Impacts of Fish Trap Fisheries on Coral Reefs near Ko Mak and Ko Kut, Trat Province, Thailand

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ABSTRACT

This study aims to enhance the knowledge of the operation of fish trap fisheries and their impacts on coral reefs through in situ underwater observation. A total of 82 fish traps were investigated during January-October 2016 near the islands of Ko Mak and Ko Kut, Trat Province, in the Eastern Gulf of Thailand. Approximately 24 % of the traps were in physical contact with juvenile corals and coral communities, particularly members of the family Fungiidae and *Porites* sp., resulting in physical damage of some corals. We found that the catch rates of fish traps ranged from 0.10 to 2.56 $kg \cdot trap^{-1} \cdot day^{-1}$ with a mean of 1.59 $kg \cdot trap^{-1} \cdot day^{-1}$. About 60 % of the total catch were target species, including groupers (Family Serranidae) and snappers (Family Lutjanidae), while the remaining 40 % were bycatch species. As many as 22 species were found in the bycatch, including 17 species of fish, four species of crustaceans and one species of sea cucumber. Based on functional groups, carnivorous fish were caught at the highest rate (mean CPUE = 1.34±0.79 $kg \cdot trap^{-1} \cdot day^{-1}$), while the mean CPUE of herbivorous fish was 0.19±0.17 $kg \cdot trap^{-1} \cdot day^{-1}$. In this study, six species of herbivorous fish were observed. Two of them were considered as corallivores: *Scarus ghobban* and *Monacanthus chinensis*. This study provides understanding of the interaction of fish trap fisheries and the coral reef ecosystem in terms of the physical damage to coral reefs and the loss of targeted and bycatch species, which may alter the overall ecological function of the coral reef ecosystem.

Keywords: Coral reefs, Fish trap, Fishing impact

INTRODUCTION

Coral reefs are recognized as globally important ecosystems providing ecological functions to various marine species and contributing to marine integrity. With only 255,000 km^2 of ocean floor covered by coral reefs, they still serve as habitat to one-third of marine species, thus forming the most diverse and productive marine ecosystem on earth (Nelson *et al*., 2016). Furthermore, coral reef ecosystems provide many services that support human livelihoods and wellbeing (Elliff and Kikuchi, 2017; Hughes *et al*., 2017). Fishing near coral reefs is practiced worldwide with various fishing gears such as gillnets, traps and pots, hooks and lines, and bottom longlines (Samoilys *et al*., 2017), causing a significant interaction between fishing activities and coral reefs.

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Even though coral reef fisheries are a major source of income and livelihood of local coastal communities (Cinner, 2014; Hoegh-Guldberg *et al*., 2019), overfishing and destructive reef fisheries can cause significant impacts on fisheries resources and reef resilience (Bozec *et al*., 2016; Lachs and Oñate-Casado, 2020). Fishing impacts on coral reefs and marine biodiversity especially concern habitat damage and bycatch issues (Jennings and Polunin, 1996; Chuenpagdee *et al*., 2003). Physical damage of coral reefs due to fishing activities has been reported for the gears that reach the seafloor, particularly traps and pots (Van Der Knaap, 1993; Stephenson *et al*., 2017), bottom trawlers and dredges (Watling and Norse, 1998; Pitcher *et al*., 2000). Sediment generated from fishing operations can affect coral growth and cause mortality due to suffocation and reduction in light penetration (Erftemeijer *et al*., 2012). Bycatch may generate an imbalance of the marine ecosystem and alteration of marine food webs (Houk *et al*., 2018). Over-exploitation of reef fish leads to the reduction of reef resilience and imbalance of the reef community (Bozec *et al*., 2016). For example, removing too many herbivorous fish may disturb coral-algal dynamics and have further effects on coral recruitment and natural recovery. Degraded coral reefs caused by multiple stressors, particularly destructive fishing practices and over-fishing, are likely to effect a decline of fishery productivity because of the changes in composition and structure of reef fish communities. Fishery productivity may decrease by as much as 35 % if the structural complexity of reefs is lost (Rogers *et al*., 2018).

In Thailand, most fish trap fisheries are operated either along coastal shorelines or in/near coral reefs or artificial reefs, found in both the Gulf of Thailand and the Andaman Sea. Fishing can be done year-round using either small- or large-scale fishing vessels. According to the Fisheries Statistics, 371 large-scale fishing vessels using fish traps were registered in 2019 (DOF, 2019c), while numerous small-scale fishing vessels with this gear are in the process of being registered. A total of 9,678 metric tonnes of fish landings were reported in 2018; 13 % were from small-scale vessels, and 87 % were from large-scale vessels. Demersal fishes were mainly targeted, especially groupers, snappers, and threadfin breams (DOF, 2019a; 2019b).

Most studies regarding the fish trap fisheries in Thailand have focused on catch composition; for example, Boutson *et al*. (2016) provided information on fish trap operation and catch composition using Rayong Province, located along the eastern Gulf of Thailand, as a case study. Kalaya (2007) mentioned that the fishers in Phuket Province, in the Andaman Sea, deployed 7-8 traps per trip and left them underwater for 7-15 days, generating a total catch of about 27.2 kg per trip. A few studies investigated the efficiency of fish traps of different sizes and models (Grasaelarb, 1997; Kritsanapuntu and Chaitanawisuti, 2000; Wungkhahart *et al*., 2000). However, the understanding of the impacts of fish trap fisheries on coral reefs is still limited (Suebpala *et al*., 2017). In this study, we observed the operation of fish trap fisheries and investigated their potential impacts on coral reefs near the islands of Ko Mak and Ko Kut, Trat Province, in the Gulf of Thailand.

