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Case study on net fisheries

in the Gulf of Thailand

Aanchal JAIN and Leander RAES

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1. Introduction

In the beginning of 2000s, plastic production increased more in a single decade than it had in the previous 40 years (UN Environment report, 2018). Today, around 300 million tonnes of plastics is manufactured annually, which is nearly equivalent to the weight of the entire human population (UN Environment report, 2018). Half of all plastic produced is designed to be used only once (Geyer et al, 2017). This means that 50% of all plastic that is produced quickly becomes waste. Out of all this plastic waste only around 9% is currently being recycled and the rest goes either into landfills, is burned, or ends up the natural environment as litter. At some point, the mismanaged plastic ends up into the oceans (National Geographic, 2018). As plastic is known to be durable, it will likely persist in the marine environment for several years, and a part of it breaks up into micro plastics (Bergmann, 2015).

According to several studies, most plastic pollution comes from land-based sources, contributing around 80% of marine plastic, and the remaining 20% comes from ocean-based activities (Hao wu, 2020; Jambeck, 2015). Land-based plastic mainly comes from mismanaged waste (Jambeck et al., 2015; IUCN, 2020), whereas among the ocean-based sources, one of the major activities contributing to plastic pollution is fisheries (Andrady et al, 2012). The fisheries sector generates 50% of all the litter out of all ocean-based activities (Hao wu, 2020) and it adds to marine plastic through discarded, lost, and abandoned fishing gear, and equipment in the oceans and waterways. In additional to this, it is also responsible for overboard throwing of litter from the vessels (Hinojosa, 2011; Lusher, 2017; Nelms, 2017; Cozar, 2014; Melli, 2017).

It is now well documented that plastic waste is negatively impacting our economy and society (Ten Brink et al., 2016). Plastic is present everywhere from shorelines to the high seas (Thompson et al., 2009), the impact of which can be seen on different economic activities including fisheries, tourism, transport, aquaculture, and other ocean-based activities (GESAMP, 2016; Jang, 2014; Thompson et al., 2011, UNEP 2005, McIlgorm 2004). A study by Beaumont et al (2019) has postulated a reduction of 1–5% in marine ecosystem service are a result of the stock of marine plastic in the oceans in 2011. Another study by McIlgorm et al. (2011) estimated that the annual loss caused by marine debris on the marine tourism sector in the Asia Pacific Economic Cooperation (APEC) region at USD 622 million in 2009 (based on the GDP from marine tourism of USD 207 billion and a loss rate of 0.3% due to marine debris). The same study estimated the cost of USD 279 million per annum on the shipping industry in APEC region, stating that plastic comprises of 60-80% of all marine debris. The fisheries sector is adversely impacted by marine plastic waste (Newman, 2013; Ronchi, 2019). The direct economic costs of marine plastic on fisheries arise from damages to gear, such as tangled propellers, dirty nets, obstructions in cooling systems, and the reduction in or contamination of catches, all of which are potential hazards for the fishing crew. Moreover, the sector faces indirect losses in fish stocks due to the impact of lost or abandoned gear (Macfadyen, 2015). A study by Arcadis (2013) estimated the costs to European Union (EU) fisheries in terms of losses and damages has reached approximately EUR 61.7 million (USD 72.6 million; 2013 prices), nearly 0.9% of impact. According to McIlgorm et al (2011), the costs of clean up, loss of fishing gear, and damage to vessels and equipment from marine litter costs the Asia-Pacific Economic Cooperation fisheries sector approximately USD 1.26 billion per year (2009 prices).

The effect of plastic on marine biodiversity is also becoming a major concern, in particular the consequences of ingestion, entanglement, and chemical contamination (Derraik, 2002; Katsanevakis, 2008; Gall and Thompson, 2015; Holmes et al., 2012; Kershaw et al., 2011; Mato et al., 2001; Teuten et al., 2009). By 2050, an estimated 99% of sea birds will have ingested plastic and can become entangled in plastic waste items (Wilcox et al, 2015).

A range of policies, crucial to reducing plastic litter from marine regions, has been implemented mainly including ex-ante and ex-post solutions. Ex-ante solutions include technical and regulatory measures such as eco-design, improved waste management, recycling, bans on single-use plastic, extended producer responsibility, taxes, subsidies, and fishing gear marking; and ex-post measures include beach, river, and ocean clean-ups (UNEP, 2019; Schnell et al., 2017; European Investment Bank, 2021).

The fishing industry, being adversely impacted by plastic debris, can play an important role in addressing the plastic pollution problem as they work in remote coastal waters, where plastic waste is often neglected (Cho, 2009, Cho, 2011). Consequently, several schemes have been devised to engage fishers in ocean protection. One of which, developed by KIMO (Local Authorities International Environmental Organization) in Thailand, is the Fishing for Litter (FFL) scheme which focuses on involving commercial fishers in the removal of ocean litter already present in the marine environment. FFL focuses on collecting marine litter during day-to-day fishing activities whereby fishermen make purposeful trips to collect litter in specific locations and get paid for their efforts (UNEP, 2015; Van Breusegem et al., 2015). Evidence about the tonnage collected and the success of FFL and similar schemes has been well documented (Cho, 2005, Cho, 2009; KIMO, 2014; Van Breusegem et al., 2015).

This issue brief presents the results of a study that estimated the impact of marine macroplastic on the Thai net fisheries operating in the Gulf of Thailand. The study has estimated the reduction in the net fisheries' revenue due to the plastic stock and annual flow into the fishing zone/Thai Exclusive Economic Zone (EEZ) (Gulf of Thailand). This brief has also analysed the benefits of an initiative started in Thailand to reduce the amount of marine plastic in the sea, called 'return garbage to the shore'. Finally, the case study also discusses the impact of marine plastics on natural assets, marine biodiversity, and ecosystems.

2. Study area: The Gulf of Thailand

Thailand is located in Southeast Asia with a population of 69.63 million in 2019 (Worldometers, 2019). Marine fisheries are important both economically and socially for Thailand. Fisheries contributed 0.8% of the total GDP of Thailand i.e. USD 3,560 million in 2018 (FAO, 2019). The total fish production in Thailand supports about 167,597 fishers. Thailand is a major seafood exporter and importer. The country exported 1.5 million tonnes in total, valued at USD 6.3 million and imported 1.9 million tonnes of fish products valued at USD 3,843 million (DOF, 2017).

Thailand has two major fishing grounds, in the Gulf of Thailand and in the Andaman Sea (FAO, 2004). This study focuses on the Gulf of Thailand (see Figure 1). This Gulf has a fishing zone/EEZ of 304,000 km^2 and marine fisheries in this region generate 69.4% of total fish production in the country (SEAFDEC, 2019). In the Gulf, the main types of fish caught are demersal fish, pelagic fish, anchovy, and shrimp mainly with nets and trawling gear (otter trawl, pair trawl, push nets, purse seines, and gillnets) (DOF, 2006; FAO, 2019). In 2019, there were 19,866 registered fishing vessels in net fisheries with an annual production of 0.9 million tonnes (DOF, 2019).

However, the fisheries sector is dealing with several threats, and if not dealt with, these could significantly impact the sector. One of these threats is marine plastic in fishing areas which leads to reduced fish catches, net damage, and fouling (Kulanujaree, 2020). Thailand itself is one of the biggest contributors of marine plastic, ranked 6th among the countries with the highest amount of mismanaged plastics in the world (Jambeck, 2015). According to a hotspot analysis by IUCN (2020) there were 336 thousand tonnes of plastic that leaked into Thai waters in 2018, including waste from the fishing sector (discarding of damaged fishing gear that is thrown overboard). Out of all the plastic waste generated by fishing vessels, 50% is generated by lost fishing nets and the rest is generated from overboard littering (IUCN, 2020).

