Marine Pollution Bulletin 135 (2018) 1107–1116

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Pollution and coral damage caused by derelict fishing gear on coral reefs around Koh Tao, Gulf of Thailand

Laura Valderrama Ballesteros[a], Jennifer L. Matthews[b], Bert W. Hoeksema[a,c,*]

[a] Taxonomy and Systematics Group, Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA, Leiden, the Netherlands.
[b] Big Blue Conservation, Big Blue Dive Resort, Koh Tao 84360, Thailand
[c] Institute of Biology Leiden, Leiden University, P.O. Box 9505, 2300 RA, Leiden, the Netherlands

ARTICLE INFO

Keywords:
Artificial substrate
Coral fragmentation
Fish cages
Fishing nets
Nylon lines
Plastic litter
Stony corals
Tissue loss

ABSTRACT

Most lost fishing gear is made of non-biodegradable plastics that may sink to the sea floor or drift around in currents. It may remain unnoticed until it shows up on coral reefs, beaches and in other coastal habitats. Stony corals have fragile skeletons and soft tissues that can easily become damaged when they get in contact with lost fishing gear. During a dive survey around Koh Tao, a small island in the Gulf of Thailand, the impact of lost fishing gear (nets, ropes, cages, lines) was studied on corals representing six different growth forms: branching, encrusting, foliaceous, free-living, laminar, and massive. Most gear (> 95%) contained plastic. Besides absence of damage (*ND*), three categories of coral damage were assessed: fresh tissue loss (*FTL*), tissue loss with algal growth (*TLAG*), and fragmentation (*FR*). The position of the corals in relation to the fishing gear was recorded as either growing underneath (*Un*) or on top (*On*), whereas corals adjacent to the gear (*Ad*) were used as controls. Nets formed the dominant type of lost gear, followed by ropes, lines and cages, respectively. Branching corals were most commonly found in contact with the gear and also around it. *Tubastraea micranthus* was the most commonly encountered coral species, either *Un*, *On*, or *Ad*. Corals underneath gear showed most damage, which predominantly consisted of tissue loss. Fragmentation was less common than expected, which may be related to the low fragility of *T. micranthus* as dominant branching species. Even if nets serve as substrate for corals, it is recommended to remove them from reefs, where they form a major component of the plastic pollution and cause damage to corals and other reef organisms.

1. Introduction

Stony corals act as major builders of coral reefs by the production of calcareous skeletons. The growth and development of these animals involves multiple physiological, biological and ecological processes, which are controlled by environmental factors such as light, salinity, water temperature, turbidity, and wave action (Buddemeier and Kinzie, 1976; Brown, 1997). Unfavorable conditions caused by disturbances of both natural and anthropogenic origin can cause stress to the corals (Brown and Howard, 1985; Risk et al., 2001). Mechanical stress related to wave action may cause corals to break, which is usually the case during storms and strong swell, but their fragments may regenerate and survive (Madin and Connolly, 2006; White et al., 2013; Baldock et al., 2014; Hoeksema et al., 2017). Cover and pressure by sediment load may cause smothering of corals and damage to their soft tissue, eventually leading to their death (Rogers, 1990; Erftemeijer et al., 2012; Yeemin et al., 2013; Lamb et al., 2014).

One source of human-induced damage to marine ecosystems is fisheries, which causes direct and collateral impact where it is practiced (Goñi, 1998; Thrush et al., 1998; Pitcher and Cheung, 2013). This is particularly witnessed on shallow coral reefs, which are susceptible to this damage and easy to study (McManus et al., 1997; Edinger et al., 1998; Fox et al., 2003; Ferse et al., 2014; Glaser et al., 2015; Suebpala et al., 2017). Severe impacts include those related to the use of fishing gear, which when abandoned or lost can continue to function passively and uncontrolled, contributing to the phenomenon known as 'ghost fishing' (Pawson, 2003; Revill and Dunlin, 2003; Matsuoka et al., 2005; Al-Masroori et al., 2009; Gilardi et al., 2010; Gilman, 2015; Uhlmann and Broadhurst, 2015). The discarded equipment itself is usually referred to as derelict fishing gear (Donohue et al., 2001; Morishige and McElwee, 2012; Edyvane and Penny, 2017), fishery debris (Ryan et al., 2009), or ghost nets (Baeta et al., 2009; Butler et al., 2013; Wilcox et al., 2015). Once fishing gear is lost at sea, it is considered marine debris and litter (Gall and Thompson, 2015; Kühn et al., 2015; de

* Corresponding author.
E-mail address: bert.hoeksema@naturalis.nl (B.W. Hoeksema).

https://doi.org/10.1016/j.marpolbul.2018.08.033
Received 31 March 2018; Received in revised form 15 August 2018; Accepted 17 August 2018
Available online 28 August 2018

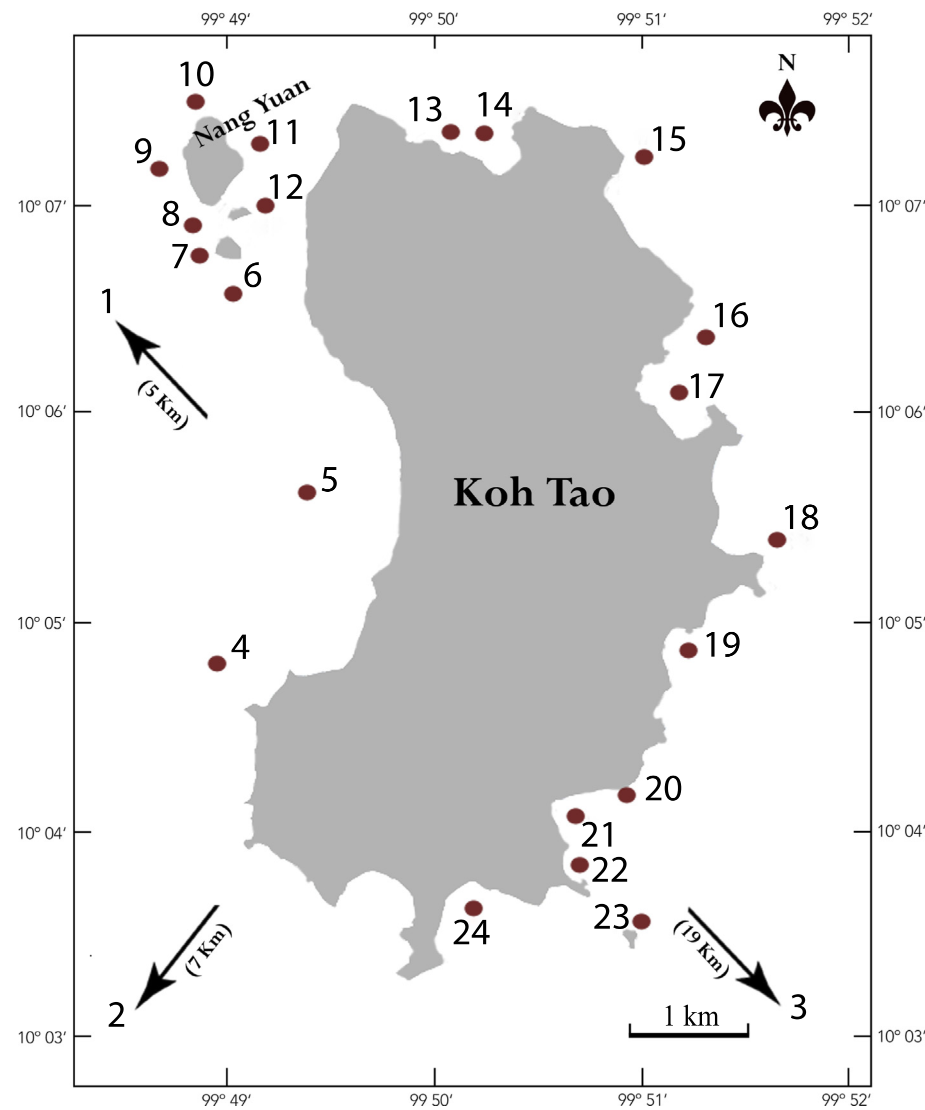

Fig. 1. Map of Koh Tao indicating the survey sites. For names of localities, see Table 1.

Carvalho-Souza et al., 2018; Naranjo-Elizondo and Cortés, 2018) and a major contributor to ocean plastic, which can cause damage to corals and other marine animals (Derraik, 2002; Lamb et al., 2018). For example, ghost nets comprise at least 46% of the Great Pacific Garbage Patch (Lebreton et al., 2018). Discarded gear is a threat to marine life as it can trap and kill marine animals indiscriminately, including those belonging to species that are endangered or of economic importance. This harm is prevalent in large animals and therefore much research attention is given to the effect of fishing gear and other marine debris on vertebrates (Wilcox et al., 2013; Thiel et al., 2018). Lost gear and plastic debris may cause direct negative impacts to coral reefs and other benthic communities by entanglement, damaging or killing stony corals and other benthic reef organisms, potentially introducing parasites and pathogens (Chiappone et al., 2005; Dameron et al., 2007; Abu-Hilal and Al-Najjar, 2009; Gilardi et al., 2010; Niaounakis, 2017; Sheehan et al., 2017; Lamb et al., 2018).

Despite advances in the characterization and assessment of impacts by lost fishing gear in marine environments, specific studies on corals are limited (Law, 2017). Some studies deal with the damage and pollution caused by nets, filament lines and lobster traps on reefs (Schleyer and Tomalin, 2000; Donohue et al., 2001; Yoshikawa and Asoh, 2004; Chiappone et al., 2002, 2005; Lewis et al., 2009), but no information was found on their effect on corals in particular. This is important to know because corals are the most important reef builders and serve as habitat for cryptobenthic invertebrates and fishes, which constitute a major component of coral reef biodiversity (Stella et al., 2011; Hoeksema, 2017; Brandl et al., 2018).