MATERIALS AND METHODS

Study site

Ko Mak (11°49′N, 102°28′E) and Ko Kut (11°39′N, 102°34′E) are islands located to the south of Ko Chang, in the eastern Gulf of Thailand (Figure 1), and have a total area of 12.40 km^2 and 111.89 km^2, respectively (Nateewathana, 2008a). They are characterized by a tropical climate with summer or pre-monsoon (March–April), rainy season influenced by the southwest monsoon (May–October) and winter influenced by the northeast monsoon (November–February). Both islands are governed under Ko Kut District and had 2,553 local residents and 1,957 registered households as of 2019. This area serves as an important fishing ground and as a tourist destination; coastal fisheries, seafood processing and tourism-related businesses represent major occupations of the local people (Yeemin *et al*., 2013; Noranarttragoon, 2014).

Field surveys

In this study, surveys were conducted during January–October 2016 in collaboration with a fisher who operates fish traps in the study area. We observed a total of 82 fish traps deployed at 14 sites around Ko Kut and Ko Mak (Figure 1). To better understand the fishing operation, personal observations were made during the field surveys and informal interviews were conducted with the vessel captain, diver, and crew members.

Fish traps used in the study area were made of a wooden frame (1.5×2×1 m) covered by polyethylene or wire mesh with a mesh-size of 2.5 cm. A fishing vessel with an inboard engine of 150 hp was used in this study. The fisher who is responsible for placing and retrieving the fish traps used a dive mask with a plastic air tube connected to an air compressor onboard. This diving gear can also be found in other countries in Southeast Asia where the fishers use it to collect sea cucumbers on the seafloor (Hoeksema, 2004). Two to three crew members were available onboard to assist the fisher, who dived to place and retrieve the traps. The traps were left submerged for about 1–2 weeks, depending on weather conditions.

At each trap, SCUBA divers observed the fish trap deployment from the surface to sea bottom as well as the retrieval of the trap, and also recorded the process using an underwater camera. The number of traps that touched corals (both live and dead) was counted and calculated as a percentage of the total traps observed in this study. Other possible impacts of fish trap deployment were also noted. At each site, the cover of live and dead coral, rubble, sand, rock and other benthic components were quantitatively estimated using a 1×1 m^2 random quadrat. Thirty quadrats were deployed at each study site.

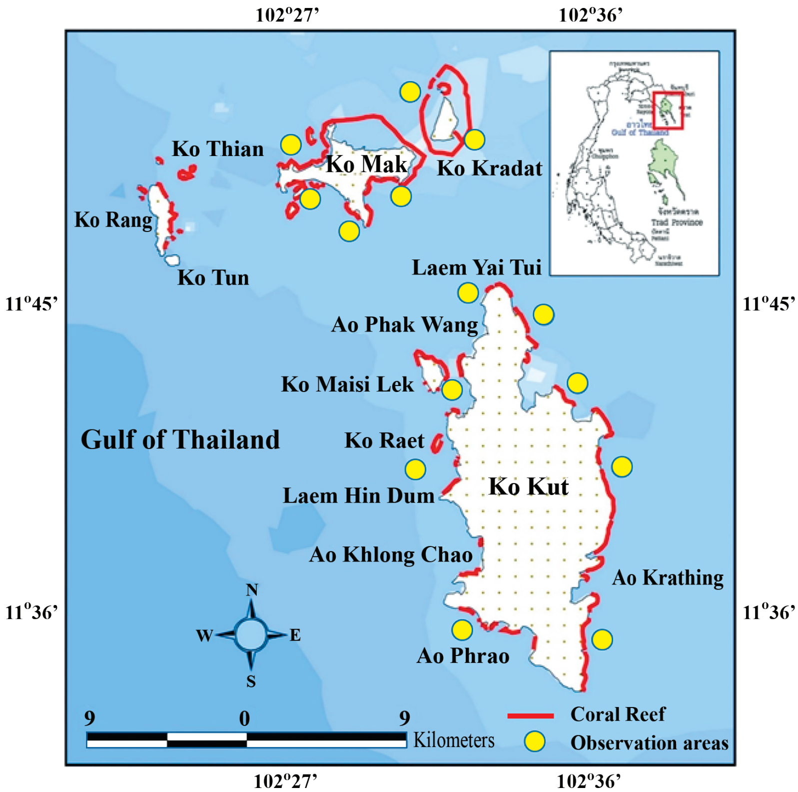

Figure 1. Study sites near Ko Mak and Ko Kut, Trat Province, Thailand.

After retrieving each trap, all specimens captured were counted, weighed and photographed on board. In the laboratory, all of the animals were identified to species level, if possible, using published standard references of reef fish and using the World Register of Marine Species (Appeltans *et al*., 2020) for classification. The fishers were asked to classify collected animals as target species, retained bycatch or discarded bycatch.

Data treatment and analyses

The data obtained from the underwater observation of fish traps were pooled and classified into two groups: 1) traps that did not touch any corals and 2) traps that touched corals. The second group was further classified by each coral species touched. Records were expressed as a percentage of all investigated traps (n = 82). Because of categorical data, Pearson's chi-square test was applied to test whether the chance of each coral species being touched by the fish traps was equally distributed. The general condition of the coral reef at each site was also assessed and expressed as a percent cover of live and dead corals, rubble, sand and rock.

The average catch per unit effort (CPUE) was calculated by the following formula (Butler and Heinrich, 2007):

$$\text{Average CPUE} = \frac{\sum_{i=1}^{n} \text{CPUE}_i}{n}$$

where CPUE_i ($kg \cdot trap^{-1} \cdot day^{-1}$) = weight of total $catch_i$ (kg)/ soaking $time_i$ (days) and n = total number of traps investigated.

The average CPUEs of the fish traps operated during dry season (January–April) and wet season (May–October) were compared using the non-parametric Mann-Whitney-U test in order to detect seasonal variation.