To overcome the problem of marine plastic pollution, the Department of Fisheries (DOF) of the Ministry of Agriculture and Cooperatives (MOAC) are taking measures (Kulanujaree, 2020). One example is the circular economy initiative by Fondation Jan & Oscar, which aims at encouraging and educating the Moken fishermen to get engaged to collect, sort, and sell plastic waste that come from land and sea in order to earn additional income (IUCN, 2021). In addition, Thailand has recently implemented the aforementioned 'return garbage to shore' program with 1,144 commercial fishermen registered to participate across the whole of Thailand (DOF, 2019). The average yearly litter collection is 674,953 kg, which is mainly composed of plastic bottles and bags (62.9%) and glass bottles (28.21%). All the trash collected from the fishing boats and the sea is brought back and reported to Port-in, Port-out authorities for entry in their central database (DOF, 2019).

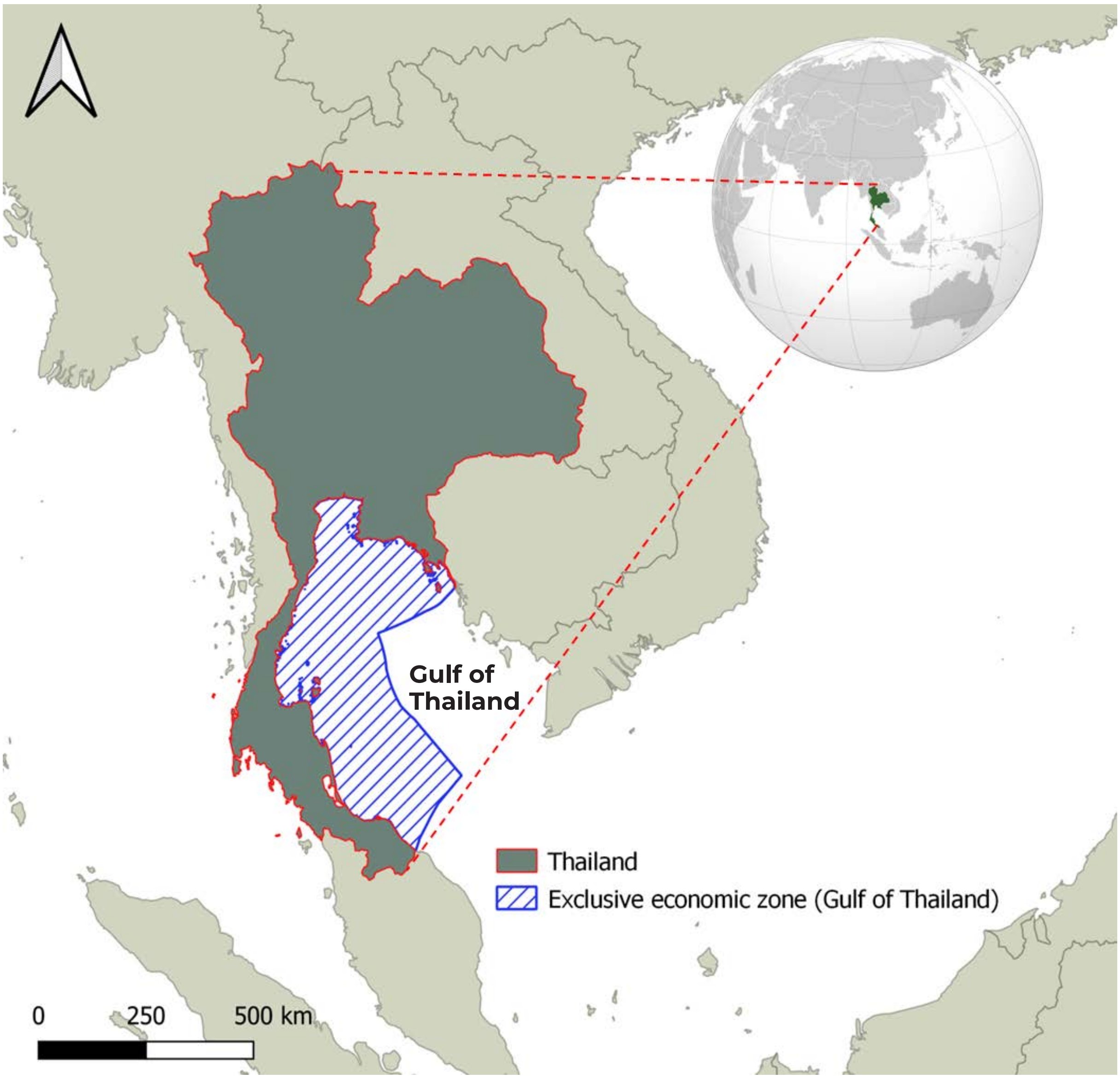

Figure 1: Map of Thailand including the Exclusive Economic Zone of this study.
Sources: Marine Regions and World Bank, 2020

3. Impact of marine plastics on Thai fisheries operating in the Gulf of Thailand

3.1. Gulf of Thailand fisheries overview

In Thailand in 2019, there were 32,529 registered vessels producing an annual catch of 1,542,465 tonnes of fish, valuing Thai Baht 67.3 billion (USD 2 billion) (FAO, 2019; DOF, 2019). According to a report of DOF (2019), the Gulf is responsible for 69.4% of the total marine fish production, it is thus considered that 69.4% of all vessels are operated in the Gulf.

Net fisheries produce 88% of the total fish catch in Thailand, which makes it significant in terms of contribution to overall fisheries revenue (DOF, 2019). As the study focuses on net fisheries, it is considered that 88% of fisheries effort in the Gulf the Thailand is through net fisheries. Estimated data of net fisheries in the EEZ in the Gulf of Thailand is presented in Table 1.

Thai net fisheries had a total production of 942,014 tonnes of catch in the EEZ of 304,000 km² valuing Thai Baht 41 billion (USD 1.2 billion) in 2019.

Table 1: Overview of data from Thai net fisheries in the Gulf of Thailand in 2008 (Source: FAO, 2019; DOF, 2019)

Vessels	Annual catch (tonnes)	Value (in 2019)	Thai EEZ (in the Gulf of Thailand in km²)
19,866	942,014	41,157,270,876	304,000

3.2. Calculating the amount of plastics present in EEZ

Thai fisheries are impacted by the plastic present in the Thai EEZ as it tears up nets, contaminates the fish catch, and leads to vessel fouling incidents. In order to estimate the plastic stock in Thai EEZ, the plastic leakage estimate was taken as per the Thailand national plastic pollution hotspotting report by IUCN (2020). Further, the plastic leakage of the neighbouring countries accounts for the exchange of plastic debris between countries via sea and ocean currents. In order to estimate the plastic waste leakage from neighbouring countries, amounts were based on the study from Lebreton and Andrady (2019). Historical accumulation of plastic since 1950 was accounted for, considering annual degradation into microplastic, using production growth a as proxy, which provides the total amount of plastic stock in Thai waters in 2019 (Ryan et al., 2012; Geyer et al., 2015; Lebreton et al., 2012). The sum of plastic estimated to be in the Thai waters was then further divided into different marine regions (seafloor, coastline, coastal waters, and offshore waters). The plastic stock was allocated to different marine regions using the estimates of UNEP GRID-Arendal (2018). This produced the estimated the amount of the plastic that is accumulated in the zones where fishing takes place. Details of plastic stock allocation in the Thai EEZ can be found in Annex 1.

Based on the calculation, macroplastic stock equivalent to 1,597,154 tonnes is estimated to be present in the fishing ground of the Gulf of Thailand in 2019.