Abandoned nets are commonly found on reefs around Koh Tao, a dive destination in the western Gulf of Thailand, where they can easily be studied. Koh Tao is a small, densely populated island (~20 km^2), which is well known for its diving tourism (Yeemin et al., 2006; Lamb et al., 2014; Szuster and Dietrich, 2014; Wongthong and Harvey, 2014; Fei, 2016). The local dive industry is aware of the importance of coral reef conservation and the necessity of a sustainable use of the reefs (Hein et al., 2015; Scott et al., 2017c). The reefs here are therefore monitored for possible threats. Previous attention has been given to the massive coral bleaching events in 1998 and 2010 (Yeemin et al., 2009; Hoeksema and Matthews, 2011, 2015; Chavanich et al., 2012; Hoeksema et al., 2012; Sutthacheep et al., 2013) and outbreaks by corallivorous invertebrates (Hoeksema et al., 2013; Scott et al., 2014, 2017a, 2017b; Moerland et al., 2016), but no information was available on reef pollution and damage caused by abandoned fishing gear.

Items of lost fishing gear consisting of nets, ropes, traps, and nylon filaments are commonly encountered by recreational divers at Koh Tao. The traps and nylon filaments are probably of local origin but it is unclear whether the nets and ropes were also discarded near Koh Tao or

Table 1
Numbers of fishing gear items found per category at each site surveyed in Koh Tao (Fig. 1) with maximum observation depths (– = 0).

Site nr.	Locality	Depth, m	Number of dives	Numbers of derelict gear				
				Nets	Ropes	Cages	Lines	Total
1	Chumphon Pinnacle	28	21	30	2	–	–	32
2	Southwest Pinnacle	24	7	17	3	2	–	22
3	Sail Rock	27	3	3	–	–	–	3
4	Near Pottery Pinnacles	16	1	–	–	–	1	1
5	Sairee Beach	7	1	1	–	–	1	2
6	White Rock	16	15	9	–	–	3	12
7	Twins, south	8	1	2	–	–	3	5
8	Twins	8	12	–	1	–	1	2
9	Green Rock	21	9	2	1	–	1	4
10	North Nang Yuan	14	1	3	–	–	4	7
11	Red Rock	9	6	3	3	–	3	9
12	Japanese Garden	21	1	–	–	–	–	–
13	Mango Bay, west	7	1	3	1	–	–	4
14	Mango Bay, east	15	1	–	–	–	–	–
15	Light House	5	1	–	–	–	2	2
16	Hin Wong Pinnacle	18	1	2	–	–	–	2
17	Hin Wong Bay	11	2	10	–	–	–	10
18	Laem Thian Pinnacle	8	6	7	1	–	2	10
19	Tanote Bay	2	1	3	–	–	–	3
20	Ao Leuk Point	3	1	1	–	–	–	1
21	Ao Leuk Bay	7	2	7	–	–	–	7
22	Hin Ngam Reef	9	2	2	1	–	–	3
23	Shark Island	16	4	–	–	–	–	–
24	Shark Bay	1	1	2	–	–	–	2
Total			101	107	13	2	21	143

arrived as flotsam from remote localities as observed in other areas (Thiel et al., 2011; Wilcox et al., 2015; Unger and Harrison, 2016; Rech et al., 2018a). Because they are considered harmful to the environment as litter and as a threat to corals they are usually directly removed by volunteers. However, no quantitative information is available on its composition and abundance, or on the actual damage caused to corals. Accordingly, the present survey was directed to (1) present an inventory of lost fishing gear on the reefs around Koh Tao, and (2) to identify and quantify the damage caused to stony corals here, depending on their growth forms.

2. Material and methods

Field work was carried out from 8 February to 2 May 2011 during four snorkeling surveys and 97 SCUBA dives of approximately 1 h each and a maximum depth of 30 m at 21 sites around Koh Tao and three offshore pinnacles (Fig. 1).

The Roving Diving Technique was used to search for as much lost fishing gear as possible, which is the most time-efficient method for this purpose (Munro, 2005; Hoeksema and Koh, 2009). Once fishing gear was found, the following data was recorded: a) the gear type (nets, ropes, cages, nylon lines); b) size of the gear (total area occupied by gear and length of lines); c) in case of nets, the stretch mesh size was measured (Timmers et al., 2005); d) the growth form and the genus of the stony corals found underneath the gear (*Un*), of those growing on top of the gear (*On*), and as control in a 25-cm wide zone around the gear, ranging 50–75 cm distance away from it (*Ad*). This allowed the controls to be close to the gear but at 50-cm distance and also far enough for not being influenced by the gear if it would move. The size of control was in proportion to that of the gear: the larger the gear, the larger the control area. Physical damage to corals was recorded for 340 corals underneath (*Un*) gear and 1218 corals close to gear (*Ad*) as: fresh tissue loss (*FTL*), tissue loss with algal growth (*TLAG*) signifying older wounds, and fragmentation (*FR*). Absence of damage was recorded as 'no damage' (*ND*). Nylon lines were excluded from damage records because they only covered small parts of corals underneath and because not all of them were fixed. The analysis of the data included comparisons of the occurrence of damage among the various taxa and growth forms of corals (*Un* vs. *Ad*) as well as among the different types of gear. For statistical analysis, the Chi square test (χ^2) was applied, in which variables with value 0 were filtered out. The composition of the material was determined by visual inspection and by burning a sample of the material with a lighter, which caused it to melt if it was synthetic.

During the survey, the works of Veron (2000) was used for preliminary coral identification. For the present report, the nomenclature of recent taxonomic revisions was followed through the World List of Scleractinia (Hoeksema and Cairns, 2018). Free-living Fungiidae of the genera *Cycloseris, Danafungia*, *Fungia*, *Lithophyllon*, and *Pleuractis* were noted as *Fungia* s.l., as in the earlier revision by Hoeksema (1989), because the field research took place before that genus was split up (Gittenberger et al., 2011). *Cycloseris* is known to consist of attached and free-living species now (Benzoni et al., 2012; Hoeksema, 2014).

3. Results

3.1. Types of gear

Altogether, 143 pieces of derelict fishing gear were observed: 107 nets (one of which was not accessible for measurements); 13 ropes; two cages, and 21 nylon lines (Table 1; Figs. 2–4). A majority were found on offshore pinnacles, where gear was recorded down to relatively greater depths: 27 m at site 1 (Chumpon Pinnacle) and 23 m at site 5 (Southwest Pinnacle). Some of the gear here appeared old because it was covered by algae and sediment. The size of the gear was predominantly small: the mean area covered by nets was 0.8 m^2 with the largest occupying 9 m^2 of substrate (Fig. 2); the largest reef area occupied by rope was 1.3 m^2 (Table 2). Most nets, ropes and lines were made of synthetic material (noted as > 95% of all observed gear) and the rest of what appeared to be biodegradable fabric. The two cages were demolished. One of them consisted partly of rusting metal wire mesh on a wooden frame (Fig. 4c) and the other one was made of fishing net and a wooden frame. The stretch mesh size among all nets varied from 0.5 cm to 14.5 cm (Fig. 2). Some nets had pieces of rope attached (Fig. 2a).

The highest numbers of corals (Table 3: *Un* + *Ad* + *On*) were found in the proximity of nets (n = 1886), followed by nylon lines (n = 288), ropes (n = 157), and cages (n = 26). Among these, corals observed