RESULTS AND DISCUSSION

Fishing operation

The fisher who participated in this study used fish traps to catch live groupers and snappers in this area. With modern fishing assistance from sonar and GPS devices along with his experience, the fisher was proficient at finding sites with the target fish species. There are various shapes and sizes of fish traps, but rectangular and semi-cylindrical shapes were mostly observed in this study. The fisher placed the traps in the spaces between coral reefs at an average depth of 9.47±2.93 m (depth range = 6.8 m). Normally, the fishing operation requires a captain, a diver and two to three crew members on board for assistance (Figure 2).

To place a trap, the captain used a GPS device, sonar, and his own experience to find an appropriate location, and recorded the GPS coordinates, date and time in a logbook. The diver was responsible for placing and retrieving fish traps and used a mask with plastic air tube connected to an air compressor onboard. Two crew members were available onboard to help guide the air tube and to deliver the trap into the water. The diver held the trap, dove to the seafloor and looked for an appropriate location which is normally a sandy area between reefs, an underwater pinnacle or even on top of a coral reef. The diver arranged the trap to be in a position to allow fish to enter, and sometimes secured the trap by putting a rock on it.

To retrieve the trap, the captain piloted the vessel to the recorded location, and then the diver entered the water to search for the trap. Once the trap was found, the diver tied it with the air tubing, then tugged at the air tube to signal the crew that the trap was ready to be retrieved. Traps that had no fish or too few fish were left submerged for a week more. After retrieving the trap, fish were sorted and punctured with a syringe to remove the gas inside the fish's swim bladder. Live target species were immediately transferred to an aerated water tank, while bycatch species were either kept in a bucket or discarded at sea. The fishers preferred to keep the target fish alive for a higher selling price.

Impacts on corals

The underwater observation of fish trap operation revealed that most of the fish traps were laid on a sandy seafloor near coral colonies or rocks, and sometimes on the reefs (Figure 3). A total of 20 (24.39 %) of the 82 fish traps observed touched juvenile corals and coral communities, including members of the family Fungiidae, *Porites* sp. *Dipsastraea* sp., *Astreopora* sp. and *Pavona* sp. However, only five of these coral colonies (three and two colonies of members of the family Fungiidae and *Porites* sp., respectively) showed breakage or small scars on the colonies (Figure 4) caused by the scraping of the wooden frame at the bottom of the trap. Among all the traps investigated, the highest incidence of contact was found for members of the family Fungiidae (15.85 %) followed by *Porites* spp. (10.98 %), *Dipsastraea* sp. (7.32 %), *Astreopora* sp. (3.66 %) and *Pavona* sp. (2.43 %) (Table 1). Pearson's Chi-square test illustrated that the probability of being touched by a trap was not equally distributed among coral species ($\chi^2(4) = 18.36$, $p<0.01$).

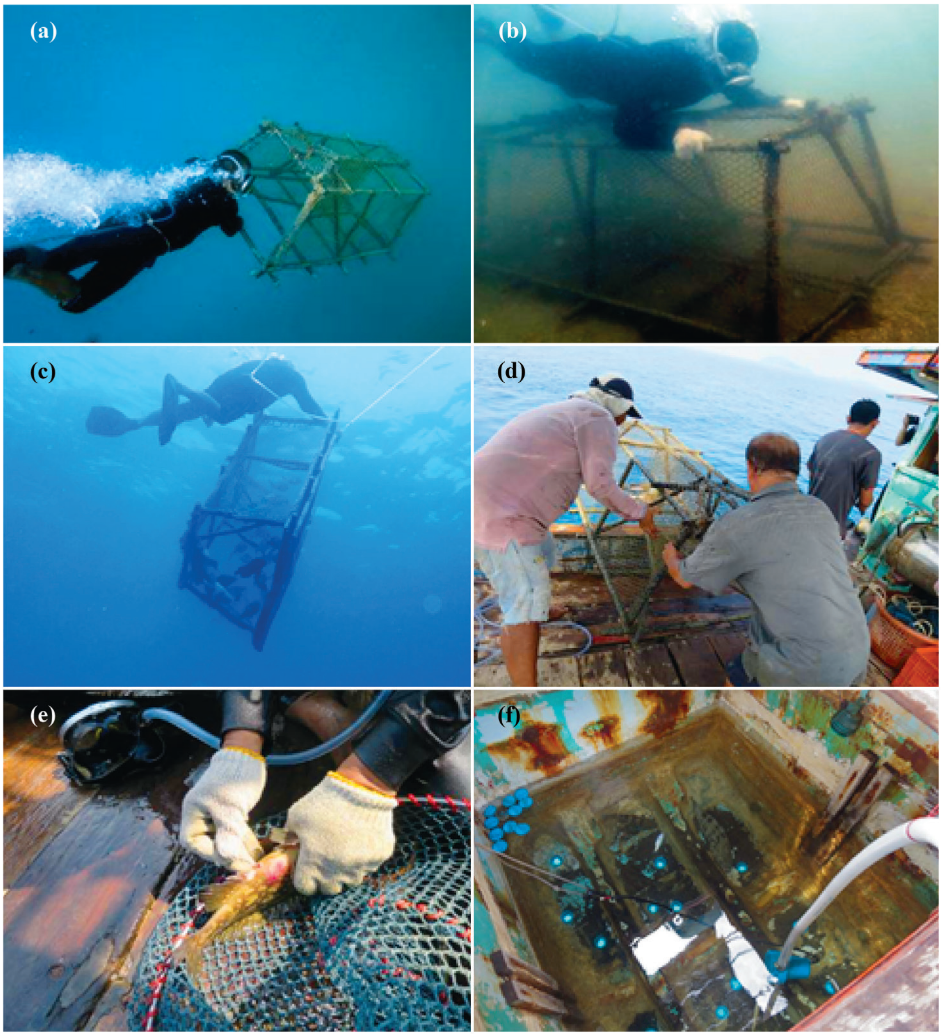

Figure 2. Stages of fish trap operation: (a) deploying a trap, (b) positioning a trap, (c) retrieving a trap, (d) retrieving a trap and sorting fish, (e) removing gas from the fish's swim bladder (f) keeping live fish in an aerated tank.

