strategic plan for 2016–2019. Document No. 2/2014. Department of Fisheries, Thailand. 84 pp.

DOF (Department of Fisheries) 2014b. Marine fisheries statistics in 2012 based on the sample survey. Document No. 14/2014. Department of Fisheries, Thailand. 157 pp.

DOF (Department of Fisheries) 2015a. Thai fishing vessels statistics in 2013. Document No. 2/2015. Department of Fisheries, Thailand. 105 pp.

DOF (Department of Fisheries) 2015b. Fisheries statistics of Thailand in 2013. Document No. 7/2015. Department of Fisheries, Thailand. 110 pp.

DOF (Department of Fisheries) 2015c. Fishing community production survey in 2013. Document No. 8/2015. Department of Fisheries, Thailand. 103 pp.

DOF (Department of Fisheries) 2015d. Marine fisheries management plan of Thailand: A national policy for marine fisheries management 2015–2019. Department of Fisheries, Thailand. 89 pp.

Ean, C.P. 2000. The trammel net fisheries for shrimps at Teluk Kumbar, Penang. Malaysian Fisheries Journal 1: 101–108.

Edwards, P., A.T. Le and G.L. Allan. 2004. A survey of marine trash fish and fish meal as aquaculture feed ingredients in Vietnam. ACIAR Working Paper No. 57. 56 pp.

FAO (Food and Agriculture Organization). 1995. Code of conduct for responsible fisheries. FAO, Rome. 41 pp.

FAO (Food and Agriculture Organization). 2003. Fisheries management: The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries 4 (Suppl. 2). FAO, Rome. 112 pp.

FAO (Food and Agriculture Organization). 2014. The state of world fisheries and aquaculture 2014. FAO, Rome. 223 pp.

FAO (Food and Agriculture Organization). 2015. Voluntary guidelines for securing sustainable small-scale fisheries. FAO, Rome. 18 pp.

Fazrul, H., S. Hajisamae, Mhd. Ikhwanuddin and S. Pradit. 2015. Assessing impact of crab gill net fishery to bycatch population in the lower Gulf of Thailand. Turkish Journal of Fisheries and Aquatic Sciences 15: 761–771.

Fuller, S.D., J Ford, C. Tsao, L.E. Morgan, D. Hangaard and R. Chuenpagdee. 2008. How we fish matters: Addressing the ecological impacts of Canadian fishing gear. Ecology Action Centre, Living Oceans Society and Marine Conservation Biology Institute: British Columbia, Canada. 25 pp.

Funge-Smith, S., E. Lindebo and D. Staples. 2005. Asian fisheries today: The production and use of low value/trash fish from marine fisheries in the Asia-Pacific region. Regional Office for Asia and the Pacific. FAO, Bangkok. 38 pp.

Garcia, S. and A. Charles. 2008. Fishery systems and linkages: Implications for science and governance. Ocean & Coastal Management 51: 505–527.

Garcia, S.M., A. Zerbi, C. Aliaume, T. Do Chi and G. Lasserre. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO, Rome. 71 pp.

Hines, E., K. Adulyanukosol, D. Duffus and P. Dearden. 2005. Community perspectives and conservation needs for Dugongs (*Dugong dugong*) along the Andaman coast of Thailand. Environmental Management 36: 654–664.

Hoimuk, S., P. Nootmorn, U. Augsornpa-op and S. Panjarat. 2015. Marine resources and commercial trawl fishery in the Andaman Sea. Technical Paper No. 6/2015. Department of Fisheries, Thailand. 62 pp.

Jaingam, W., P. Wisespongpand and T. Thamrongnawasawat. 2007. Species diversity of crabs from bottom gill net fisheries in Thailand. In 45th Kasetsart University Annual Conference: Fisheries, pp. 603-612. Kasetsart University, Bangkok, Thailand.

Jindalikit, J., K. Sereeruk, M. Treeerathran, S. Sriprapa and A. Sengwong. 2010. Blue swimming crab (*Portunus pelagicus*) from small otter board trawl and push net in the inner Gulf of Thailand. Technical Paper No. 2/2010. Department of Fisheries, Thailand. 15 pp.

Jindalikit, J. and P. Thaochalee. 2008. Survey on economic bivalve in Mahachai Bay, Samut Sakhon Province. Technical Paper No. 4/2008. Department of Fisheries, Thailand. 64 pp.

Kaewnern, M. and S. Wangvoralak. 2005. Status of trash fish and utilization for aquaculture in Thailand. Kasetsart Journal (Natural Science) 39: 70–77.