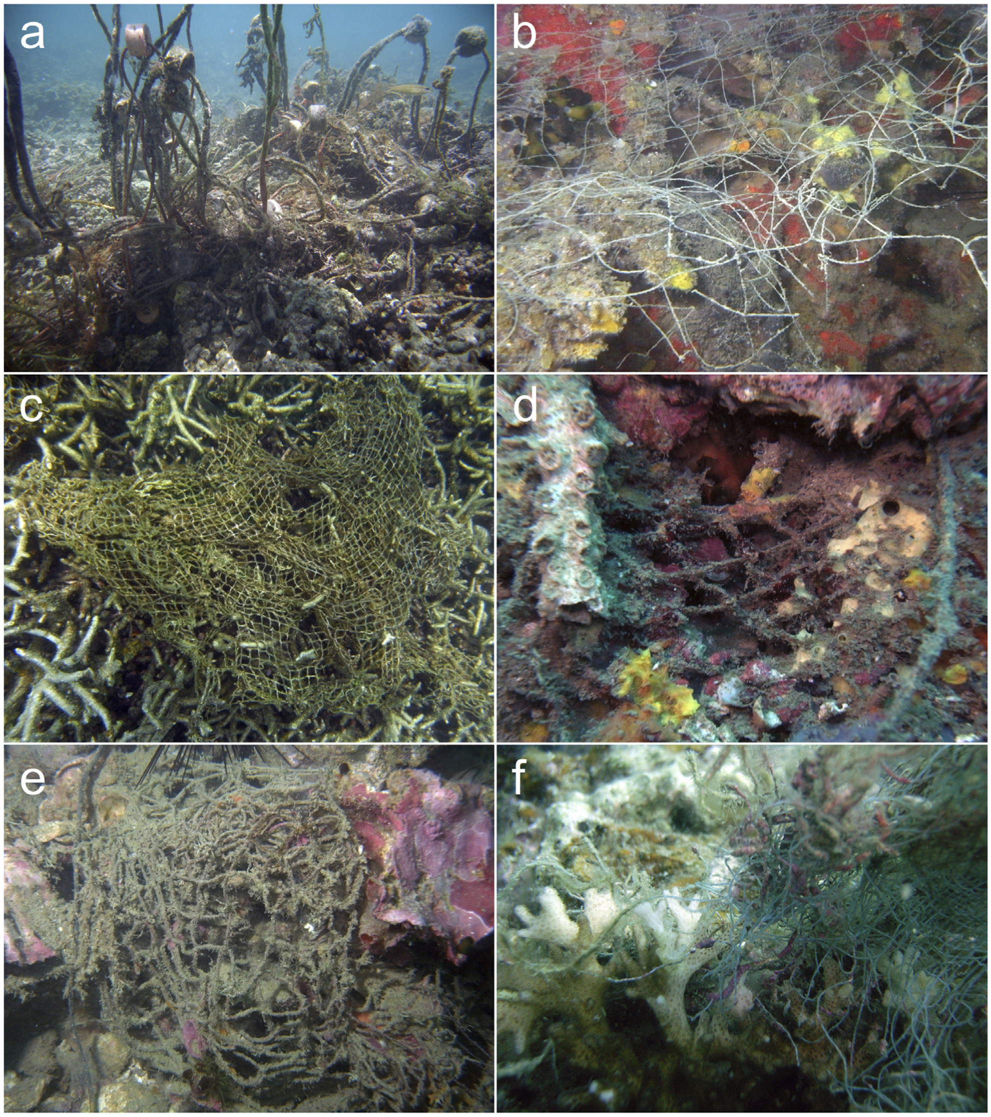

Fig. 2. Examples of nets and coral damage observed around Koh Tao: **a.** net with ropes and buoys stuck to shallow reef in Shark Bay; **b.** thin nylon net with large mesh size at Sail Rock; **c.** thick net with small mesh size at shallow depth at Chalok Ban Kao; **d.** piece of old net with a broken branch of dead *Tubastraea micranthus* at SW Pinnacle; **e.** piece of old net at Chumphon Pinnacle; **f.** piece of net caught in dead *Pocillopora damicornis* coral at Red Rock.

around the fishing gear (controls) formed the majority (*Ad*, n = 1544), followed by corals on top (*On*, n = 410) and corals underneath (*Un*, n = 403).

3.2. Types of coral

Six coral growth forms were distinguished and their position in relation to the fishing gear was noted (Table 3). Branching corals were most commonly found in direct contact with the derelict gear but also around it, followed by corals with an encrusting, massive, free-living, foliaceous, or laminar growth form, respectively. Although a relatively larger proportion of free-living mushroom corals (FL, 44/167 = 26%) appeared to live on top of nets (Fig. 5a), this was only slightly higher (but significantly so, $\chi^2 = 4.13$, $p = 0.04$) than in all attached corals together (Br + Encr + Mass + Fol + Lam, 339/1380 = 25%). The difference between the proportions of free-living corals (FL) and massive ones found on top of nets (Mass, 19/259 = 7%) is much larger ($\chi^2 = 29.12$, $p < 0.001$). This may be due to the apparent low proportion of massive corals settled on artificial substrate compared to other attached corals (Br + Encr + Fol + Lam, 317/1457 = 22%, $\chi^2 = 29.04$, $p < 0.001$) because many more massive corals occurred in proximity to the nets or underneath (Table 3). Coral growth underneath ropes (*Un*, n = 24) and settlement on ropes (*On*, n = 9) were generally uncommon. Among the latter were also corals overgrowing the substrate (Fig. 5). Regarding nylon lines (Fig. 3b), it is obvious that few corals were found underneath (*Un*, n = 67) or on top (*On*, n = 6) as compared to the controls (*Ad*, n = 215) considering the small area occupied by lines.

A total of 38 coral genera were recorded, some of which were represented by more than one growth form (Table 4). Corals of the genus *Tubastraea* (all of them branching *T. micranthus*) were distinctly the most abundant on all types of gear. Other genera that were abundantly represented are *Platygyra* (encrusting or massive), *Fungia* s.l., and *Porites* (branching, encrusting or massive). *Cycloseris mokai* was the most abundant encrusting species in this study. Nets, ropes and chicken wire of cages was a suitable artificial substrate for the settlement of *Tubastraea* corals (Table 4; Fig. 5b).

3.3. Coral damage underneath and around fishing gear

Some of the derelict gear was hidden by biofouling and therefore not all corals underneath could be evaluated for damage. A total of 338 live corals (*Un*) could be studied of which 226 (69%) showed damage, whereas of the 1108 corals in close proximity, 25–75 cm distance away

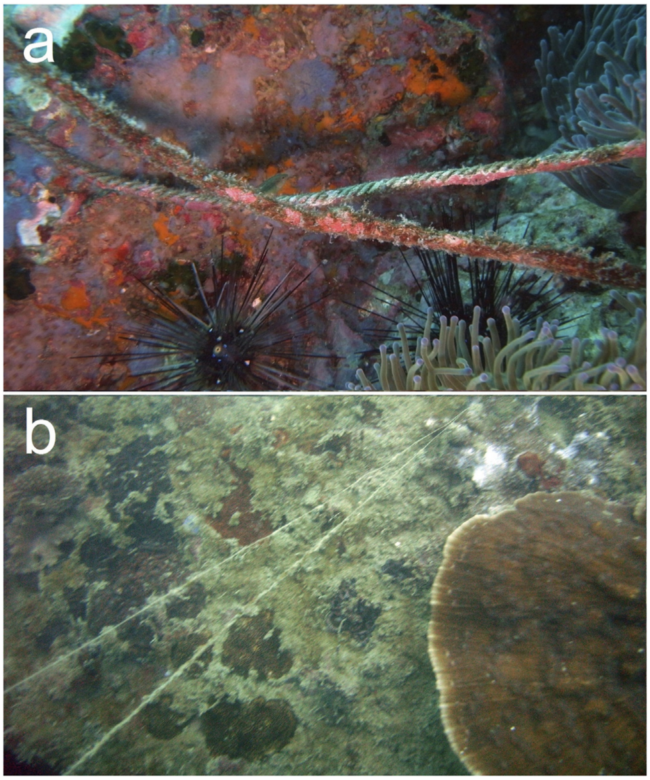

Fig. 3. Examples of derelict fishing gear observed around Koh Tao: **a.** ropes at SW Pinnacle; **b.** nylon filaments at Red Rock.

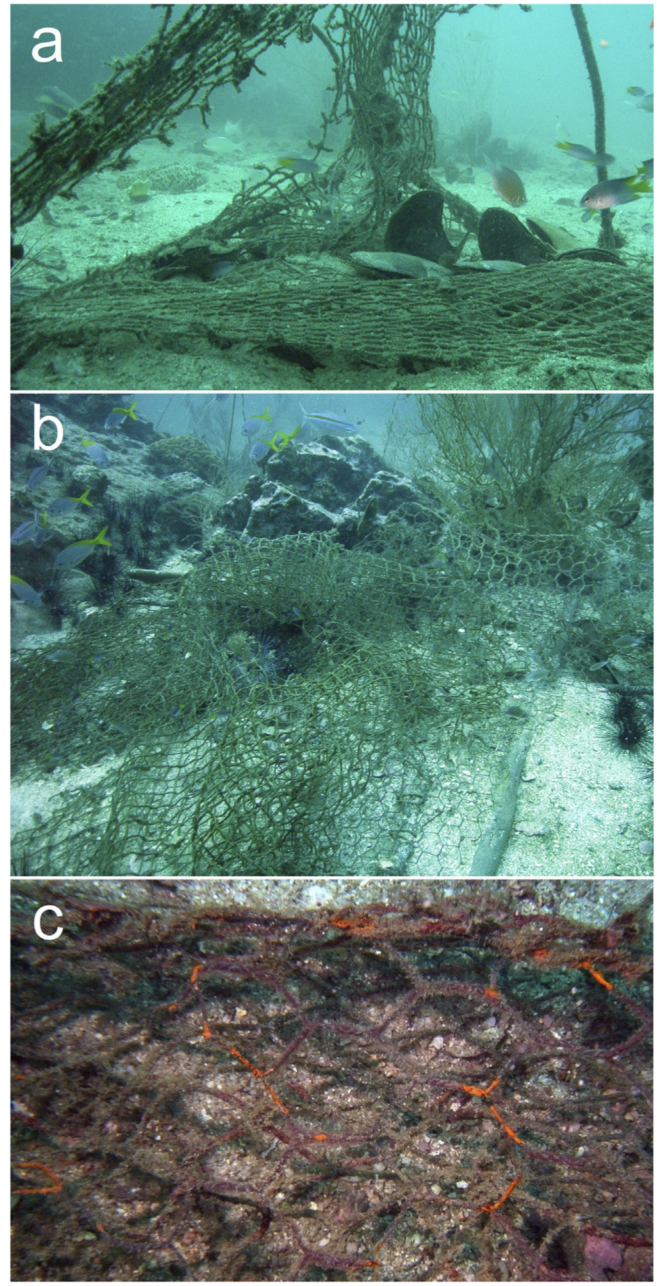

Fig. 4. Two demolished fish traps at SW Pinnacle, Koh Tao. **a.** broken cage consisting of shredded net and ropes; **b.** broken cage consisting of wooden debris, pieces of shredded net and wire mesh; **c.** close-up of rusty wire mesh.