Figure 3. Examples of fish traps placed on coral communities near Ko Kut and Ko Mak, Trat, Thailand.

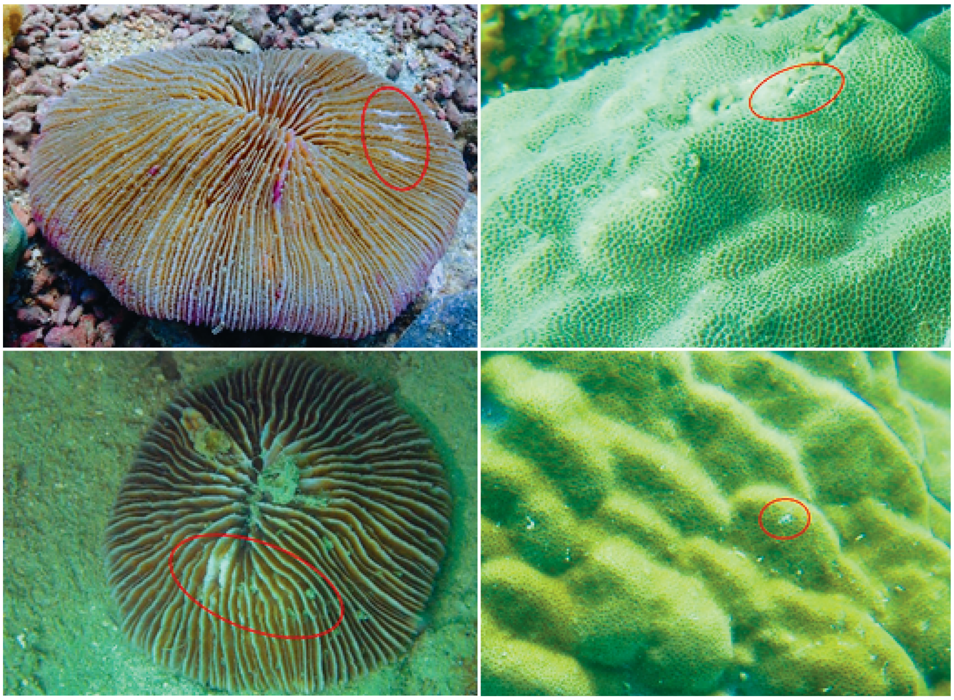

Figure 4. Examples of breakage and scarring of some coral species caused by fish traps.

Table 1. Frequency of fish traps that touched and did not touch corals, categorized by coral species found at the trap sites.

Number of fish traps	Coral species/family				
	Family Fungiidae	***Dipsastraea* sp.**	***Porites* spp.**	***Astreopora* sp.**	***Pavona* sp.**
Touching coral	13	6	9	3	2
Touch without damage	10	6	7	3	3
Touch with damage	3	0	2	0	0
Not touching coral	69	76	73	79	80
Total	82	82	82	82	82
Percentage (%)	15.85	7.32	10.98	3.66	2.43

Note: Some traps touched more than one coral species.

Random quadrat surveys revealed that overall, the study sites near Ko Kut and Ko Mak had substrates of sand (88.73±3.76 %), live coral (3.43±2.82 %), dead coral (2.34±1.76 %), rubble (2.08±0.97), rock (1.91±3.62 %) and others (1.51± 2.09 %) (Figure 5). On the reef, *Porites* spp. was the most dominant species. Common coral species found on the reef included *Platygyra* spp., *Favites* spp., *Pavona* spp., *Dipsastraea* sp., *Astreopora* spp. Small colonies of *Porites* spp. and members of the family Fungiidae were also found on sandy substrates near or between the reefs. Corals of these taxa were more likely to be touched by the fish traps compared to the other coral species, especially members of the family Fungiidae, which are distributed on sandy substrate, where most traps were placed.

Approximately 24 % of the fish traps observed in this study touched corals, leading to physical damage of some of the corals. Although the percentage of these traps that were found to cause breakage or scarring of corals was considerably low, the risk would be higher if fishers were not aware of this impact. Physical damage caused by trap fisheries has been reported worldwide. Some authors reported that fish traps placed in shallow water (<30 m) touched some hard corals, gorgonians

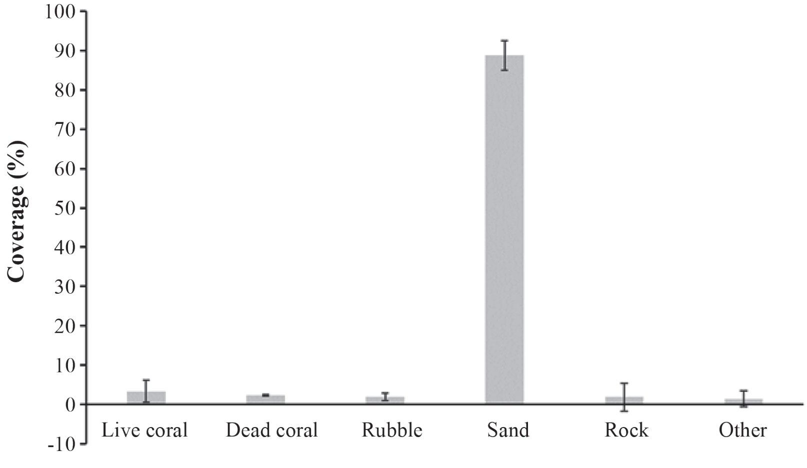

Figure 5. Overall reef substrate composition at the study sites near Ko Kut and Ko Mak, Trat Province, Thailand.

or sponges, resulting in patchy damage to these marine organisms (Sheridan *et al*., 2003; 2005). A few studies conducted in the Caribbean illustrated that trap fisheries did not only damage coral reefs but also other benthic habitats such as seagrasses, macroalgae and sponges (Mangi and Roberts, 2006; Uhrin *et al*., 2014). Traps also caused tissue abrasion on scleractinian corals, octocorals and sponges (Miller *et al*., 2008). Physical damage and injury may lead to negative impacts on coral health. According to Lamb *et al*. (2014), injured corals were more susceptible to skeletal eroding band disease, and that additional stressors, such as elevated water temperature and poor water quality are likely to promote coral disease development.