Kalaya, C. 2007. Status evaluation of reef fisheries in Phuket province. M.Sc. thesis, Faculty of Science, Chulalongkorn University. Bangkok, Thailand. 79 pp.

Kelleher, K. 2005. Discards in the world's marine fisheries: An update. FAO Fisheries Technical Paper. No. 470. FAO, Rome. 131 pp.

Kittiwattanawong, K. 2004. Biology and conservation of green turtle *Chelonia mydas* in Thailand. Doctoral Dissertation. Kyoto University. 135 pp.

Krajangdara, T. 2005. Species, maturation and fishery of sharks in the Andaman Sea of Thailand. Technical Paper No. 8/2005. Department of Fisheries, Thailand. 31 pp.

Loychuen, K., P. Kawmanee, C. Sangangm and C. Arunrojprapai. 2010. Anchovy fisheries along the Andaman Sea, Coast of Thailand. Technical Paper No. 15/2010. Department of Fisheries, Thailand. 43 pp.

Loychuen, K., W. Panthakit, S. Boonsuk, P. Kaewmanee and T. Suppapruek. 2013. Marine resources from small fisheries along the Andaman Sea coast of Thailand. Technical paper No. 8/2013. Department of Fisheries, Thailand. 66 pp.

Marsh, H., H. Penrose, C. Eros, and J. Hugues. 2002. Dugong status reports and action plans for countries and territories. UNEP Early Warning and Assessment Report Series. The World Conservation Union, Gland, Switzerland.162 pp.

Matsuoka, T. 2008. A review of bycatch and discard issue: Toward solution. In 5th World Fisheries Congress 2008: Fisheries for global welfare and environment (eds. K. Tsukamoto, T. Kawamura, T. Takeuchi, T.D. Beard Jr. and M.J. Kaiser), pp. 169–180. Terrapub, Tokyo.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Current state and trends, Volume 1. Island Press, USA. 838 pp.

Morgan, L.E. and R. Chuenpagdee. 2003. Shifting gears: Assessing the collateral impacts of fishing methods in US waters. Island Press, USA. 41 pp.

Moore, J.E., T.M. Cox, R.L. Lewison, A.J. Read, R. Bjorkland, S.L. McDonald, L.B. Crowder, E. Aruna, I. Ayissi, P. Espeut, C. Joynson-Hicks, N. Pilcher, C.N.S. Poonian, B. Solarin, and J. Kiszka. 2010. An interview-based approach to assess marine mammal and sea turtle captures in artisanal fisheries. Biological Conservation 143: 795–805.

Nakrobru, C. and P. Saikliang. 2003. The effect of mackerel encircling gill net fishery to Indo-Pacific mackerel parent stock in protected area, Prachuap Khiri Khan, Chumphon and Surat Thani provinces. Technical Paper No. 14/2003. Department of Fisheries, Thailand. 40 pp.

Noranarttragoon, P., C. Mahasawasde, P. Saiklieng and P. Jantrarotai. 2006. Species composition, size and catch per unit effort of marine fauna by luring purse seine gear in the Gulf of Thailand. Technical Paper No. 44/2006. Department of Fisheries, Thailand. 10 pp.

Noranarttragoon, P., P. Sinanan, N. Boonjohn, P. Khemakorn and A. Yakupitiyage. 2012. FADs fishery in the Gulf of Thailand: Time to manage [abstract]. In Annual Conference on Fisheries 2012, pp. 170–171, Department of Fisheries, Bangkok, Thailand.

Nunoo, F.K.E., J.O. Boateng, A.M. Ahulu, K.A. Agyekum and U.R. Sumaila. 2009. When trash fish is treasure: The case of Ghana in West Africa. Fisheries Research 96: 167–172.

Pauly, D. and R. Chuenpagdee. 2003. Development of fisheries in the Gulf of Thailand large marine ecosystem: Analysis of an unplanned experiment. In Large marine ecosystems of the world: Trends in exploitation, protection and research (eds. G. Hempel and K. Sherman), pp. 337–354. Elsevier Science, USA.

Pauly, D., R. Watson and J. Alder. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of the Royal Society B: Biological Sciences, 360: 5–12.

Petchkamnerd, J., S. Srichanngam, P. Kaewnuratchadasorn and S. Arnupapboon. 2004. Crab fisheries in locally based coastal fisheries management, Pathew District, Chumphon Province. Technical Paper No. 28/2004. Department of Fisheries, Thailand. 26 pp.

Petchkamnerd, J. and T. Suppanirun. 2004. Impacts of octopus pot fishers in the Middle Gulf of Thailand. Technical Paper No.12/2004. Department of Fisheries, Thailand. 54 pp.