(*Ad*), only 18% (n = 204) were harmed (Table 5). Thus, corals underneath derelict gear showed a significantly higher proportion of damage than the controls around them ($\chi^2 = 291.00$, $p < 0.0001$). The damage was visible as fresh tissue loss (*FTL*), tissue loss with algal growth (*TLAG*), or fragmentation (*FR*). Among damaged corals underneath gear (*Un*, n = 226) the proportions of damage categories (*FTL* 62%, *TLAG* 23%, *FR* 15%) differed from those around (*Ad*, n = 204), which acted as controls (*FTL* 21%, *TLAG* 75%, *FR* 4%). These proportions differ significantly ($\chi^2 = 116.47$, $p < 0.0001$), meaning that damage underneath gear consists mostly of tissue loss, while damage in the controls is predominantly represented by tissue loss and algal growth, implying that wounds are older here. The proportion of fragmented corals is also less among the controls, which is more pronounced when undamaged corals are also taken into account (*Un*, *FR* 33/338 = 10%; *Ad*, *FR* 8/1108 = 1%; $\chi^2 = 76.85$, $p < 0.0001$).

Harm to corals varied little among the four types of fishing gear. For the cages and nylon lines just *FTL* and *TLAG* were observed (Table 5). The nets and ropes showed no significant difference in the variation of proportions among *FTL*, *TLAG* and *FR* ($\chi^2 = 0.03$, p = 0.98).

The proportions of five growth forms corals (laminar was absent) among damaged and non-damaged categories differed significantly (Table 6; $\chi^2 = 15.38$, $p < 0.005$). Due to their fragile architecture, branching corals were expected to break more easily, but they were also represented by slightly higher fractions among non-damaged corals (72/112 = 64%) than among damaged corals (117/226 = 52%). Although it seems that the proportion of fragmented corals was higher among branching corals (23/189 = 12%) than among all the other corals (10/149 = 7%), this difference was too small to be significant ($\chi^2 = 2.81$, p = 0.093).

4. Discussion

The present study demonstrates that derelict fishing gear on the coral reefs of Koh Tao is common. A total of 143 pieces of derelict gear were observed to have caused damage to 226 corals. Comparisons of various kinds of damage underneath and around fishing gear suggest that derelict fish gear is harmful to corals, which is most obviously demonstrated by recent coral wounds (*FTL* and *FR*). Coral death also appears to be a consequence of derelict gear (Fig. 2d) but causes of mortality were not always clear and not measured in the present study.

The gear consisted of nets, ropes, cages and nylon lines, which were almost all made of non-biodegradable materials; this is not unexpected given much plastic litter in open sea and on the sea floor is related to fishing or aquaculture (Eriksen et al., 2014; Law, 2017; Rech et al., 2018a, 2018b). Nets were by far the most dominant type of lost gear on Koh Tao, followed by lines and ropes, which together are also commonly found in other coastal areas over the world (Donohue et al., 2001; Wilcox et al., 2013; Oliveira et al., 2015; Perez-Venegas et al.,

Table 2
Size measurements (area or length) occupied by derelict fishing gear listed in Table 1.

	Nets, m^2	Ropes, m^2	Cages, m^2	Nylon lines, m
n	106	13	2	21
Range area/length	0.006–9.0	0.03–1.30	0.66–4.20	0.5–9.3
Total area/length	84.8	3.0	4.9	38.9
Mean area/length	0.8	0.2	2.4	1.9
s.d.	1.3	0.4	2.5	2.1

2017; Farias et al., 2018; Krishnakumar et al., 2018). Much of the gear was found on offshore pinnacles serving as offshore dive sites.

The size of the gear found in this research is small in comparison with that in other studied areas (Donohue et al., 2001; Good et al., 2010). Dive operators organize clean-up operations, in which volunteers help to remove lost fishing gear from the reefs. When the gear is too big, it is cut in pieces, which may drop to the bottom and get lost out of sight. This explains the encounter of pieces of nets that are spread out but can be recognized as similar, especially on the seafloor around the pinnacles.

Higher proportions (total 67%, n = 338) of corals underneath lost gear (mostly nets) showed damage as compared to controls around them (total 18%, n = 1108). Fresh tissue loss (*FTL*) was more common than fragmentation and was probably caused by abrasion. Tissue loss with algal growth (*TLAG*) was also common, implying that the damage occurred earlier, which allowed time for algae to settle on the wounds. A total of 410 corals used the lost gear as artificial substrate, which also indicates that much of the gear had already settled some time earlier (Hoeksema and Hermanto, 2018).

Branching corals were the most commonly found growth form in close proximity to the lost gear. Branching corals can easily become entangled in lines, nets, and ropes, which was observed in the present study and in previous ones (Schleyer and Tomalin, 2000; Yoshikawa and Asoh, 2004; Chiappone et al., 2005; Sheehan et al., 2017). Although branching corals are expected to be more fragile than other growth forms (Highsmith, 1982), they did not show much fragmentation in the present study. *Tubastraea micranthus* was the most common coral species encountered. This reef-building species is azooxanthellate and therefore is not restricted to phototrophic depths, allowing it to occur over a large depth range (Schuhmacher, 1984). In Koh Tao, *T. micranthus* typically form small, densely built colonies (*personal observations*), thus, the strength of this dominant species may explain why fragmentation is less than expected for the branching growth form than other kinds of damage.

Tubastraea micranthus was able to settle on top of lost gear, even on ropes. The capacity of this widespread Indo-Pacific species to colonize artificial substrates is also reflected by its success as an invasive species in the Gulf of Mexico, where it inhabits oil platforms (Sammarco et al., 2014, 2017). Its congener *T. coccinea* is also able to grow on nets (Hoeksema and Hermanto, 2018). This species is well known as a colonizer of artificial substrates (Ng et al., 2016; Ho et al., 2017), which

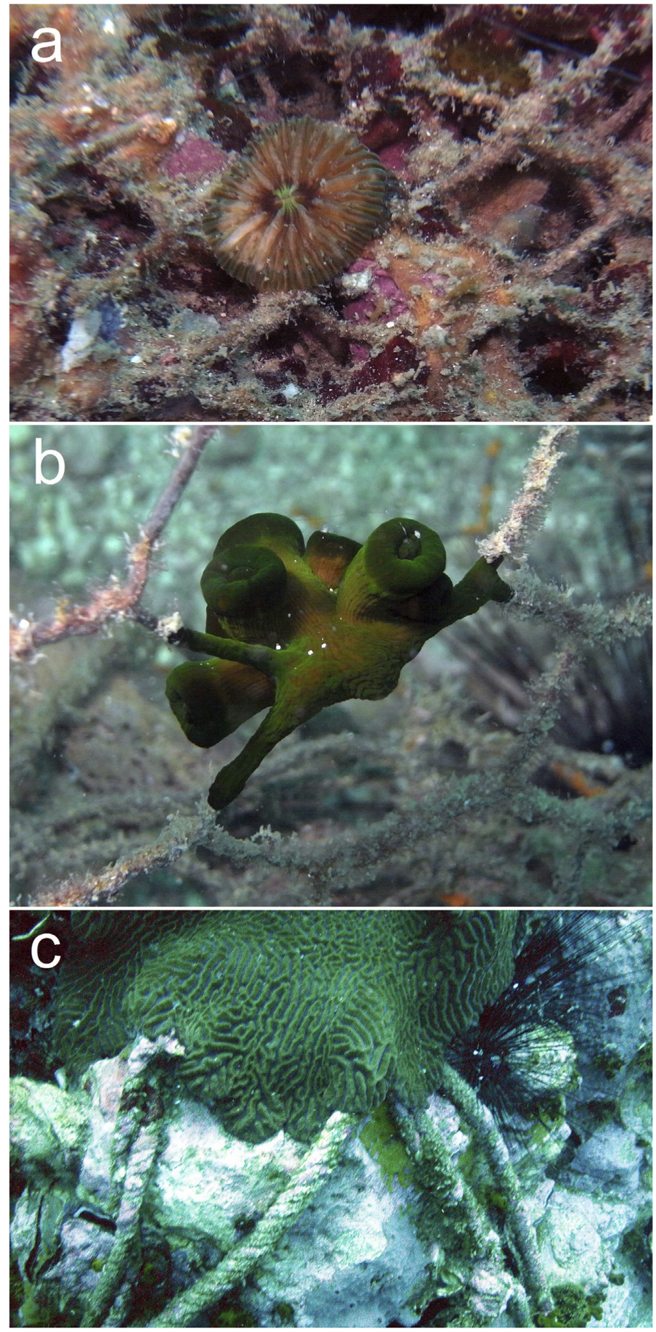

Fig. 5. Examples of corals settled on top or overgrowing derelict fishing gear at Koh Tao. **a.** juvenile mushroom coral, *Danafungia scruposa*, on top of a net covered by algae at SW Pinnacle; **b.** juvenile branching *Tubastraea micranthus* attached to wire mesh of a cage at SW Pinnacle; **c.** large massive colony of *Platygyra daedalea* at Chumphon Pinnacle.

Table 3
Numbers of hard corals by growth form around Koh Tao growing underneath (*Un*), adjacent to (*Ad*), and on the gear (*On*); – = 0.

Growth form	Abbreviation	Nets			Ropes			Cages			Nylon lines			Total
		Un	*Ad*	*On*	*Un*	*Ad*	*On*	*Un*	*Ad*	*On*	*Un*	*Ad*	*On*	
Branching	Br	170	502	236	19	45	6	–	–	11	14	6	–	1009
Encrusting	Encr	49	306	80	2	30	2	3	2	–	17	60	2	553
Massive	Mass	44	196	19	1	24	–	1	3	–	32	63	2	385
Free-living	FL	10	113	44	1	18	1	–	5	1	–	80	2	275
Foliaceous	Fol	34	58	1	1	5	–	–	–	–	2	5	–	106
Laminar	Lam	1	20	3	–	2	–	–	–	–	2	1	–	29
Total		308	1195	383	24	124	9	4	10	12	67	215	6	2357

Table 4
Numbers of hard corals by genus around Koh Tao (with growth forms encountered; see Table 3) growing underneath (*Un*), adjacent to (*Ad*), and on the gear (*On*); – = 0.