Sediment dispersion caused by setting and moving traps was also observed. Sediment is one of the factors that can obstruct the growth of corals (Erftemeijer *et al*., 2012). It also reduces light penetration, which is one of the limiting factors of coral growth. Elevated suspended sediment concentrations and reduced light, as well as sediment deposition could decrease photosynthetic yield and induce coral bleaching and partial mortality (Bessell-Browne *et al*., 2017; Jones *et al*., 2019). Some studies reported an association between the accumulation of sediment on coral tissues and the occurrence of coral diseases such as white syndrome (Lamb *et al*., 2014). Sediment may serve as a disease reservoir or vector to promote infection of intolerant coral hosts (Pollock *et al*., 2014). Also, prolonged exposure to suspended sediments may decrease fertilization success (Ricardo *et al*., 2015) and the growth and survival of coral juveniles (Humanes *et al*., 2017). However, the impacts from sediment dispersion depend on various factors such as degree of exposure, tolerance (sediment shedding ability), and current (Jones *et al*., 2019). The severity of these impacts also depends on the tolerance of individual coral species to sediment stress. Each coral species has mechanisms to eliminate sediments deposited on their colonies. For example, some species of *Porites* sp. produce mucus to eliminate sediment, and are able to tolerate a sedimentation rate of 39.6 $mg \cdot cm^{-2} \cdot day^{-1}$ for two weeks (Erftemeijer *et al*., 2012).

Harvest of reef fishes

The CPUE of the 82 fish traps observed in this study varied considerably, ranging from 0.1–2.56 $kg \cdot trap^{-1} \cdot day^{-1}$, with a mean of 1.59±0.92 $kg \cdot trap^{-1} \cdot day^{-1}$. The average CPUE observed in the rainy season was 1.32±0.98 $kg \cdot trap^{-1} \cdot day^{-1}$ (n = 24), while CPUE in the dry season was 1.71±0.88 $kg \cdot trap^{-1} \cdot day^{-1}$ (n = 58). No significant differences between rainy and dry seasons were found for CPUEs of total catch (U = 511, p = 0.059), target species (U = 545, p = 0.124), retained bycatch (U = 556, p = 0.155) or discarded bycatch (U = 505, p = 0.052) (Figure 6). About 60 % of total catch comprised target species including groupers (Family Serranidae) and snappers (Family Lutjanidae), while the remaining 40 % was bycatch. About 5–15 % of the bycatch was discarded at sea, while 85-95 % was retained for household consumption or used as bait.

Of the seven target species that were commonly found, three of them, i.e., duskytail grouper (*Epinephelus bleekeri*), leopard grouper (*Plectropomus leopardus*) and orange-spotted grouper (*Epinephelus coioides*) were categorized as "nearly threatened," while three others, i.e., blue line grouper (*Cephalopholis formosa*), blacktip grouper (*Epinephelus fasciatus*) and longfin grouper (*Epinephelus quoyanus*) were categorized as "least concern," and one species, John's snapper (*Lutjanus johnii*), has not yet been evaluated for its IUCN Red List status (IUCN, 2016). The "nearly threatened" status reflects that these species are being exploited worldwide because of their high market value and are likely to become endangered in the near future.

Overexploitation of reef fish and other organisms is likely to cause a decline in fish populations, biodiversity loss and ecosystem alteration (Hawkins *et al*., 2007; Bozec *et al*., 2016). Top- and meso-predators, like groupers, sharks and giant trevally, are important components in a coral reef ecosystem (Dale *et al*., 2011). Loss of groupers and other top predatory fish due to overfishing might affect the ecosystem food web, especially in terms of the predator-prey relationship and fish community structure, as well as a decrease in abundance of small benthic invertebrates with limited mobility (Chiappone *et al*., 2000; McCauley *et al*., 2010). Groupers also act as a natural biocontrol of some invasive species such as the lionfish, which is a problematic species in the Caribbean region (Mumby *et al*., 2011).

Bycatch is the unintentional capture of non-target species during fishing, and has become one of the most important issues in fisheries sustainability and biodiversity (Chuenpagdee *et a*l., 2003). Trap fisheries seem to be more selective and produce less bycatch compared to other fishing methods such as gillnets, trawling and dredging (Shester and Micheli, 2011; Major *et al*., 2017; Suebpala *et al*., 2017). The amount of bycatch from trap fisheries varies considerably by geographical location, trap structure and size, as well as the specific definition of bycatch for each location or fisher. For instance, the quantity of fish trap bycatch in southern Africa and the southern Atlantic ranged from 11–64 %, while only 2.6–4.3 % of bycatch was reported in the Middle East (Vadziutsina and Riera, 2020). Our study revealed that as many as 22 species of bycatch were captured, including 17 species of fish, four species of crustaceans and one species of sea cucumber (Table 2). Of these, 13 species of fish were retained for household consumption or sold as fresh fish, while the other nine species were discarded at sea, including four species of fish (*Diodon liturosus*, *Acanthostracion polygonius*, *Chelmon rostratus*, *Cantherhines pardalis*), four species of crabs (*Charybdis hellerii*, *Atergatis integerrimus*, *Myomenippe hardwickii*, *Dardanus megistos*) and an unidentified species of sea cucumber. Most of the 11 bycatch species were carnivorous fish, while five were herbivorous fish and another was an omnivore (Figure 7).