However, more than one study has estimated the distribution of plastic stock. This report has considered UNEP GRID-Arendal (2018) as its baseline study. To compare the results, two alternative scenarios have been considered, alternative scenario 1 is based on distribution estimates by Boucher and Billard (2020) and alternative scenario 2 is based on Lebreton et al (2019). Detailed calculations of alternative scenario 1 and alternative scenario 2 can be found in Annex 1.

3.3. Methodology

The impact of macroplastics on the fisheries of Thailand operating in the Gulf of Thailand was estimated with the help of what is referred to as 'value transfer method'. Value transfer method (VTM) is often used in the impact analysis (Johnston et al. 2018, Nelson and Kennedy 2009, Johnston and Rosenberger 2010). VTM is applied by assigning existing economic estimates of a current study/region/ecosystem for a similar problem elsewhere (UNEP, 2019). Following Arcadis (2013) and Trucost, (2014), who estimated the impact of marine plastics on EU and global fisheries, respectively, this study will apply VTM based on the results from Mouat et al. (2010).

Mouat et al (2010) conducted a study through a survey on Scottish fisheries to investigate the extent by which this sector is impacted by marine litter, concluding that 5% of marine litter has impacted Scottish fisheries in 2008. Globally, out of all marine litter, 80% is on average composed of plastics (Dunlop et al., 2020). It can be inferred that the impact of marine plastics on net fisheries was 4%. The impact of 4% is broken down into four costs categories: dumped catch, net repairs, fouling incidents, and time lost clearing nets (Mouat et al., 2010).

Moaut et al (2010) impact estimates were transferred to the Thai fisheries system. However, Scottish and Thai fisheries are quite different in terms of fishing vessels, fishing area, fish catch, and the amount of plastic that is present in each of the fishing zones. Before transferring the estimated value from Scottish to Thai fisheries, this study adjusted for size of fisheries (which includes amount of fish catch, number of vessels and area of EEZ, as these variables are different in both countries). The detailed methodology which presents the adjustment of fisheries size and impact estimation is found in Annex 2. There are many more variables that decide fisheries size. The impact size is also a function of attributes, such as size of fishnets used, time spent on sea by each vessel, zone with plastic accumulation, etc. The data on all these variables were not available, thus, not included in the current study.

The input used to translate the impact from Scottish to Thai fisheries is found in Annex 3.

4. Results

4.1. Impact of the total plastic stock on Thai fisheries operating in the Gulf of Thailand (2019)

Following the methodology (Annex 2), **there was an estimated impact of 1.88% on net fisheries value in Thailand operating in the Gulf of Thailand** in 2019 due to the presence of 1,597,154 tonnes of macroplastics stock in Thai EEZ (plastic flow and stock report of IUCN, 2020). Fishing gear and vessels experience various impacts due to marine plastics as these get caught in nets and contaminate the fish catch; it damages the vessels by fouling incidents, etc.

As shown in Table 2, the impact of 1.88% impact of plastic debris on fisheries damage can be broken down by category.

Considering the revenue generated by the fishing sector, **marine plastics pollution generated revenue losses of approximately Thai Baht 772 million** (based on a **total value of Thai fisheries** at USD 23 million)[1] in the Gulf of Thailand in 2019.

Table 2: The impact breakdown by category of plastic leakage on fisheries operating in the Gulf of Thailand.

Impact category	Impact %
Dumped catch	0.23%
Net repairs	0.39%
Fouling incidents	0.02%
Time lost clearing net	1.24%
Total impact	**1.88%**

4.2. Ghost fishing

The fisheries sector also contributes to marine plastic through discarded, lost, abandoned fishing gear and equipment, which in return impacts the global fishing industry (Lusher, 2017). Fish get caught up in lost fishing gear which leads to increased fish mortality, reduced fish catch, and reduced revenue (Warden & Murray, 2011). In net fisheries, the ghost fishing mortality rate was estimated at 1% of the total fish catch. Considering this study, **Thai fisheries have lost Thai Baht 423 million (USD 12.5 million) in 2019 due to derelict fishing gears.**

According to the estimates, Thai fisheries have lost Thai Baht 772 million (USD 23 million) from macroplastics and Thai Baht 411 million (USD 12.5 million) from ghost fishing. **Thai fisheries have incurred an estimated loss of Thai Baht 1.183 billion (USD 53 million) due to marine plastics and ghost fishing in 2019. In long term this could result in reduced wages and income and eventually can affect livelihoods. Given that currently 167,597 fishers are directly working in fishing industry of Thailand (in the Gulf of Thailand), they could end up losing their jobs.**

1 Average exchange rate from Baht to USD in 2019: 0.03 USD.

4.3. Alternative scenarios

The impact of marine plastic pollution on fisheries will change according to the amount of plastics present in the Thai EEZ. Change in impact percentage is estimated following plastics stock estimates according to alternative scenario 1 and alternative scenario 2. A cost of 2.79% has been incurred on the total fisheries revenue due to the presence of macro plastics in the Thai EEZ (see Table 3, alternative scenario 1). Thus, macroplastics leakage can be calculated at a cost of Thai Baht 1.4 billion (USD 34 million) to Thai fisheries in 2019. Whereas, alternative scenario 2, assumes an impact of 0.6% upon total fisheries revenue due to marine plastics leakage in Thai EEZ (Table 3, alternative scenario 2). Plastic leakage generated damages of Thai Baht 246 million (USD 7.3 million) to Thai fisheries in 2019. The results are sensitive to the amount of plastic and where it is found.

Table 3: Alternative scenarios: the impact of pollution in the marine environment on fisheries revenue, based on different plastic stock estimates.

Impact category	Baseline Scenario	Alternative scenario 1	Alternative scenario 2
Dumped catch	0.23%	0.3%	0.1%
Net repairs	0.39%	0.6%	0.1%
Fouling	0.02%	0.03%	0.01%
Time lost clearing nets	1.24%	2%	0.4%
Total impact	1.88%	2.79%	0.60%

Based on distribution estimates in % from GRID-Arendal, 2018 (baseline study); Boucher and Billard, 2020 (Alternative scenario 1); Lebreton et al, 2019 (Alternative scenario 2).

4.4. Impact of plastic leakage on Thai fisheries operating in the Gulf of Thailand (2019)

Significantly, this study shows that plastic accumulated in the Thai EEZ has cost the fisheries sector Thai Baht 772,705,291 (USD 23 million). Based on this figure, every tonne of plastic that leaks into the ocean represents a cost of Thai Baht 483 (USD 14) (Table 4). In the Gulf of Thailand, the annual leakage of plastic in 2019 was 111,861 tonnes. Given the leakage of 111,861 tonnes of plastics that was added to the existing stock in 2019, this additional leakage was valued at a negative impact of Thai Baht 54 million (USD 1.6 million) (Table 4), showing that the annual leakage generated has an impact of 0.13% on fisheries revenue.

Table 4: Cost of annual plastic leakage on Thai fisheries operating in the Gulf of Thailand

Impact of plastics stock on Thai fisheries (1.88%)	Thai Baht 772,705,291
Amount of macro plastics stock accumulated in Thai EEZ by 2019	1,597,154 tonnes
Cost of one tonne of plastics	Thai Baht 483
Annual plastics leakage impacting fisheries 2019 (from Thailand + other countries in semi-closed system)	111,861 tonnes
Cost of annual plastics leakage of 2019 (from Thailand + other countries in semi-closed system)	Thai Baht 54,118,387

4.5. Indirect economic impact

When fisheries production is impacted, it is not only the fishermen who suffer the loss, but also the supporting industries, such as fish processing, shipbuilding, canning, freezing, and fish meal factories. About 515,000 people are employed in supporting industries, most of whom are women (DOF, 2015-2019) in more than 345 fish processing factories (FAO 2019) in Thailand.