Genus	Growth form(s)	Nets			Ropes			Cages			Nylon lines			Total
		Un	*Ad*	*On*	*Un*	*Ad*	*On*	*Un*	*Ad*	*On*	*Un*	*Ad*	*On*	
Acropora	Br	14	1	–	2	–	–	–	–	–	7	5	–	29
Ctenactis	FL	–	14	2	–	3	–	–	–	–	–	27	–	46
Cycloseris	Encr	6	76	17	–	5	1	1	–	–	–	12	–	118
Cyphastrea	Encr	2	9	3	–	1	–	1	1	–	–	–	–	17
Diploastrea	Encr, Mass	3	12	3	–	2	–	–	–	–	–	2	–	22
Dipsastraea	Encr, Mass	14	65	12	–	4	–	–	–	–	2	15	–	112
Echinophyllia	Encr, Lam	1	9	1	–	1	–	–	–	–	2	–	–	14
Echinopora	Encr	–	2	–	–	1	–	1	–	–	–	–	–	4
Euphyllia	Mass	–	1	–	–	–	–	–	–	–	–	–	–	1
Favites	Encr, Mass	3	9	–	–	–	–	–	–	–	–	1	–	13
Fungia s.l.	FL	10	77	42	–	14	1	–	5	1	–	51	2	203
Galaxea	Encr	–	1	2	–	1	–	–	–	–	1	3	–	8
Goniastrea	Encr, Mass	9	36	3	–	4	–	1	–	–	2	5	–	60
Goniopora	Encr, Mass	2	9	6	–	–	–	–	–	–	1	1	–	19
Herpolitha	FL	–	14	–	–	–	–	–	–	–	–	–	–	14
Hydnophora	Encr, Mass	–	7	–	1	1	–	–	–	–	3	3	–	15
Leptastrea	Encr, Mass	4	9	–	–	2	–	–	1	–	1	1	–	18
Leptoria	Mass	–	2	–	–	–	–	–	–	–	–	–	–	2
Leptoseris	Encr	–	1	1	–	–	–	–	–	–	–	–	–	2
Lobophyllia	Mass	5	20	4	1	2	–	–	–	–	3	5	–	40
Merulina	Encr, Lam	–	8	1	–	–	–	–	–	–	–	–	–	9
Montipora	Encr, Lam	3	11	4	–	5	–	–	–	–	–	4	1	28
Pachyseris	Encr, Lam	–	7	2	–	–	–	–	–	–	–	2	1	12
Pavona	Encr, Fol	38	74	18	1	9	–	–	–	–	2	5	–	147
Pectinia	Fol	1	4	–	–	–	–	–	–	–	1	–	–	6
Platygyra	Encr, Mass	21	122	8	1	7	1	–	–	–	11	40	2	213
Plerogyra	Mass	–	4	–	–	–	–	–	–	–	–	–	–	4
Pocillopora	Br	16	8	–	4	2	–	–	–	–	6	–	–	36
Podabacia	Encr, Lam	–	3	–	–	–	–	–	–	–	–	–	–	3
Polyphyllia	FL	–	5	–	1	–	–	–	–	–	–	2	–	8
Porites	Br, Encr, Mass	13	71	18	3	18	–	–	3	–	25	30	–	181
Psammocora	Br, Encr, Mass	3	6	–	–	1	–	–	–	–	–	–	–	10
Pseudosiderastrea	Br, Encr	–	4	–	–	–	–	–	–	–	–	–	–	4
Sandalolitha	FL	–	3	–	–	1	–	–	–	–	–	–	–	4
Tubastraea	Br	139	493	236	10	40	6	–	–	11	–	–	–	935
Turbinaria	Encr, Lam	1	2	1	–	–	–	–	–	–	–	1	–	5
Total		308	1195	383	24	124	9	4	10	12	67	215	6	2357

Table 5
Numbers of derelict fishing gear around Koh Tao with coral damage found underneath (*Un*) and around (*Ad*); – = 0.

Gear type	Fresh tissue loss (*FTL*)		Tissue loss with algae (*TLAG*)		Fragmentation (*FR*)		Total damage		No damage (*ND*)	
	Un	*Ad*	*Un*	*Ad*	*Un*	*Ad*	*Un*	*Ad*	*Un*	*Ad*
Nets	122	38	40	130	31	6	193	174	49	719
Ropes	9	1	3	8	2	1	14	10	5	59
Cages	1	–	–	2	–	–	1	2	3	12
Nylon lines	8	3	10	14	–	1	18	18	55	114
Total	140	42	53	154	33	8	226	204	112	904

Table 6
Types of damage and their numbers associated with various growth forms of stony corals underneath (*Un*) fishing gear around Koh Tao with proportions divided over the growth forms (columns); – = 0.

Growth form	Fresh tissue loss (*FTL*)	Tissue loss with algae (*TLAG*)	Fragmentation (*FR*)	Total damage	No damage (*ND*)
Branching	68	26	23	117	72
Encrusting	27	11	1	39	15
Massive	23	12	3	38	8
Foliaceous	18	4	6	28	7
Free-living	4	–	–	4	7
Laminar	–	–	–	–	3
Total	140	53	33	226	112

may explain its success as a widespread and common invasive species in the western Atlantic, where it interacts with native reef species (Creed et al., 2017; Hoeksema and Ten Hove, 2017; Kolian et al., 2017). On sandy seafloors, lost nets can perhaps become stepping stones in the dispersal of invasive species, like other artificial substrates (Bishop et al., 2017; Heery et al., 2017). As floating objects, plastic nets and other litter may serve as a vector for the dispersal of benthic organisms (including reef corals) and potentially cause the introduction of non-native species (Hoeksema et al., 2018; Rech et al., 2018b).

Other corals that appeared successful colonizers of gear were mushroom corals of the genera *Ctenactis*, *Cycloseris* and *Fungia* s.l. The *Cycloseris* specimens, all identified as *Cycloseris mokai*, were small and encrusting (see Benzoni et al., 2012). The other mushroom corals on top of gear belonged to free-living species, which start as small polyps attached by a stalk from which they detach themselves later on (Hoeksema and Yeemin, 2011). Because of their mobility as free-living corals (Hoeksema, 1988; Chadwick-Furman and Loya, 1992; Hoeksema et al., 2014; Hoeksema and Bongaerts, 2016), they can also have arrived after detachment from their original substrate (Hoeksema and Hermanto, 2018). When they risk becoming entangled in nets, they may be able to free themselves and move away (Hoeksema and De Voogd, 2012).

The damage caused by lost gear may contribute to coral mortality (Fig. 5), but no quantitative information is available about this. Once nets and ropes settle, they may become substrate for benthic organisms and act as sediment traps. Corals underneath such nets and ropes can easily become submerged within the sediments, which has been shown to cause mortality (Rogers, 1990; Erftemeijer et al., 2012). Because they are trapped and their movements become restricted, they cannot easily clean themselves by sediment shedding (e.g. Bongaerts et al., 2012). Tissue damage in coral caused by plastics may cause infections by microbes and develop into diseases (Lamb et al., 2018). Removal of stabilized gear from entangled corals may easily cause damage to corals and their environment (Donohue et al., 2001). Therefore, it is recommended to remove newly arrived nets from the reefs as soon as possible in order to prevent ghost fishing and coral damage. Future studies might include monitoring of lost nets and see how they interact with reefs over time.

Declarations of interest

None.

Acknowledgements

The first author received a research grant from the Alida B. Buitendijkfonds (Naturalis Biodiversity Center). She wants to thank Dr. Ronald Osinga (Wageningen University) for his advice during finalizing her MSc thesis. The authors want to thank staff and volunteers of Big Blue Diving for their help during the surveys. We are grateful to Chad Scott of New Heaven Reef Conservation Program for logistic support at southern Koh Tao. We want to thank the anonymous reviewer for his excellent comments, which helped us to improve the ms. This paper is part of a special volume dedicated to Dr. Charles Sheppard, previous editor-in-chief of Marine Pollution Bulletin. By being very productive as outstanding researcher and editor, he has contributed much to our understanding of coral reefs, ranging from natural history to human impact.

References

Abu-Hilal, A., Al-Najjar, T., 2009. Marine litter in coral reef areas along the Jordan Gulf of Aqaba, Red Sea. J. Environ. Manag. 90, 1043–1049. https://doi.org/10.1016/j.jenvman.2008.03.014.

Al-Masroori, H.S., Al-Oufi, H., Mc Shane, P., 2009. Causes and mitigations on trap ghost fishing in Oman: scientific approach to local fisheries' perception. J. Fish. Aquat. Sci. 4, 129–135. https://doi.org/10.3923/jfas.2009.129.135.

Baeta, F., Costa, M.J., Cabral, H., 2009. Trammel nets' ghost fishing off the Portuguese central coast. Fish. Res. 98, 33–39. https://doi.org/10.1016/j.fishres.2009.03.009.

Baldock, T.E., Karampour, H., Sleep, R., Vyltla, A., Albermani, F., Golshani, A., Callaghan, D.P., Roff, G., Mumby, P.J., 2014. Resilience of branching and massive corals to wave loading under sea level rise – a coupled computational fluid dynamics-structural analysis. Mar. Pollut. Bull. 86, 91–101. https://doi.org/10.1016/j.marpolbul.2014.07.038.