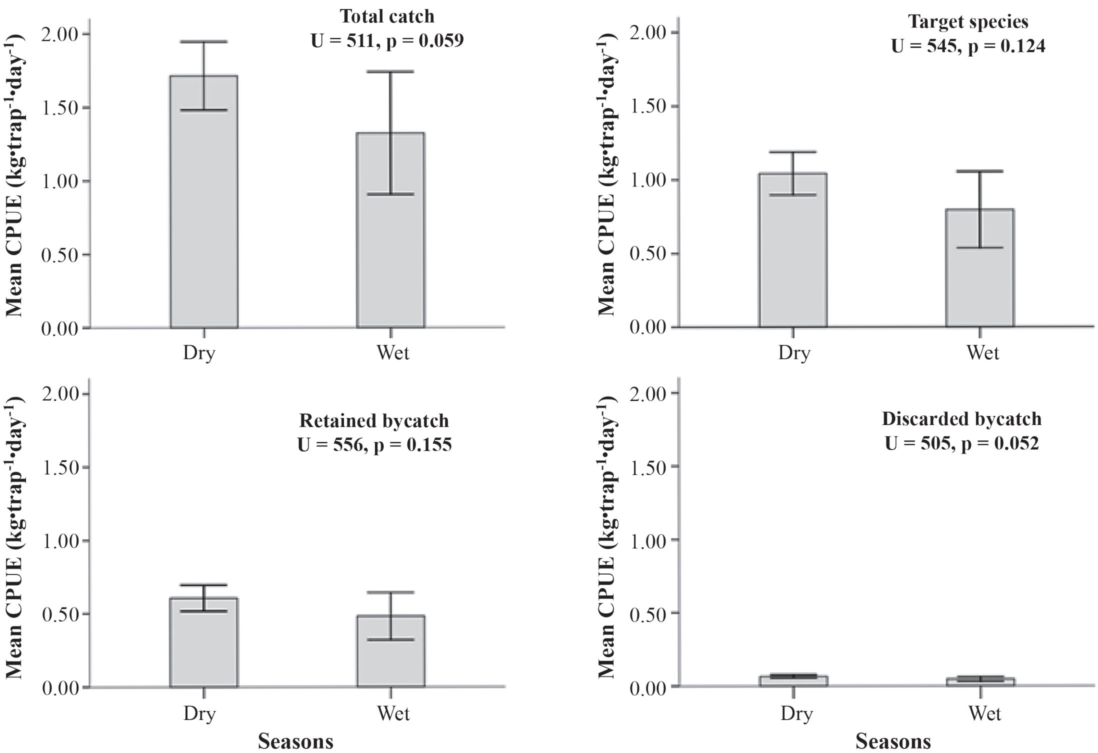

Figure 6. Mean CPUE (kg·trap^{-1}·day^{-1}) of total catch, target species, retained bycatch and discarded bycatch in wet and dry seasons at study sites near Ko Kut and Ko Mak, Trat Province, Thailand.

Table 2. List of target and bycatch species caught by fish traps near Ko Mak and Ko Kut, Trat Province, Thailand.

Common name	**Scientific name**	**Family**	**IUCN status[b]**	**functional group[c]**
Duskytail grouper[a]	*Epinephelus bleekeri*	Serranidae	Near Threatened	Carnivore
Leopard grouper[a]	*Plectropomus leopardus*	Serranidae	Near Threatened	Carnivore
Orange-spotted grouper[a]	*Epinephelus coioides*	Serranidae	Near Threatened	Carnivore
Blueline grouper[a]	*Cephalopholis formosa*	Serranidae	Least Concern	Carnivore
Blacktip grouper[a]	*Epinephelus fasciatus*	Serranidae	Least Concern	Carnivore
Longfin grouper[a]	*Epinephelus quoyanus*	Serranidae	Least Concern	Carnivore
John's snapper[a]	*Lutjanus johnii*	Lutjanidae	Not Evaluated	Carnivore
Black-blotched porcupinefish	*Diodon liturosus*	Diodontidae	Least Concern	Carnivore
Boxfish	*Acanthostracion polygonius*	Ostraciidae	Least Concern	Carnivore
Bluebarred parrotfish	*Scarus ghobban*	Scaridae	Least Concern	Herbivore
Two-banded soapfish	*Diploprion bifasciatum*	Serranidae	Not Evaluated	Carnivore
Copperbanded butterflyfish	*Chelmon rostratus*	Chaetodontidae	Not Evaluated	Carnivore
Tripletail wrasse	*Cheilinus trilobatus*	Labridae	Least Concern	Carnivore
Doubletooth soldierfish	*Myripristis hexagona*	Holocentridae	Least Concern	Carnivore
Redcoat	*Sargocentron rubrum*	Holocentridae	Least Concern	Carnivore
Whitecheek monocle bream	*Scolopsis vosmeri*	Nemipteridae	Not Evaluated	Carnivore
Yellowspotted rabbitfish	*Siganus guttatus*	Siganidae	Not Evaluated	Herbivore
Whitespotted rabbitfish	*Siganus canaliculatus*	Siganidae	Not Evaluated	Herbivore
Yellow-spot goatfish	*Parupeneus indicus*	Mullidae	Not Evaluated	Carnivore
Pearly monocle bream	*Scolopsis margaritifera*	Nemipteridae	Not Evaluated	Carnivore
Red-bellied fusilier	*Caesio cuning*	Caesionidae	Not Evaluated	Carnivore
Fan-bellied leatherjacket	*Monacanthus chinensis*	Monacanthidae	Least Concern	Omnivore
Double-barred rabbitfish	*Siganus virgatus*	Siganidae	Not Evaluated	Herbivore
Java rabbitfish	*Siganus javus*	Siganidae	Not Evaluated	Herbivore
Swimming crab	*Charybdis hellerii*	Portunidae	Not Evaluated	Omnivore
Stone crab	*Myomenippe hardwickii*	Menippidae	Not Evaluated	Omnivore
Spotted hermit crab	*Dardanus megistos*	Diogenidae	Not Evaluated	Omnivore
Red egg crab	*Atergatis integerrimus*	Xanthidae	Not Evaluated	Omnivore
Sea cucumber	Unidentified sea cucumber	Unidentified sea cucumber	NA	Scavenger