Thailand, as a major seafood producer and exporter, gains a revenue of Thai Baht 196 billion (USD 6.32 billion) per year due to the export of its fish and fisheries products (SEAFDEC, 2019). Of the total export value, shrimp products and canned tuna contributed 36% and 27%, respectively (FAO, 2019). In addition to the export market, there is a large domestic market for fisheries products within Thailand. Euromonitor International reports that the amount of fresh fishery products being sold in the retail market and food service sectors grew by 25%, from 1.6 million tonnes in 2013 to 2.2 million tonnes in 2017. Reduction in fish catch therefore has significant impact on national and domestic employment, livelihood and revenue in the supporting industries.

4.6. Impact on human health

i. Food security: fish and fishery products constitute a major part of the Thai diet, supplying 35% of their protein intake, 6% of calcium, 11% of iron, and 4% of zinc intake (Sampantamit, 2021). The current Thai average intake is 32g a day. More than 2,500 villages of artisanal fishing communities along the coasts are dependent on fish production for their food security (DOF, 2019). Reduction in fish production would eventually impact the communities who consume fish as their main food source (Garcia, 2010)

ii. Plastic ingestion by humans: plastic ingested by marine species can be transferred to humans through the food chain. Nanoparticles of plastics could potentially affect the central nervous system and the reproductive system if absorbed in high quantities (Campanale et al, 2020). A quantitative study on the impact of marine plastic on human health in Thailand has yet to be conducted. However, there are studies that well stated that the consumption of contaminated seafood can damage brain cells, given the dependence of Thai communities on the fish production for their food security can eventually transfer the plastic sediments into the human system (Landrigan et al., 2020).

5. Broader impacts of marine plastic pollution

5.1. Marine ecosystems

Beyond the direct impact on fish stocks, there are a number of challenges that could lead to serious impact on the future of fisheries and marine natural assets. These include the degradation of fisheries habitat, namely; coral reefs, seagrass beds and mangroves. There are a number of studies showing negative impacts and reduced health of fisheries habitats due the presence of macro and microplastics. Marine plastic gets trapped in low circulation biotas, deteriorating their health and blocking the sunlight which stimulates their growth (Kirstein et al., 2016, Galgani et al. 1996; Schlining et al. 2013; Pham et al. 2014; Dameron et al. 2007; Kühn et al. 2015, Uhrin and Schellinger 2011; Viehman et al. 2011, Uhrin et al. 2005).

The Gulf of Thailand has 121 km² of coral reef area, 693 km² mangroves area and 96 km² seagrass beds (Figure 2) (Department of Marine and Coastal Resources, 2016a). These habitats act as a barrier against natural calamities, assure food security by protecting the fish species, and attract tourists to local communities. Hence, the coastal ecosystems provide value for both Thai fisherfolk and residents (Spaldin et al., 2017, Lange et al., 2019). According to a study by the United Nations Environment Programme (UNEP), the value of mangroves has been estimated at USD 3.5 million per km² per year. Another study in Trang Province, estimated the direct use value generated by seagrass beds to be USD 1.2 million/ per year (?) for fisheries.

Marine ecosystem in Thailand is important for a variety of reasons. These important fisheries habitats contribute to assuring food security, sequestration and storage of carbon, shoreline protection against storms, as well as attracting tourism. These habitats are being degraded and lost at an alarming rate. One of the causes contributing to degradation in habitat quality is attributed marine plastic pollution. In just one decade, the damage to coral reefs has increased from 30% to 77% (Thamrongnawasawat, 2018). By 2030, 99% of coral reefs in Southeast Asia are predicted to be under threat, with the vast majority at high (over 80%), very high, or critical levels (Burke, Reytar, Spalding and Perry, 2012). In the last 30 years, approximately 80–90% of mangrove forests along the Gulf of Thailand have disappeared (Thampanya *et al*., 2006).

5.2. Marine wildlife

Marine plastics are also a danger to marine mega fauna and bird species, such as sea turtles, and cetaceans. These species ingest or are entangled in marine debris, which causes severe injuries and death**. Evidence of** plastic litter has been found in the stomach contents of a variety of marine mammals and bird species.3 Plastic accumulates in animals over time, causing long-term suffering before death (UNEP, 2015). About half marine mammals, all species of marine turtles, and one-fifth of sea bird species are affected by entanglement or ingestion of marine debris. About 15% of species affected by entanglement and ingestion are categorised as vulnerable or endangered according to the IUCN Red List (GEF, 2012). Table 5 provides an overview of vulnerable and endangered marine turtles and marine mammals in the Gulf of Thailand. Figure 3 illustrates the presence of turtles, dolphins and whales in the Gulf of Thailand.

Table 5: IUCN Red List status sea turtles and marine mammals in the Gulf of Thailand. Source: IUCN Red List of Threatened Species, 2020

Sea turtles		
Green Turtle	*Chelonia mydas*	Endangered
Hawksbill Turtle	*Eretmochelys imbricate*	Critically endangered
Marine mammals		
Irrawaddy dolphin	*Orcaella brevirostris*	Endangered
Indo-pacific Humpback dolphins	*Sousa chinensis*	Vulnerable
Indo-pacific Finless porpoises	*Neophocaena phocaenoides*	Vulnerable
Fin whale	*Balaenoptera physalus*	Vulnerable
Dugong	*Dugong dugon*	Vulnerable

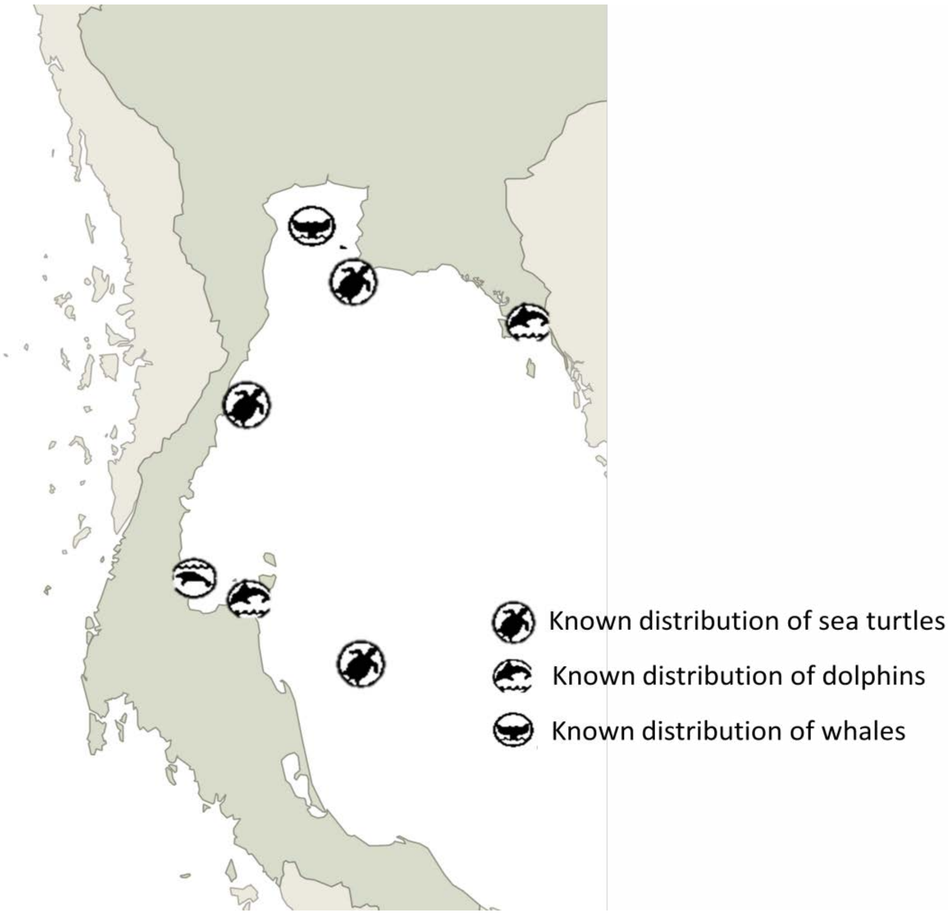

Figure 3: The known distribution of marine species (sea turtles, whales, and dolphins), Gulf of Thailand. Source: DMCR, 2015.