Benzoni, F., Arrigoni, R., Stefani, F., Reijnen, B.T., Montano, S., Hoeksema, B.W., 2012. Phylogenetic position and taxonomy of *Cycloseris explanulata* and *C. wellsi* (Scleractinia: Fungiidae): lost mushroom corals find their way home. Contrib. Zool. 81, 125–146.

Bishop, M.J., Mayer-Pinto, M., Airoldi, L., Firth, L.B., Morris, R.L., Loke, L.H.L., Hawkins, S.J., Naylor, L.A., Coleman, R.A., Chee, S.Y., Dafforn, K.A., 2017. Effects of ocean sprawl on ecological connectivity: impacts and solutions. J. Exp. Mar. Biol. Ecol. 492, 7–30. https://doi.org/10.1016/j.jembe.2017.01.021.

Bongaerts, P., Hoeksema, B.W., Hay, K.B., Hoegh-Guldberg, O., 2012. Mushroom corals overcome live burial through pulsed inflation. Coral Reefs 31, 399. https://doi.org/10.1007/s00338-011-0862-z.

Brandl, S.J., Goatley, C.H.R., Bellwood, D.R., Tornabene, L., 2018. The hidden half: ecology and evolution of cryptobenthic fishes on coral reefs. Biol. Rev. https://doi.org/10.1111/brv.12423.

Brown, B.E., 1997. Adaptations of reef corals to physical environmental stress. Adv. Mar. Biol. 31, 222–301. https://doi.org/10.1016/S0065-2881(08)60224-2.

Brown, B.E., Howard, L.S., 1985. Assessing the effects of "stress" on reef corals. Adv. Mar. Biol. 22, 1–63. https://doi.org/10.1016/S0065-2881(08)60049-8.

Buddemeier, R.W., Kinzie, R.A., 1976. Coral growth. Oceanogr. Mar. Biol. Annu. Rev. 14, 183–225.

Butler, J.R.A., Gunn, R., Berry, H., Wagey, G.A., Hardesty, B.D., Wilcox, C., 2013. A value chain analysis of ghost nets in the Arafura Sea: identifying trans-boundary stakeholders, intervention points and livelihood trade-offs. J. Environ. Manag. 3, 14–25. https://doi.org/10.1016/j.jenvman.2013.03.008.

Chadwick-Furman, N.E., Loya, Y., 1992. Migration, habitat use, and competition among mobile corals (Scleractinia: Fungiidae) in the Gulf of Eilat, Red Sea. Mar. Biol. 114, 617–623. https://doi.org/10.1007/BF00357258.

Chavanich, S., Viyakarn, V., Adams, P., Klammer, J., Cook, B., 2012. Reef communities after the 2010 mass coral bleaching at Racha Yai Island in the Andaman Sea and Koh Tao in the Gulf of Thailand. Phuket Mar. Biol. Cent. Res. Bull. 71, 103–110.

Chiappone, M., White, A., Swanson, D.W., Miller, S.L., 2002. Occurrence and biological impacts of fishing gear and other marine debris in the Florida keys. Mar. Pollut. Bull. 44, 597–604. https://doi.org/10.1016/S0025-326X(01)00290-9.

Chiappone, M., Dienes, H., Swanson, D.W., Miller, S.L., 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary. Biol. Conserv. 121, 221–230. https://doi.org/10.1016/j.biocon.2004.04.023.

Creed, J.C., Fenner, D., Sammarco, P., Cairns, S., Capel, K., Junqueira, A., Cruz, I., Miranda, R., Junior, L., Mantelatto, M., Oigman-Pszczol, S.S., 2017. The invasion of the azooxanthellate coral *Tubastraea* (Scleractinia: Dendrophylliidae) throughout the world: history, pathways and vectors. Biol. Invasions 19, 283–305. https://doi.org/10.1007/s10530-016-1279-y.

Dameron, O.J., Park, M., Albins, M.A., Brainard, R., 2007. Marine debris accumulation in the Northwestern Hawaiian islands: an examination of rates and processes. Mar. Pollut. Bull. 54, 423–433. https://doi.org/10.1016/j.marpolbul.2006.11.019.

de Carvalho-Souza, G.F., Llope, M., Tinôco, M.S., Medeiros, D.V., Maia-Nogueira, R., Sampaio, C.L.S., 2018. Marine litter disrupts ecological processes in reef systems. Mar. Pollut. Bull. 133, 464–471. https://doi.org/10.1016/j.marpolbul.2018.05.049.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852. https://doi.org/10.1016/S0025-326X(02)00220-5.

Donohue, M.J., Boland, M.C., Sramek, C.M., Antonelis, G.A., 2001. Derelict fishing gear in the Northwestern Hawaiian islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. Mar. Pollut. Bull. 42, 1301–1312. https://doi.org/10.1016/S0025-326X(01)00139-4.

Edinger, E.N., Jompa, J., Limmon, G.V., Widjatmoko, W., Risk, M.J., 1998. Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time. Mar. Pollut. Bull. 36, 617–630. https://doi.org/10.1016/S0025-326X(98)00047-2.

Edyvane, K.S., Penny, S.S., 2017. Trends in derelict fishing nets and fishing activity in Northern Australia: implications for trans-boundary fisheries management in the shared Arafura and Timor seas. Fish. Res. 188, 23–37. https://doi.org/10.1016/j.fishres.2016.11.021.

Erftemeijer, P.L., Riegl, B., Hoeksema, B.W., Todd, P.A., 2012. Environmental impacts of dredging and other sediment disturbances on corals: a review. Mar. Pollut. Bull. 64, 1737–1765. https://doi.org/10.1016/j.marpolbul.2012.05.008.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the World's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. PLoS One 9, e111913. https://doi.org/10.1371/journal.pone.0111913.

Farias, E.G.G., Preichardt, P.R., Dantas, D.V., 2018. Influence of fishing activity over the marine debris composition close to coastal jetty. Environ. Sci. Pollut. Res. 25, 16246–16253. https://doi.org/10.1007/s11356-018-2012-4.

Fei, W., 2016. Agent-based Model on the Effects of Dive Tourism in Coral Related Socialecological System - a Case Study on Koh Tao, Thailand. PhD thesis. University of Bremen. https://elib.suub.uni-bremen.de/edocs/00105460-1.pdf.

Ferse, S.C.A., Glaser, M., Neil, M., Schwerdtner Mánez, K., 2014. To cope or sustain? Eroding long-term sustainability in an Indonesian coral reef fishery. Reg. Environ. Chang. 14, 2053–2065. https://doi.org/10.1007/s10113-012-0342-1.

Fox, H.E., Pet, J.S., Dahuri, R., Caldwell, R.L., 2003. Recovery in rubble fields: long-term impacts of blast fishing. Mar. Pollut. Bull. 46, 1024–1031. https://doi.org/10.1016/S0025-326X(03)00246-7.

Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041.

Gilardi, K.V.K., Carlson-Bremer, D., June, J.A., Antonelis, K., Broadhurst, G., Cowan, T., 2010. Marine species mortality in derelict fishing nets in Puget Sound, WA and the cost/benefits of derelict net removal. Mar. Pollut. Bull. 60, 376–382. https://doi.org/10.1016/j.marpolbul.2009.10.016.

Gilman, E., 2015. Status of international monitoring and management of abandoned, lost and discarded fishing gear and ghost fishing. Mar. Policy 60, 225–239. https://doi.org/10.1016/j.marpol.2015.06.016.

Gittenberger, A., Reijnen, B.T., Hoeksema, B.W., 2011. A molecularly based phylogeny reconstruction of mushroom corals (Scleractinia: Fungiidae) with taxonomic consequences and evolutionary implications for life history traits. Contrib. Zool. 80, 107–132. http://repository.naturalis.nl/document/215227.