Petsalapsri, O., W. Panthakit, S. Boonsuk and C. Sa-nga-ngam. 2013. Small-scale fisheries in the closed area during spawning and breeding season in the Andaman Sea. Technical Paper No. 18/2013. Department of Fisheries, Thailand. 56 pp.

Phoonsawat, R., K. Chuapun and S. Srisanga. 2009. Cost, return and financial loss from stow-net fishery at Klong Sanphasamit. Technical Paper No. 5/2009. Department of Fisheries, Thailand. 62 pp.

Pikitch E.K., C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D.O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E. D. Houde, J. Link, P.A. Livingston, M. Mangel, M.K. Mcallister, J. Pope and K.J. Sainsbury. 2004. Ecosystem-based fishery management. Science 305: 346–347.

Pikitch, E., P.D. Boersma, I.L. Boyd, D.O. Conover, P. Cury, T. Essington, S.S. Heppell, E.D. Houde, M. Mangel, D. Pauly, É. Plagányi, K. Sainsbury, and R.S. Steneck. 2012. Little fish, big impact: Managing a crucial link in ocean food webs. Lenfest Ocean Programme. Washington, DC. 108 pp.

Pramokchutima, S. 1993. Catch composition of fishes from king mackerel driftnet. Technical Paper No. 3/1993. Department of Fisheries, Thailand. 28 pp.

Preecha, A., A. Tunkijjanukij and S. Boutson. 2011. Comparative fishing of shrimp trammel net between conventional and modified nets. In 49th Kasetsart University Annual Conference: Fisheries, pp. 254–262. Kasetsart University, Bangkok, Thailand.

Putsa, S. A. Boutson and S. Tunkijjanukij. 2016. Comparison of ghost fishing impacts on collapsible crab trap between conventional and escape vents trap in Si Racha Bay, Chon Buri province. Agriculture and Natural Resources 50: 125–132.

Sanitmajjaro, W., S. Tossapornpitakkul, K. Vibunpant and J. Songnui. 2012. Commercial fisheries status of Nakhon Si Thammarat province in 2009. Technical Paper No. 24/2012. Department of Fisheries, Thailand. 102 pp.

SEAFDEC. 2005. Introduction of set-net fishing to develop the sustainable coastal fisheries management in Southeast Asia: case study in Thailand 2003–2005. Training Department/Southeast Asian Fisheries Development Center, Samutprakan, Thailand. 402 pp.

Sinanun, P., T. Sinanun, P. Noranarttragoon, N. Boonjorn, and S. Tossapornpitakkul. 2012. Anchovy fisheries in the Gulf of Thailand. Technical Paper No. 18/2012. Department of Fisheries, Thailand. 61 pp.

Siripitrakool, P. and T. Thapanand-Chaidee. 2009. Catch composition of fisheries resources by tuna purse seine in the Indian Ocean by R/V Mahidol. Technical Paper No. 2/2009. Department of Fisheries, Thailand. 9 pp.

Siripitrakool, P., W. Uttayamakul, P. Lirdwitayaprasit, C. Chookong, K. Chuapun, A. Wongkeaw and W. Chumchuen. 2011. Fish community structure in the middle Gulf of Thailand by otter board trawl during 2004–2005. Technical Paper No. 4/2011. Department of Fisheries, Thailand. 38 pp.

Sompong, P. 2009. Marine organisms caught by push net at Thungka-Sawi Bay, Chumphon province. Research Project Report, Faculty of Science, Maejo University. Chumphon, Thailand. 65 pp.

Srikum, T. and P. Binraman. 2008. Collapsible squid trap fisheries in Ban Jao-Lhao, Chantaburi Province. Technical Paper No. 17/2008. Department of Fisheries, Thailand. 26 pp.

Sudara, S. 1999. Who and what is to be involved in successful coastal zone management: a Thailand example. Ocean & Coastal Management 42: 39–47.

Suksumran, N. and K. Thongsila. 2015. Push net fisheries in the eastern Gulf of Thailand. Technical Paper No. 11/2015. Department of Fisheries, Thailand. 33 pp.

Supongpan, M. and J. Jindalikit. 2015. Short-necked clam fishery and jointly survey with fishers. Technical Paper No. 9/2015. Department of Fisheries, Thailand. 57 pp.

Supongpan, M. and P. Boonchuwong. 2010. Bycatch management in trawl fisheries in the Gulf of Thailand: A national report to submit for the GEF: Bycatch management and reducing discard from trawl fisheries in the coral triangle and Southeast Asian waters. 108 pp.