5.3. Marine protected areas (MPAs)

Marine protected area (MPAs) protects marine biodiversity and ecosystem. MPAs are also subject to the impacts of marine pollution. Most MPAs in the Gulf of Thailand region (UNEP-WCMC & IUCN, 2020) are located in near shore areas (Figure 4), and provide protection to 29.51% of the identified marine-turtle nesting sites, 8.36% of the sea-grass ecosystems and 34.9% of the coral-reef ecosystems (Wang, 2020). The area coverage of MPAs for the Gulf of Thailand was estimated as 5,509 km² using the geodatabase of Thailand[2]. Of the total number of MPAs in Thailand, 4,339 km² are classified as less protected and the remaining 1,170 km² as highly protected. Based on previous studies by Reddy (2018) the presence of plastic in these areas poses a significant threat to the health of these protected resources. The estimated amount of plastic present in this region is presented in Table 6.

Table 6: Tonnes of plastic in Marine protected area in the Gulf of Thailand
(a) Plastic estimates from baseline scenario

Marine regions	Plastics in highly protected MPAs (in tonnes)	Plastics in less protected MPAs (in tonnes)	Total amount of plastics present in MPAs (in tonnes)
Sea surface	69	255	324
Coastline and seafloor	6,466	23,966	30,432
Coastal waters	6,081	22,538	28,619
Total	12,615	46,760	59,375

*(Based on distribution estimates in % from GRID-Arendal, 2018 (baseline study); Boucher and Billard, 2020 (Alternative 1); Lebreton et al, 2019 (Alternative 2)

(b) Plastic estimates from alternative scenario 1

Marine regions	Plastics in highly protected MPAs (in tonnes)	Plastics in less protected MPAs (in tonnes)	Total amount of plastics present in MPAs (in tonnes)
Seafloor	12,489	46,292	58,781
Shoreline	50	187	238
Marine organism[3]	13	47	59
Sea surface	25	94	119
Water column	13	47	

(c) Plastic estimates from alternative scenario 2

Marine regions	Plastics in highly protected MPAs (in tonnes)	Plastics in less protected MPAs (in tonnes)	Total amount of plastics present in MPAs (in tonnes)
Shoreline	12,441	46,115	58,556
Coastal water (less than 200m)	23	84	107
Offshore (more than 200m)	151	561	713

2 https://www.protectedplanet.net/country/THA

3 This is an estimation based on the plastic allocation by Boucher and Billard, 2020.

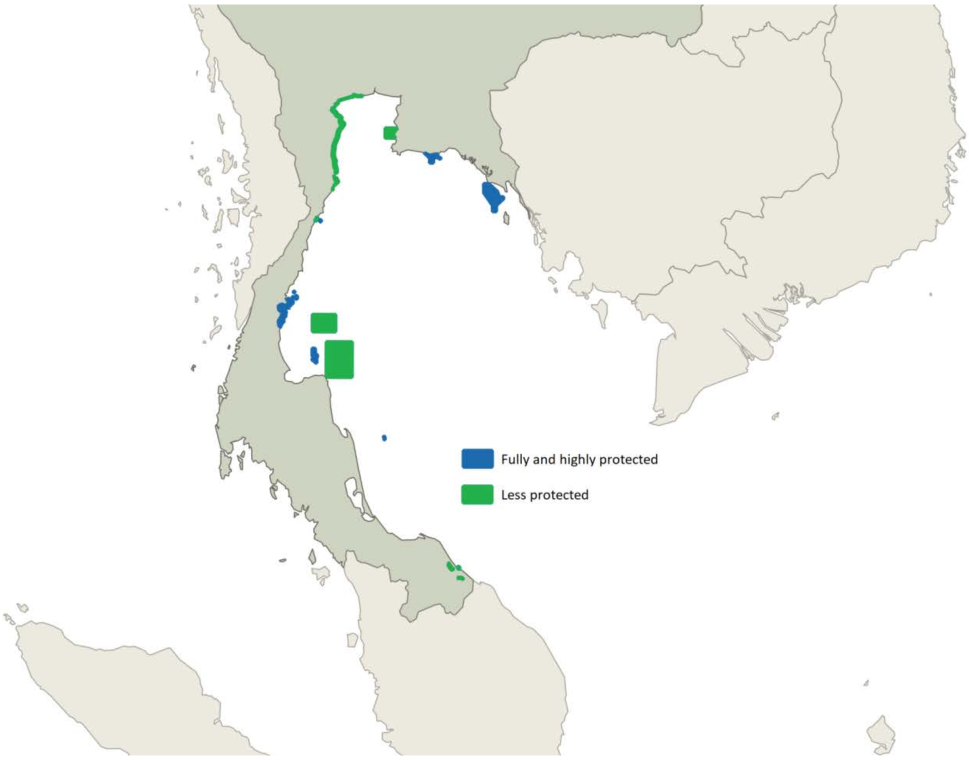

Figure 4: Marine protected areas in the Gulf of Thailand, Source: Protected planet, 2021; MPAtlas, 2021

5.4. Overfishing

Fish mortality has increased due to plastic pollution (FAO, 2017), but there are other factors contributing to reductions in fish stocks, such as overfishing. Overfishing can have an impact on the reproduction rate of fish by extracting the mature, fecund fish population and leaving behind less mature fish which negatively impact the capacity of reproduction of fish.

Fishing down the food chain has fundamentally altered the trophic function of ecosystems, especially in the Gulf of Thailand (Pauly & Chuenpagdee, 2003). In the Gulf of Thailand, the catch per unit effort (CPUE) has decreased by as much as 9% compared to the catch in 1961 (Lange et al. 2019). Fishing activities have exceeded the maximum sustainable yield (MSY) by 27% to 33% for demersal and pelagic fish species (Department of Fisheries Thailand, 2015).

5.5. Illegal fishing

Cases of illegal fishing in Thailand have caused negative impacts to marine resources and the environment (FAO, 2021). In this regard, the European Union announced in 2015 that Thailand was in breach of illegal, unreported, and unregulated (IUU) fishing regulations. Along these lines, the total fishery production of Thailand has decreased about 39% in the last 10 years because of substandard fishing equipment , overfishing and illegal fishing.

These faulty fishing practices are negatively affecting Thai food security (Kroodsma et al. 2018). Thailand has received a yellow card which obliges Thailand to take measures against illegal fishing. As a result, since 2015, illegal fishing has significantly decreased which resulted in increase in fish production by registered vessels and thus increase in the fishing trade (Wongrak et al. 2021).

5.6. Climate change and ocean warming

Fisheries are also vulnerable to climate change. Around 93% of all heat generated in the atmosphere is absorbed by the ocean and leads to warming and disturbing fish growth patterns. Changing precipitation, temperature, climatic patterns, and the melting of snow and ice affect the quantity, quality, and seasonality of water resources. That is to say, climate change has contributed to significant changes in the productivity of aquatic ecosystems. According to a report by the FAO, 2018, the value of Thai fisheries (in the Gulf of Thailand) will be reduced by 26.08% by 2050 if no mitigation efforts are introduced.