Glaser, M., Breckwoldt, A., Deswandi, R., Radjawali, I., Baitoningsih, W., Ferse, S.C.A., 2015. Of exploited reefs and fishers - a holistic view on participatory coastal and marine management in an Indonesian archipelago. Ocean Coast. Manag. 116, 193–213. https://doi.org/10.1016/j.ocecoaman.2015.07.022.
Goñi, R., 1998. Ecosystem effects of marine fisheries: an overview. Ocean Coast. Manag. 40, 37–64. https://doi.org/10.1016/S0964-5691(98)00037-4.
Good, T.P., June, J.A., Etnier, M.A., Broadhurst, G., 2010. Derelict fishing nets in Puget Sound and the north west straits: patterns and threats to marine fauna. Mar. Pollut. Bull. 60, 39–50. https://doi.org/10.1016/j.marpolbul.2009.09.005.
Heery, E., Bishop, M.J., Critchley, L., Bugnot, A.B., Airoldi, L., Mayer-Pinto, M., Sheehan, E.V., Coleman, R.A., Loke, L.H.L., Johnston, E.L., Komyakova, V., Morris, R.L., Strain, E., Naylor, L.A., Dafforn, K.A., 2017. Identifying the consequences of ocean sprawl for sedimentary habitats. J. Exp. Mar. Biol. Ecol. 492, 31–48. https://doi.org/10.1016/j.jembe.2017.01.020.
Hein, M.Y., Lamb, J.B., Scott, C., Willis, B.L., 2015. Assessing baseline levels of coral health in a newly established marine protected area in a global scuba diving hotspot. Mar. Environ. Res. 103, 56–65. https://doi.org/10.1016/j.marenvres.2014.11.008.
Highsmith, R.C., 1982. Reproduction by fragmentation in corals. Mar. Ecol. Prog. Ser. 7, 207–226. https://doi.org/10.3354/meps007207.
Ho, M.J., Hsu, C.M., Chen, C.A., 2017. Wall of orange cup coral, *Tubastraea coccinea*, at the inlet breakwaters of a nuclear power plant, Southern Taiwan. Mar. Biodivers. 47, 163–164. https://doi.org/10.1007/s12526-016-0469-2.
Hoeksema, B.W., 1988. Mobility of free-living fungiid corals (Scleractinia), a dispersion mechanism and survival strategy in dynamic reef habitats. In: Proc. 6th Int. Coral Reef Symp. Townsville. 2. pp. 715–720.
Hoeksema, B.W., 1989. Taxonomy, phylogeny and biogeography of mushroom corals (Scleractinia: Fungiidae). Zool. Verh. 254, 1–295. http://www.repository.naturalis.nl/document/149013.
Hoeksema, B.W., 2014. The "*Fungia patella* group" (Scleractinia, Fungiidae) revisited with a description of the mini mushroom coral *Cycloseris boschmai* sp. n. ZooKeys. 371, 57–84. https://doi.org/10.3897/zookeys.371.6677.
Hoeksema, B.W., 2017. The hidden biodiversity of tropical coral reefs. Biodiversity 18, 8–12. https://doi.org/10.1080/14888386.2017.1307787.
Hoeksema, B.W., Bongaerts, P., 2016. Mobility and self-righting by a free-living mushroom coral through pulsed inflation. Mar. Biodivers. 46, 521–524. https://doi.org/10.1007/s12526-015-0384-y.
Hoeksema, B.W., Cairns, S.D., 2018. World List of Scleractinia. Accessed through: World Register of Marine Species at: http://www.marinespecies.org/index.php.
Hoeksema, B.W., De Voogd, N.J., 2012. On the run: free-living mushroom corals avoiding interaction with sponges. Coral Reefs 31, 455–459. https://doi.org/10.1007/s00338-011-0856-x.
Hoeksema, B.W., Hermanto, B., 2018. Plastic nets as substrate for reef corals in Lembeh Strait, Indonesia. Coral Reefs 37, 631. https://doi.org/10.1007/s00338-018-1686-x.
Hoeksema, B.W., Koh, E.G., 2009. Depauperation of the mushroom coral fauna (Fungiidae) of Singapore (1860s–2006) in changing reef conditions. Raffles Bull. Zool. Suppl. 22, 91–101.
Hoeksema, B.W., Matthews, J.L., 2011. Contrasting bleaching patterns in mushroom coral assemblages at Koh Tao, Gulf of Thailand. Coral Reefs 30, 95. https://doi.org/10.1007/s00338-010-0675-5.
Hoeksema, B.W., Matthews, J.L., 2015. Partial bleaching in an assemblage of small apozooxanthellate corals of the genera *Heteropsammia* and *Heterocyathus*. Coral Reefs 34, 1227. https://doi.org/10.1007/s00338-015-1314-y.
Hoeksema, B.W., Ten Hove, H.A., 2017. The invasive sun coral *Tubastraea coccinea* hosting a native Christmas tree worm at Curaçao, Dutch Caribbean. Mar. Biodivers. 47, 59–65. https://doi.org/10.1007/s12526-016-0472-7.
Hoeksema, B.W., Yeemin, T., 2011. Late detachment conceals serial budding by the free-living coral *Fungia fungites* in the Inner Gulf of Thailand. Coral Reefs 30, 975. https://doi.org/10.1007/s00338-011-0784-9.
Hoeksema, B.W., Matthews, J.L., Yeemin, T., 2012. The 2010 coral bleaching event and its impact on the mushroom coral fauna of Koh Tao, western Gulf of Thailand. Phuket Mar. Biol. Cent. Res. Bull. 71, 71–81.
Hoeksema, B.W., Scott, C., True, J.D., 2013. Dietary shift in corallivorous *Drupella* snails following a major bleaching event at Koh Tao, Gulf of Thailand. Coral Reefs 32, 423–428. https://doi.org/10.1007/s00338-012-1005-x.
Hoeksema, B.W., Dekker, F., De Voogd, N.J., 2014. Free-living mushroom corals strike back by overtopping a coral-killing sponge. Mar. Biodivers. 44, 3–4. https://doi.org/10.1007/s12526-013-0188-x.
Hoeksema, B.W., Hassell, D., Meesters, E.H.W.G., Van Duyl, F.C., 2017. Wave-swept coralliths of Saba Bank, Dutch Caribbean. Mar. Biodivers. https://doi.org/10.1007/s12526-017-0712-5.
Hoeksema, B.W., Pedoja, K., Propawski, Y., 2018. Long-distance transport of a West Atlantic stony coral on a plastic raft. Ecology. https://doi.org/10.1002/ecy.2405.
Kolian, S.R., Sammarco, P.W., Porter, S.A., 2017. Abundance of corals on offshore oil and gas platforms in the Gulf of Mexico. Environ. Manag. 60, 357–366. https://doi.org/10.1007/s00267-017-0862-z.
Krishnakumar, S., Srinivasalu, S., Saravanan, P., Vidyasakar, A., Magesh, N.S., 2018. A preliminary study on coastal debris in Nallathanni Island, gulf of Mannar biosphere reserve, southeast coast of India. Mar. Pollut. Bull. 131A, 547–551. https://doi.org/10.1016/j.marpolbul.2018.04.026.
Kühn, S., Rebolledo, E.L.B., van Franeker, J.A., 2015. Deleterious effects of litter on marine life. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer, Berlin, pp. 75–116. https://doi.org/10.1007/978-3-319-16510-3_4.
Lamb, J.B., True, J.D., Piromvaragorn, S., Willis, B.L., 2014. Scuba diving damage and intensity of tourist activities increases coral disease prevalence. Biol. Conserv. 178, 88–96. https://doi.org/10.1016/j.biocon.2014.06.027.
Lamb, J.B., Willis, B.L., Fiorenza, E.A., Couch, C.S., Howard, R., Rader, D.N., True, J.D., Kelly, L.A., Ahmad, A., Jompa, J., Harvell, C.D., 2018. Plastic waste associated with disease on coral reefs. Science 359, 460–462. https://doi.org/10.1126/science.aar3320.
Law, K.L., 2017. Plastics in the marine environment. Annu. Rev. Mar. Sci. 9, 205–229. https://doi.org/10.1146/annurev-marine-010816-060409.
Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., Hajbane, S., Cunsolo, S., Schwarz, A., Levivier, A., Noble, K., Debeljak, P., Maral, H., Schoeneich-Argent, R., Brambini, R., Reisser, J., 2018. Evidence that the Great Pacific garbage patch is rapidly accumulating plastic. Sci. Rep. 8, 4666. https://doi.org/10.1038/s41598-018-22939-w.
Lewis, C.F., Slade, S.L., Maxwell, K.E., Matthews, T.R., 2009. Lobster trap impact on coral reefs: effects of wind-driven trap movement. N. Z. J. Mar. Freshw. Res. 43, 271–282. https://doi.org/10.1080/00288330909510000.
Madin, J.S., Connolly, S.R., 2006. Ecological consequences of major hydrodynamic disturbances on coral reefs. Nature 444, 477–480. https://doi.org/10.1038/nature05328.
Matsuoka, T., Nakashima, T., Nagasawa, N., 2005. A review of ghost fishing: scientific approaches to evaluation and solutions. Fish. Sci. 71, 691–702. https://doi.org/10.1111/j.1444-2906.2005.01019.x.
McManus, J.W., Reyes, R.B., Nañola, C.L., 1997. Effects of some destructive fishing methods on coral cover and potential rates of recovery. Environ. Manag. 21, 68–78. https://doi.org/10.1007/s002679900006.
Moerland, M.S., Scott, C.M., Hoeksema, B.W., 2016. Prey selection of Corallivorous muricids at Koh Tao (Gulf of Thailand) four years after a major coral bleaching event. Contrib. Zool. 85, 291–309.
Morishige, C., McElwee, K., 2012. At-sea detection of derelict fishing gear in the North Pacific: an overview. Mar. Pollut. Bull. 65, 1–6. https://doi.org/10.1016/j.marpolbul.2011.05.017.
Munro, C., 2005. Diving systems. In: Eleftheriou, A., McIntyre, A. (Eds.), Methods for the Study of the Marine Benthos, 3rd ed. Blackwell Science, Oxford, pp. 112–159.
Naranjo-Elizondo, B., Cortés, J., 2018. Observations of litter deposited in the deep waters of Isla del Coco National Park, Eastern Tropical Pacific. Front. Mar. Sci. 5, 91. https://doi.org/10.3389/fmars.2018.00091.
Ng, C.S.L., Toh, T.C., Chou, L.M., 2016. Coral restoration in Singapore's sediment-challenged sea. Reg. Stud. Mar. Sci. 8, 422–429. https://doi.org/10.1016/j.rsma.2016.05.005.
Niaounakis, M., 2017. Management of Marine Plastic Debris: Prevention, Recycling, and Waste Management. Elsevier, Amsterdam. https://doi.org/10.1016/B978-0-323-44354-8.09001-7.
Oliveira, F., Monteiro, P., Bentes, L., Henriques, N.S., Aguilar, R., Gonçalves, J.M., 2015. Marine litter in the upper Sao Vicente submarine canyon (SW Portugal): abundance, distribution, composition and fauna interactions. Mar. Pollut. Bull. 97, 401–407. https://doi.org/10.1016/j.marpolbul.2015.05.060.
Pawson, M.G., 2003. The catching capacity of lost static fishing gears: introduction. Fish. Res. 64, 101–105. https://doi.org/10.1016/S0165-7836(03)00208-X.
Perez-Venegas, D., Pavés, H., Pulgar, J., Ahrendt, C., Seguel, M., Galbán-Malagón, C.J., 2017. Coastal debris survey in a remote island of the Chilean Northern Patagonia. Mar. Pollut. Bull. 125, 530–534. https://doi.org/10.1016/j.marpolbul.2017.09.026.
Pitcher, T.J., Cheung, W.W., 2013. Fisheries: hope or despair? Mar. Pollut. Bull. 74, 506–516. https://doi.org/10.1016/j.marpolbul.2013.05.045.
Rech, S., Borrell Pichs, Y.J., García-Vazquez, E., 2018a. Anthropogenic marine litter composition in coastal areas may be a predictor of potentially invasive rafting fauna. PLoS One 13, e0191859. https://doi.org/10.1371/journal.pone.0191859.
Rech, S., Salmina, S., Borrell Pichs, Y.J., García-Vazquez, E., 2018b. Dispersal of alien invasive species on anthropogenic litter from European mariculture areas. Mar. Pollut. Bull. 131A, 10–16. https://doi.org/10.1016/j.marpolbul.2018.03.038.
Revill, A.S., Dunlin, G., 2003. The fishing capacity of gillnets lost on wrecks and on open ground in UK coastal waters. Fish. Res. 64, 107–113. https://doi.org/10.1016/S0165-7836(03)00209-1.
Risk, M.J., Heikoop, J.M., Edinger, E.N., Erdmann, M.V., 2001. The assessment 'toolbox': community-based reef evaluation methods coupled with geochemical techniques to identify sources of stress. Bull. Mar. Sci. 69, 443–458.
Rogers, C.S., 1990. Responses of coral reefs and reef organisms to sedimentation. Mar. Ecol. Prog. Ser. 62, 185–202. https://doi.org/10.3354/meps062185.
Ryan, P.G., Moore, C.J., van Franeker, J.A., Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. Philos. Trans. R. Soc. B 364, 1999–2012. https://doi.org/10.1098/rstb.2008.0207.
Sammarco, P.W., Porter, S.A., Sinclair, J., Genazzio, M., 2014. Population expansion of a new invasive coral species, *Tubastraea micranthus*, in the northern Gulf of Mexico. Mar. Ecol. Prog. Ser. 495, 161–173. https://doi.org/10.3354/meps10576.
Sammarco, P.W., Brazeau, D.A., McKoin, M., Strychar, K.B., 2017. *Tubastraea micranthus*, comments on the population genetics of a new invasive coral in the western Atlantic and a possible secondary invasion. J. Exp. Mar. Biol. Ecol. 490, 56–63. https://doi.org/10.1016/j.jembe.2017.02.003.
Schleyer, M.H., Tomalin, B.J., 2000. Damage on South African coral reefs and an assessment of their sustainable diving capacity using a fisheries approach. Bull. Mar. Sci. 67, 1025–1042.
Schuhmacher, H., 1984. Reef-building properties of *Tubastraea micranthus* (Scleractinia, Dendrophylliidae), a coral without zooxanthellae. Mar. Ecol. Prog. Ser. 20, 93–99.
Scott, C.M., Mehrotra, R., Urgell, P., 2014. Spawning observation of *Acanthaster planci* in the Gulf of Thailand. Mar. Biodivers. https://doi.org/10.1007/s12526-014-0300-x.
Scott, C.M., Mehrotra, R., Hein, M.Y., Moerland, M.S., Hoeksema, B.W., 2017a. Population dynamics of corallivores (*Drupella* and *Acanthaster*) on coral reefs of Koh Tao, a diving destination in the Gulf of Thailand. Raffles Bull. Zool. 65, 68–79.
Scott, C.M., Mehrotra, R., Hoeksema, B.W., 2017b. *In-situ* egg deposition by corallivorous snails on mushroom corals at Koh Tao (Gulf of Thailand). J. Molluscan Stud. 83,