Note: [a]Target species; [b]IUCN (2016) [c]FishBase (www.fishbase.org)

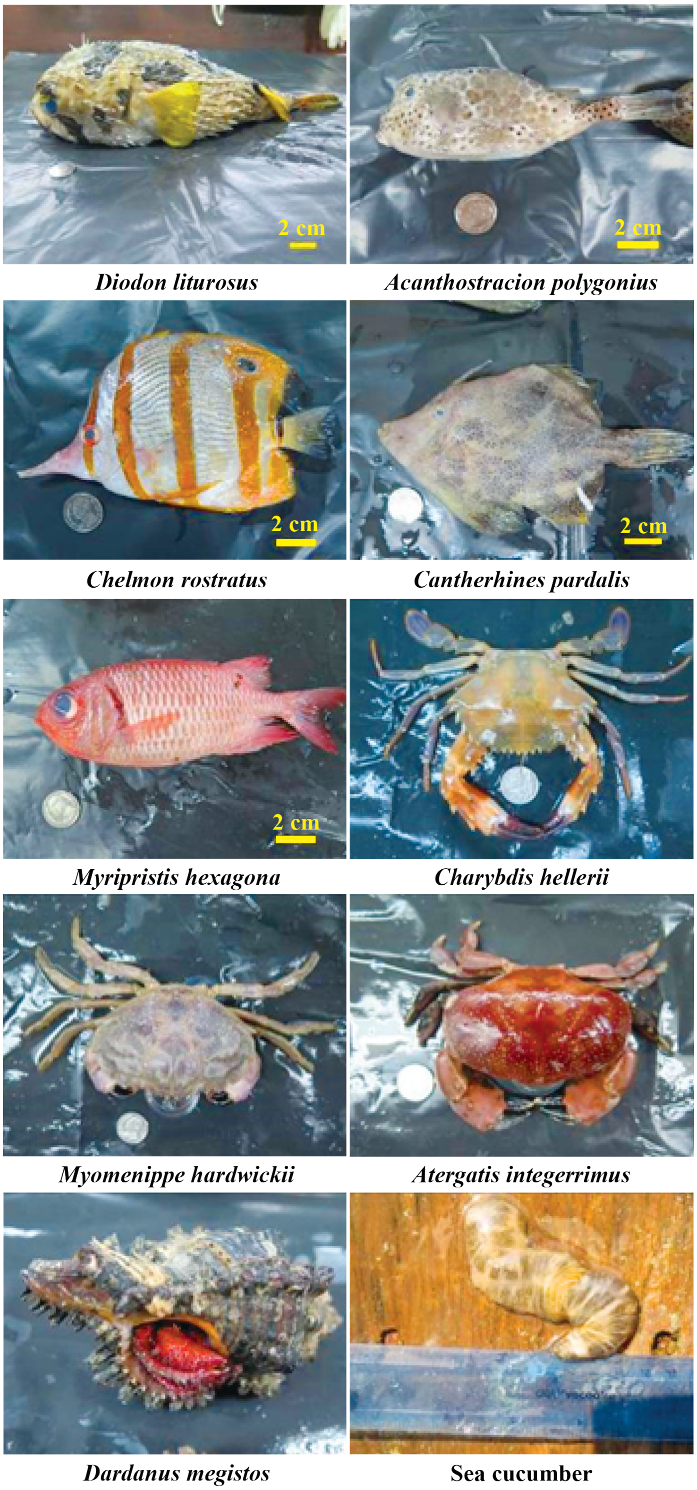

Figure 7. Examples of discarded bycatch species caught by fish traps at the study sites near Ko Kut and Ko Mak, Trat Province, Thailand.

Based on functional group, catch rates from all fish traps showed that the majority of fish caught were carnivorous, with a mean CPUE of 1.34±0.79 kg·trap^{-1}·day^{-1}, while mean CPUE for herbivorous fish was 0.19±0.17 kg·trap^{-1}·day^{-1}. Herbivorous fish species contributed about 12 % of the total CPUE. No significant differences between rainy and dry season were found in the CPUEs of herbivorous fish (U = 521, p = 0.075) and omnivorous fish and scavengers (U = 655, p = 0.673), but there was a difference for carnivorous fish (U = 471, p = 0.022) (Figure 8). In this study, six fish species captured by traps were herbivores that feed on algae and seaweeds. Two of them were considered as corallivores, namely blue-barred parrotfish (*Scarus ghobban*, Family Scaridae) and fan-bellied leatherjacket (*Monacanthus chinensis*, Family Monacanthidae).

Extensive studies have reported that removing herbivorous fish from coral reef communities alter the reef's ecosystem balance and may further impact reef resilience. For example, coral recruitment benefited from herbivorous fish as they help reduce overgrowth of macroalgal cover, thus providing more substrate for coral larvae to recruit and also preventing a coral–macroalgal phase shift (Cheal *et al*., 2010; Mumby, 2016). Parrotfish is one of the key functional groups of reef organisms helping to control macroalgae that compete with coral growth and recruitment. However, parrotfish are targets of both subsistence and commercial fisheries, particularly in the Indo-Pacific, and these fish have been heavily exploited, making them more vulnerable to local and regional extinction (Russ, 1991; Comeros-Raynal *et al*., 2012; Bejarano *et al*., 2013; Pearse *et al*., 2018).