5.7. Marine transport

About 80% of internationally traded goods are transported by ships (UNCTAD, 2019). Marine transport often results in collisions with marine fauna (Jägerbrand et al., 2019; Pirotta et al., 2019),chemical pollution of water from fuel spills, waste dumping, and exhaust (Lachmuth et al., 2011; Endres et al., 2018; Arzaghi et al., 2020; Czermański et al., 2020), further degrading conditions for aquatic lifeforms. It also creates noise pollution which causes stress, loss of hearing and behavioural changes in marine species, thus, impacting their health (Wysocki et al., 2006; Badino et al., 2016). Of the four major ports along the Thai coast, three are located in the Gulf. The Gulf ports handled more than 100 million tonnes of cargo (World Bank, 2006). Marine transport generates negative impacts on the marine environment and health of marine fauna (Walker et al., 2018).

5.8. Ocean deoxygenation

Deoxygenation affects fisheries in two ways: impacts on fish populations which in turn, affect catch, and fisherman's behaviour. That is to say, vessel dynamics change, as fishermen alter fishing locations and put pressure on new fishing grounds (IUCN, 2019). There are few studies about the impact of ocean deoxygenation on Thai fisheries. Considering that a significant part of energy resources comes from fossil fuels (around 21%) in Thailand (Ministry of Energy of Thailand, 2019), the impact of nitrogen levels (deoxygenation) merits further research. Moreover, research in the Gulf of Thailand, shows that eutrophication has contributed to mass mortality in nearby shrimp and shellfish farms (Cheevaporn et al., 2003).

5.9. Other types of pollution

The Gulf of Thailand is polluted not just by plastic waste, but other types of pollution, such as untreated municipal and industrial waste water, trace metals contamination, petroleum hydrocarbons, untreated waste and sewage water nitrogen. Around 70% of domestic waste was discharged in the Gulf of Thailand without any prior treatment (Cheevaporn et al., 2003). Few studies from 1994 have reported a significant level of mercury, lead, cadmium and zinc in the water of the Gulf of Thailand (Cheevaporn et al.,1994). According to the Pollution Control Department, from 1973 to 2004, there were 162 oil spills accidents resulting in a total of 150 2,100 tonnes of oil ending up in the Gulf of Thailand (World Bank, 2006). While few records are maintained on the impacts of oil and chemical spills and their long-term environmental effects, immediate impacts include the killing of marine species and pollution of nearby coastal areas and beaches (UEPA, 1999).

5.10. Depletion of natural capital assets

Marine natural capital is the stock of marine natural assets which is the source of a wide range of marine ecosystem 'goods and services' and enable humans to live and exploit the natural world (Buonocore et al., 2020). Marine natural assets (including marine sediment carbon, coral reefs, cold corals, seagrasses, mangroves, saltmarshes, tidal flats, seamounts, cold seeps, and hydrothermal vents) support livelihoods and drive economic growth in Thailand. Along these lines, the total economic value of coastal and marine resources in Thailand was estimated at USD 27.67 billion for 2016 (UNESCAP, 2017). However, rapid economic development has often led to unsustainable exploitation of these natural resources. Marine-based natural capital is subject to considerable stress due to various human activities and pollution generated from these activities (Buonocore et al., 2020). Figure 5 below shows areas where there is 'high stress' on natural capital due to human activities (also known as hotspots). Some regions have more than one hotspot which means that there is an even higher level of stress; and related resources are at a higher risk of depletion. Table 7 represents the number of hotspots and the percentage of surface area affected. Given that many activities (such as import, export, tourism, fisheries, etc) are dependent on the integrity of these assets, there is a dire need to protect these resources.

Table 7: Gulf of Thailand hotspots showing surface area of natural capital depletion

Number of hotspots	Percentage of surface area
1 hotspot	69%
2 hotspots	9%
3 hotspots	12%
4 hotspots	9%
5 hotspots	1%

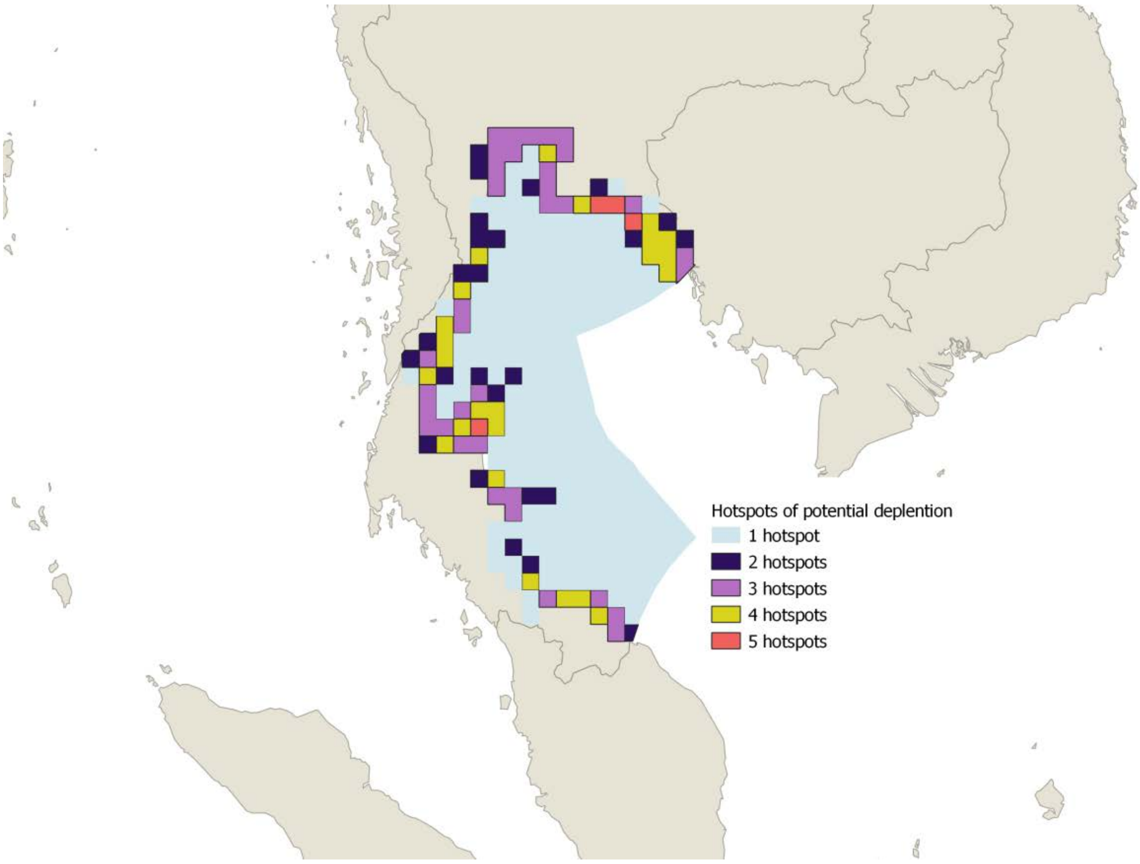

Figure 5: Number of hotspots of potential depletion of natural capital assets where there is high human pressure. Source: WCMW, 2021

5.11. Impact on Tourism

Other than fisheries, another economic sector highly impacted by plastic litter is tourism (Watkins et al., 2017). Tourism contributes 9%-10% of the Thai GDP and 6.3% of total employment. The economic value of tourism is forecast to rise to 14% of total GDP in 2026 (World Travel and Tourism Council, 2016). The presence of litter on Thai beaches reduces its aesthetic value and could adversely affect the popularity, and this phenomenon has been well documented in studies conducted in other countries. For instance, a study conducted by Krelling et al. (2017) estimated that 21% to 83% tourists would not be willing to visit Brazilian beaches with a considerable amount of litter. Another study by Ballance et al. (2000) observed that, on average, 91% of tourists won't be willing to go to a litter filled beach in Cape Town, particularly where 96% of all debris is plastic.