360–362. https://doi.org/10.1093/mollus/eyx020.

Scott, C.M., Mehrotra, R., Cabral, M., Arunrugstichai, S., 2017c. Changes in hard coral abundance and composition on Koh Tao, Thailand, 2006–2014. Coast. Ecosyst. 4, 26–38.

Sheehan, E.V., Rees, A., Bridger, D., Williams, T., Hall-Spencer, J.M., 2017. Strandings of NE Atlantic gorgonians. Biol. Conserv. 209, 482–487. https://doi.org/10.1016/j.biocon.2017.03.020.

Stella, J.S., Pratchett, M.S., Hutchings, P.A., Jones, G.P., 2011. Coral-associated invertebrates: diversity, ecology importance and vulnerability to disturbance. Oceanogr. Mar. Biol. Annu. Rev. 49, 43–104. https://doi.org/10.1201/b11009-3.

Suebpala, W., Chuenpagdee, R., Nitithamyong, C., Yeemin, T., 2017. Ecological impacts of fishing gears in Thailand: knowledge and gaps. Asian Fish. Sci. 30, 284–305.

Sutthacheep, M., Yucharoen, M., Klinthong, W., Pengsakun, S., Sangmanee, K., Yeemin, T., 2013. Impacts of the 1998 and 2010 mass coral bleaching events on the Western Gulf of Thailand. Deep-Sea Res. II Top. Stud. Oceanogr. 96, 25–31. https://doi.org/10.1016/j.dsr2.2013.04.018.

Szuster, B.W., Dietrich, J., 2014. Small island tourism development plan implementation: the case of Koh Tao, Thailand. EnvironmentAsia 7, 124–132. https://doi.org/10.14456/ea.2014.31.

Thiel, M., Bravo, M., Hinojosa, I.A., Luna, G., Miranda, L., Núñez, P., Pacheco, A.S., Vásquez, N., 2011. Anthropogenic litter in the SE Pacific: an overview of the problem and possible solutions. J. Integr. Coast. Zone Manag. 11, 115–134. http://www.redalyc.org/html/3883/388340132013.

Thiel, M., Luna-Jorquera, G., Álvarez-Varas, R., Gallardo, C., Hinojosa, I.A., Luna, N., Miranda-Urbina, D., Morales, N., Ory, N., Pacheco, A.S., Portflitt-Toro, M., Zavalaga, C., 2018. Impacts of marine plastic pollution from continental coasts to subtropical gyres – Fish, seabirds, and other vertebrates in the SE Pacific. Front. Mar. Sci. 5, 238. https://doi.org/10.3389/fmars.2018.00238.

Thrush, S.F., Hewitt, J.E., Cummings, V.J., Dayton, P.K., Cryer, M., Turner, S.J., Funnell, G.A., Budd, R.G., Milburn, C.J., Wilkinson, M.R., 1998. Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. Ecol. Appl. 8, 866–879. https://doi.org/10.1890/1051-0761(1998)008[0866:DOTMBH]2.0.CO;2.

Timmers, M.A., Kistner, C.A., Donohue, M.J., 2005. Marine debris of the Northwestern Hawaiian Islands: ghost net identification. Marine Debris Program, NOAA. Grant publication: UNIHI-SEAGRANT-AR-05-01.

Uhlmann, S.S., Broadhurst, M.K., 2015. Mitigating unaccounted fishing mortality from gillnets and traps. Fish Fish. 16, 183–229. https://doi.org/10.1111/faf.12049.

Unger, A., Harrison, N., 2016. Fisheries as a source of marine debris on beaches in the United Kingdom. Mar. Pollut. Bull. 107, 52–58. https://doi.org/10.1016/j.marpolbul.2016.04.024.

Veron, J.E.N., 2000. Corals of the World. 3 Australian Institute of Marine Science, Townsville.

White, K.N., Ohara, T., Fujii, T., Kawamura, I., Mizuyama, M., Montenegro, J., Shikiba, H., Naruse, T., McClelland, T.Y., Denis, V., Reimer, J.D., 2013. Typhoon damage on a shallow mesophotic reef in Okinawa, Japan. PeerJ 1, e151. https://doi.org/10.7717/peerj.151.

Wilcox, C., Hardesty, B.D., Sharples, R., Griffin, D.A., Lawson, T.J., Gunn, R., 2013. Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern Australia. Conserv. Lett. 6, 247–254. https://doi.org/10.1111/conl.12001.

Wilcox, C., Heathcote, G., Goldberg, J., Gunn, R., Peel, D., Hardesty, B.D., 2015. Understanding the sources and effects of abandoned, lost, and discarded fishing gear on marine turtles in northern Australia. Conserv. Biol. 29, 198–206. https://doi.org/10.1111/cobi.12355.

Wongthong, P., Harvey, N., 2014. Integrated coastal management and sustainable tourism: a case study of the reef-based SCUBA dive industry from Thailand. Ocean Coast. Manag. 95, 138–146. https://doi.org/10.1016/j.ocecoaman.2014.04.004.

Yeemin, T., Sutthacheep, M., Pettongma, R., 2006. Coral reef restoration projects in Thailand. Ocean Coast. Manag. 49, 562–575. https://doi.org/10.1016/j.ocecoaman.2006.06.002.

Yeemin, T., Saenghaisuk, C., Sutthacheep, M., Pengsakun, S., Klinthong, W., Saengmanee, K., 2009. Conditions of coral communities in the Gulf of Thailand: a decade after the 1998 severe bleaching event. Galaxea J. Coral Reef Stud. 11, 207–217.

Yeemin, T., Pengsakun, S., Yucharoen, M., Klinthong, W., Sangmanee, K., Sutthacheep, M., 2013. Long-term changes of coral communities under stress from sediment. Deep-Sea Res. II Top. Stud. Oceanogr. 96, 32–40. https://doi.org/10.1016/j.dsr2.2013.04.019.

Yoshikawa, T., Asoh, K., 2004. Entanglement of monofilament fishing lines and coral death. Biol. Conserv. 117, 557–560.