Swan, J. and D. Gréboval. 2004. Report and documentation of the international workshop on the implementation of international fisheries instruments and factors of unsustainability and overexploitation in fisheries. Mauritius, 3–7 February 2003. FAO Fisheries Report. No. 700. FAO, Rome. 305 pp.

Syed S.A.K. and O. Abe. 2009. Report of the third regional technical consultation on research for stock Enhancement of sea turtles (Japanese Trust Fund IV Program). SEAFDEC-MFRDMD/RM/24. 203 pp.

Szaro, R.C., J. Berc, S. Cameron, S. Cordle, M. Crosby, L. Martin, D. Norton, R. O'Malley and G. Ruark. 1998. The ecosystem approach: science and information management issues, gaps and needs. Landscape and Urban Planning 40: 89–101.

Teh, L.C.L., D. Zeller and D. Pauly. 2015. Preliminary reconstruction of Thailand's marine fisheries catches: 1950–2010. Fisheries Centre Working Paper No. 2015–01, University of British Columbia, Vancouver. 14 pp.

Thailand Ministry of Agriculture and Cooperatives. 2016a. Ministerial announcement on prohibition of the use of fishing gears and methods in fishing areas. Thai Government Gazette, Vol 133 (Special Issue 46d). p. 9.

Thailand Ministry of Agriculture and Cooperatives. 2016b. Ministerial announcement on prohibition of catching and fishing of marine mammals, endangered or rare species of marine animals. Thai Government Gazette, Vol 133 (Special Issue 98d). pp. 28–29.

Thongsila, K. and T. Sinanun. 2013. Stock assessment of banana prawn (*Penaeus merguiensis* De Man, 1888) in the Eastern Gulf of Thailand. Technical Paper No. 2/2013. Department of Fisheries, Thailand. 38 pp.

Tossapornpitakkul, S., P. Khemakorn, A. Kongprom, K. Vibunpant and S. Chumpuvorn. 2008. Small otter board trawl fisheries in the area of Nakhon Si Thammarat and Songkhla province. Technical Paper No. 10/2008. Department of Fisheries, Thailand. 35 pp.

Tsagarakis, K., A. Palialexis and V. Vassilopoulou. 2013. Mediterranean fishery discards: review of the existing knowledge. ICES Journal of Marine Science DOI: 10.1093/icesjms/fst074

Tunvilai, R. and N. Suksumran. 2012. Status of small-scale fisheries before and after artificial reef installation in Nayai-am district, Chanthaburi province. Technical Paper No. 1/2012. Department of Fisheries, Thailand. 55 pp.

UNEP (United Nations Environment Programme). 2004. Seagrass in the South China Sea: Reversing environmental degradation trends in the South China Sea and Gulf of Thailand. UNEP/GEF/SCS Technical Publication No. 3. 14 pp.

Uttayamakul, W., N. Darumas and C. Chookong. 2010. Tuna resource survey with purse seine in the eastern Indian Ocean by R.V. Mahidol. Technical Paper No. 9/2010. Department of Fisheries, Thailand. 32 pp.

Vo, S.T., J.C. Pernetta and C.J. Paterson. 2013. Status and trends in coastal habitats of the South China Sea. Ocean & Coastal Management 85: 153–163.

Whitty, T.S. 2014. Conservation-scapes: An interdisciplinary approach to assessing cetacean bycatch in small-scale fisheries. PhD dissertation. University of California, San Diego. 265 pp.

Wisespongpand, P., T. Sirivirintarat, W. Jaingam, K. Inbumrung and W. Srichomngam. 2013. Diversity of crabs from bottom gill net, Rayong province. In 51st Kasetsart University Annual Conference, pp. 422–429. Kasetsart University, Bangkok, Thailand.

Wongsuryrat, M., K. Chunkao, P. Prabuddham and M. Daungsavat. 2011. Distribution, abundance and conservation status of dugong around Koh Talibong, Trang Province, Thailand. Sustainable Development 4: 118–124.

Wungkhahart, W. 1994. A survey on fishing gears in the restricted seagrass areas in Trang Province. In Seminar on Fisheries 1994, pp. 314–327. National Inland Fisheries Institute, Bangkok, Department of Fisheries, Thailand.

Yeemin, T., C. Saenghaisuk, M. Yuchareon, W. Donsomjit and M. Sutthacheep. 2010. Effects of clam dredging on population density of the surf clam *Paphia undulata* in the eastern Gulf of Thailand. A paper presentation at the 25th International Congress for Conservation Biology. Christchurch. New Zealand.

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