Litter on beaches is generated due to many factors, such as direct dumping, poor waste management practices, and tourism contributes as well. Tourists are one of the main sources of coastal and marine litter (Ordóñez et al., 2019). It was noted in another study in Brazil at Cassino beach that tourism creates a major part of beach litter. The amount of litter generated by each tourist depends on different socio economic character of each beach user, including gender, education, income, and other factors. (Santos et al., 2005). In Chile, around half of the tourists who participated in a survey admitted to having littered the beaches (Eastman et al., 2013).

Tourism is impacted by marine plastic, but even more they get indirectly impacted by degraded marine biota. In the tourism sector, reef-adjacent values were set as a fixed proportion of 9% of the total tourism expenditure (Spaldin et al., 2017). Another study in Trang Province, Thailand, estimated the direct use value generated by seagrass beds to be USD 5 million for tourism. Degradation of marine biodiversity will lead to losses in tourism sector.

6. Reducing plastic leakage and its impact: case study of 'Return garbage to the shore initiative'

There was an initiative launched by the Thailand Department of Fisheries in 2019 to engage fishing vessels to collect plastic litter from the sea and fishing activities, and bring this litter back to shore. The government utilized 22 Port-in Port-out centres (PIPO) previously established in the Gulf of Thailand (Figure 6) to help monitor the "return garbage to the shore" program. At the time of this research, there were 842 commercial vessels involved in the fishing for litter activities in the Gulf of Thailand. Data collected from this research shows that 75% of this plastic waste was generated from their own fishing activities and the remaining 25% was picked up from the sea. In one year 2019-2020, 74 tonnes of marine waste were collected during fishing activities in the Gulf of Thailand, out of which 18 tonnes were collected directly from the sea (25%) and 56 tonnes generated by the vessels (75%).

Moreover, according the data, 63% of it was composed of plastic waste this means that currently 47 tonnes of total plastics waste is collected from the Gulf of Thailand by 842 vessels.

This initiative will provide two direct economic benefits. First, this initiative will reduce the amount of stock in the fishing zone. This means that there are fewer plastics in the Thai EEZ to impact fishnets, catch and vessels and hence the cost of dumped catch, net repairs and fouling will reduce. Reduction in plastic will reduce the impact on fisheries revenue.

Secondly, there would be revenue generated from the plastics collected when sold. This will further help fishermen to increase their profits. Recycling units, plastic product manufacturing units are always interested in finding a good deal to buy plastic waste. Also, the Thai government can incentivise this initiative by fixing an amount that will be paid for every tonne of plastic brought back to the shore. This will motivate the fishers and help to generate some revenue.

Table 8: Scenario A: Business-as-usual scenarios (BAU) of return garbage to shore initiative

Plastics leakage in 2019 (in tonnes)	111,8613
Cost of plastics leakage in 2019 (Thai Bahts)	54,118,387
Number of vessels participating in the initiative	842
Amount of plastics brought back to the shore (in tonnes)	47
Cost of plastics leakage (after collecting 47 tonnes of plastics) (Thai Bahts)	54,095,648
Avoided cost (Thai Bahts)	22,739

Figure 6: Maps of Port-in Port-out centres in the Gulf of Thailand. Source: Kulanujaree et al, 2020

In 2019, there were 6,760 commercial vessels operating in the Gulf of Thailand in 2019. Currently, only 842 commercial vessels are participating in the initiative (12% of all commercial vessels). The avoided costs[4] to the fishing industry due to current efforts of this initiative is shown in Table 8.

If the number of participating vessels increase and bring more plastic back to the shore, this will result in less plastic accumulation in the sea. This will further increase the avoided cost. To capture this positive impact, three alternative scenarios have been introduced to see how much cost will decrease if more vessels are participating in the initiative (assuming that all the vessels will collect plastics based on the current average collection rates). The results from the alternative scenarios are represented in Tables 9 and 10.

(i) Scenario B: if 30% of all vessels will participate

(ii) Scenario C: if 60% of all vessels will participate

(iii) Scenario D: if 100% of all vessels will participate

4 Avoided cost is the cost that the fisheries industry could incur in the absence of a policy/initiative.

Table 9: Number of vessels participating and plastic collected in each of the four scenarios

	Scenario A: BAU	Scenario B	Scenario C	Scenario D
Number of commercial vessels	842	2,028	4,056	6,760
Number of artisanal vessels	0	3,932	7,864	13,106
Plastics collection by commercial vessels (in tonnes)	47	114	227	378
Plastics collection by artisanal vessels (in tonnes)	0	16	32	53
Total number of vessels	842	5,960	11,920	19,866
Total amount of plastics collection (in tonnes)	47	129	259	431

Based on the available data, the current plastics collection efforts are relatively low in order to avoid the impact from marine plastics. Even with the 100% involvement from all the fishing vessels, with current efforts, only 0.4% of impact will be reduced (out of 1.88% of total impact on fisheries). Fishers, however, can gain additional benefits by selling the amount of plastics they collect to the government or recycling units. The impact of marine plastics on fisheries can further decrease if the vessels which are participating increase their plastics collection efforts.

Table 10: Impact reduction in each of the four scenarios

Scenarios	Scenario A BAU	Scenario B	Scenario C	Scenario D
Plastics leakage in 2019 (in tonnes)	111,861	111,861	111,861	111,861
Cost of plastics leakage in 2019 (Thai Bahts)	54,118,387	54,118,387	54,118,387	54,118,387
Total number of vessels	842	5,960	11,920	19,866
Amount of plastics brought back to the shore (in tonnes)	47	129	259	431
Cost of plastics leakage (after plastics collection) (Thai Bahts)	54,095,648	54,055,777	53,993,167	53,909,879
Avoided cost (Thai Bahts)	22,739	62,610	125,220	208,508
Impact reduction %	0.04%	0.10%	0.20%	0.40%

To conclude, with 842 vessels deployed in the Gulf of Thailand, around 47 tonnes of plastic is coming back to the shore. There was an impact of 1.88% of fisheries revenue i.e. Thai Baht 772 million (USD 23 million). With the implementation of Return to garbage' initiative, this impact will reduce by 0.04% and will help to avoid a cost of Thai Baht 22,739 (Out of a total cost of Thai Baht 772 million). If 100% of fishing vessel will engage in the program, the impact of marine plastics on fisheries revenue will decrease by 0.4%, i.e. the avoided cost will increase to Thai Baht 208,508.

7. Summary and final remarks

Marine plastics affect Thai fisheries directly through damage to ships, plastic in fishnets, and the impact of lost fishing gear. Plastics present in the sea not only negatively affect the economy, but also impact individual households' livelihoods and food security, especially in coastal communities.

As for the direct impacts, Thailand's net fisheries are responsible for 88% of marine capture, and incur an estimated loss of 1.88% on the fisheries revenue. Considering the revenue generated by the fishing sector, marine macroplastics pollution are responsible for revenue losses to Thai fisheries of Thai Baht 772 million (USD 23 million) to Thai fisheries (operating in the Gulf of Thailand) in 2019 due to the presence of 1,597,154 tonnes of macroplastics stock in Thai EEZ. Out of 1,597,154 tonnes of macroplastics stock, 111,861 tonnes were added to the Gulf of Thailand in 2019. Based on 2019 figures, it is estimated that plastic leakage contributed to a 0.13% of impact on Thai fisheries.

Fisheries revenue was further impacted by ghost fishing with a loss of Thai Baht 411 million (USD 12.5 million). Thai fisheries have incurred a summed loss of Thai Baht 1.8 billion (USD 35 million). The industry also suffered further loss from overfishing and illegal fishing and the impacts of climate change (Hussein et al., 2020; UNCTAD, 2017).