Other possible impacts

Impact on marine benthic invertebrates

In this study, impacts on marine benthic invertebrates were observed during trap movement and placement. In most study sites, some benthic organisms (e.g., sea urchins, bivalves, sea cucumbers, sea whips, juvenile corals) were found on the seafloor where the traps were placed. Dragging of the trap could injure these marine benthic invertebrates. Shester and Micheli (2011) mentioned that dragging of traps on the seafloor caused damage to the corals more frequently than by crushing during placement of the traps. In the case of lobster fisheries, the movement of traps by wind and storms caused the reduction of sessile fauna cover by scraping and fragmenting these organisms. The movement also caused injury or abrasion of stony corals, octocorals and sponges (Lewis *et al*., 2009). Although these marine benthic invertebrates may have less economic importance than targeted species, they play important roles as ecosystem components supporting the ecosystem balance.

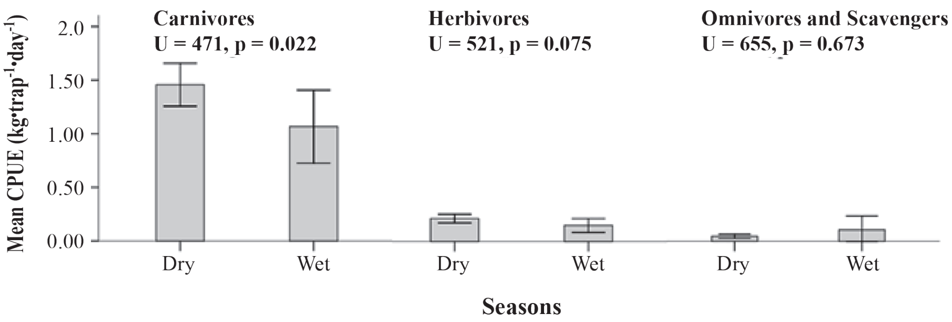

Figure 8. Mean CPUE (kg·trap^{-1}·day^{-1}) of total catch categorized by functional groups in wet and dry seasons at the study sites near Ko Kut and Ko Mak, Trat Province, Thailand.

Ghost fishing impacts and marine debris

We also found a few abandoned fish traps during our observations. Abandoned or lost traps could be a cause of fish mortality through "ghost fishing," or the ability of a trap to continue to catch fish after it has been lost/abandoned (Matsuoka *et al*., 2005; Renchen *et al*., 2012; 2014). Additionally, ghost fishing by fish traps causes skin wounds or abrasions of entrapped fish (Clark *et al*., 2012; Renchen *et al*., 2014). However, a trap that has escape vents has been designed for use to minimize the negative impacts of ghost fishing (Putsa *et al*., 2016). Since most of the fish traps are made of a plastic (polyethylene) that is non-biodegradable, the issues of marine debris and plastic pollution in the ocean are of concern (Lusher *et al*., 2017; Ballesteros *et al*., 2018). This plastic can be fragmented into smaller particles of plastic called microplastics, which can be ingested by marine species, leading to the contamination of the marine environment and the marine food web (Lusher *et al*., 2017).

Governing the impacts

To enhance sustainable fisheries and to maintain the ecosystem balance and productivity of coral reefs, fishing impacts should be carefully governed by applying a precautionary principle (Chuenpagdee *et al*., 2003; Darling and D'agata, 2017). About 70 % (168 km^2) of coral reefs in Thailand are within Marine Protected Areas (marine national parks and marine sanctuaries) (Phongsuwan and Yeemin, 2018), which prohibit fishing and harvest (Nateewathana, 2008b), while 30 % of reefs are outside the MPAs and are where fish traps, lines and gillnets are generally found. The coral reefs outside the MPAs should not be neglected, since they could be threatened by overexploitation and improper fisheries practices.

Establishment of MPAs is a classic tool for marine fisheries management and biodiversity conservation in which various solutions can be applied, e.g., restrictions in gear, effort and species, spatial and temporal closure of sensitive areas (Hargreaves-Allen *et al*., 2011; Vadziutsina and Riera, 2020). Such areas can be designated by various authorities such as the Department of Fisheries, Department of Marine and Coastal Resources, or local governments of coastal provinces. Since MPAs inevitably affect local fishing livelihoods, the local context should be given significant consideration in the establishment process (Hargreaves-Allen *et al*., 2011).

Modification of traps and fishing methods is a useful approach to deal with the issues of bycatch, ghost fishing and marine debris. A trap with the proper size, mesh-size and escape vent increases gear selectivity (both size and species selection) and efficiency (Grasaelarb, 1997; Wungkhahart *et al*., 2000; Boutson *et al*., 2009). The presence of the escape vent reduces the negative impacts of ghost fishing (Putsa *et al*., 2016). To reduce plastic pollution in the ocean, biodegradable materials have been suggested for the construction of fishing gears (Lusher *et al*., 2017).

Fisheries management tends to move toward fisheries co-management in which all relevant stakeholders are engaged, resulting in better collaboration and compliance, as well as corresponding to local needs (Berkes, 2007). In terms of fish trap fisheries, a critical impact on coral reefs was seen during trap placement and movement, which obviously cause physical harm to coral reefs. An important means to minimize the impacts of fish trap fisheries is by engaging the fishers into a management process along with raising their environmental awareness and providing knowledge on how to operate fish trap fisheries with less negative environmental impact.

CONCLUSIONS

Our research provides exploratory results regarding impacts of fish trap fisheries on coral reefs from in situ observations near Ko Mak and Ku Kut, Trat Province, Thailand. By monitoring the operation of 82 fish traps, we found several possible negative impacts, including 1) physical contact between traps and corals, 2) sediment dispersion generated during trap movement, 3) removal of top predatory and herbivorous fish, 4) impacts on other marine benthic invertebrates, and

5) ghost fishing and marine debris. Some strategies to minimize the impacts were also proposed. This is the first study of the impacts of fish trap fisheries on coral reefs in Thailand, providing some baseline information. These findings may support further research and the implementation of ecosystem-based fisheries management in Thailand.

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