Marine plastic affects the fishing industry indirectly by damaging and reducing the value of fish habitats, such as coral reefs, mangroves, and seagrass. In recent decades, the survival of these habitats has become a huge concern. These habitats have a great importance and value not only because they protect fish and the fishing industry, but also help other sectors to prosper and protect against other types of human pollution. Marine plastic results in further losses to the tourism sector due to decreased willingness to visit tourists in the presence of marine plastic and increased costs of beach clean-ups to avoid these losses (Galgani et al., 2019). Thus, reducing ocean plastic leakage is an important factor restoring balance to marine ecosystems.

Thai commercial fishery operators started collecting plastic waste from the vessels and at sea to reduce the impacts of plastic litter. The continued deployment of fishing vessels to collect plastic will indeed help reduce waste flows. However, to significantly reduce marine plastic stocks new policies will have to be enacted. More focus is needed on land-based activities that contribute to marine plastic flows. Better waste management infrastructure, and the introduction of circular economy initiatives (i.e. increase in available recycling facilities, Extended Producer Responsibility (EPR), and efforts to reduce ghost fishing) are needed to regulate industries (which produce plastic products) alongside 'return to garbage' initiatives to reduce plastic pollution. The improved management of plastic waste and the reduction of plastics in the marine environment should be an integral part of any strategy that attempts to strengthen the economic sectors that depend on the marine environment.

Currently, there are about 172,430 Thai people from coastal communities employed in supporting industries. It is suggested that small scale projects be designed to increase the involvement of local communities. These efforts can increase the participation of local stakeholders to co-manage marine resources and decentralize decision making power. Thailand has already introduced measures through the Fisheries Act B.E. 2558 (2015) which include registration of fishing vessels, licensing of fishing vessels, licensing of some types of fishing gear, and freezing the number of trawlers, anchovy purse seiners, and anchovy lift nets. There is also a ban on the use of push nets. Other than these regulations, they have taken measures to reduce the efficacy of fishing nets to reduce/limit fish catches (DOF, 2015-2019). The participation of the local community is very important in order to ensure that these regulations are agreed upon and followed.

It should be noted that this study only examines official fisheries, not illegal, unreported, and unregulated fishing. This may have a bigger impact on fish stock depletion; and a higher plastic leakage level (including ghost fishing and illegal fishing gear). Moreover, an estimated 64,000 tonnes of gear is thrown into the ocean annually by vessel operators who fear getting caught fishing illegally by regulatory authorities (FAO, 2021). Global losses from illegal fishing cost up to USD 36.4 billion each year due to the over extraction of the fish population (World resource institute, 2014).

Lastly, the current estimates were calculated using the Value Transfer Method (VTM) combined with data from secondary sources. In order to get more exact estimates, it is recommended to collect data directly with fishermen and the Thai fishery institutions on the amount of fish catch, vessel impacts, and related factors.

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Annex

1.A. Estimation of tonnes of plastics in Thai EEZ on the basis of baseline scenario

Marine regions	Plastics (in tonnes)
Sea surface	17,895
Coastline and seafloor	1,679,289
Coastal waters	1,579,259

Based on baseline study UNEP GRID-Arendal, 2018

The table represents the estimated amount of macroplastics present in different marine region of Thailand, according to the estimates by UNEP GRID-Arendal, 2018, which is the baseline study for this report. The sum of plastics present on sea surface and coastal waters is considered for the impact analysis, which is represented as below:

Total amount of plastics impacting fisheries (in tonnes)
1,597,154

1.B. Estimation of tonnes of plastics in Thai EEZ on the basis of Alternative scenario 1

Marine regions	plastics (in tonnes)
Seafloor	3,543,293
Shoreline	19,932
Marine organism	3,579
Sea surface	7,158
Water column	3,579

Based on Alternative scenario 1 (plastic distribution estimates presented by Boucher and Billard, 2020)

Alternative scenario 1: Total amount of plastics impacting fisheries (in tonnes)
10,737

1.C. Estimation of tonnes of plastics in Thai EEZ on the basis of Alternative scenario 2

Marine regions	plastics (in tonnes)
Shoreline	4,914,288
Coastal water (less than 200m)	10,607

Based on Alternative scenario 2 (plastic distribution estimates presented by Lebreton et al., 2019)

Alternative scenario 2: Total amount of plastics impacting fisheries (in tonnes)
10,607

2. Methodology for Impact analysis

The problem is solved using value transfer and the direct rule of three. The 'direct rule of three' helps solving the problems based on proportionality. It states

$$\text{If, } A \rightarrow B$$

$$\& \quad X \rightarrow Y$$

$$\text{Then, } X = \frac{A * Y}{B}$$

Where A, B, X and Y are random variables. If the values of A, B and Y are known, one can estimate the value of X. The direct rule of three states that B is related to A in the same proportion as Y is related to X.

Coming back to the current relation, revenue is the function of price of the fish catch in market and quantity of fish catch

Revenue = price X quantity

The amount of plastics in the ocean will not change the fish price, whereas it impacts the quality of fish catch due to fish contamination, reduced net size due to plastics accumulation in nets, reduced efficiency due to fouling etc. Hence, it can be stated that impact is a relation of (1) amount of plastics present in the fishing zone and (2) total amount of fish catch.

Impact% on fisheries ⟶ Amount of plastics present in the sea (in tonnes)

Impact % on fisheries ⟶ Quantity of fish catches (in tonnes)

The relation between amount of plastics and amount of fish, which both have an influence on the estimated impact, can also be written as:

$$Impact\ 1 = PI_x * FC_x$$

Where, impact 1 is the impact% of marine plastics on fisheries

PI_x is the amount of plastics present in the Thai EEZ in tonnes in X country

And FC_x if the amount of fish catch in tonnes inn X country

Plastics' impact is not only related to the amount of catch, but also the number of vessels and the total size of the fishing area where the marine plastics is located. This relation can be represented by the equation below. Aside from this, the impact size is also a function of attributes such as size of fishnets used, time spent on sea by each vessel, zone with plastic accumulation, etc. The data on all these variables were not available, thus, not included in the current study.

$$\text{Impact 1} = \frac{PI_x}{(V_x * EEZ_x)} * \frac{FC_x}{(V_x * EEZ_x)}$$

Where, V_x is the amount of vessel in the Thai EEZ and EEZ_x is the size of Thai EEZ in km^2 of X country (it is considered that EEZ is equal to Thai EEZ).

The aim is to translate the impact of the given dataset to Thai fisheries(operating in the Gulf of Thailand). This is done with the help of data of Scottish fisheries. Given that both countries have a different amount of plastics present in the Thai EEZ and it catches different number of fishing, the relation of two countries can be stated as follows:

$$\text{Impact 1} = \frac{PI_{Scotland}}{(V_{Scotland} * EEZ_{Scotland})} * \frac{FC_{Scotland}}{(V_{scotland} * EEZ_{Scotland})}$$

$$\text{Impact 2} = \frac{PI_{Thailand}}{(V_{Thailand} * EEZ_{Thailand})} * \frac{FC_{Thailand}}{(V_{Thailand} * EEZ_{Thailand})}$$

Applying the direct rule of three, and solving for '% impact 2' (i.e. impact on Thai fisheries), it can be represented as follows:

$$\%\ \text{impact2} = \%\text{impact 1} * \frac{\left[\frac{PI_{Thailand}}{(V_{Thailand} * EEZ_{Thailand})} * \frac{FC_{Thailand}}{(V_{Thailand} * EEZ_{Thailand})} \right]}{\left[\frac{PI_{Scotland}}{(V_{Scotland} * EEZ_{Scotland})} * \frac{FC_{Scotland}}{(V_{scotland} * EEZ_{Scotland})} \right]}$$

3. Input data from Scotland

Scotland fisheries overview

Mouat et al., 2010 conducted a study through a survey on the Scottish fisheries to understand the extent by which this sector is impacted by marine litter. It concluded that 5% of marine litter has impacted Scottish fisheries in 2008. Considering 80% of all the marine litter is composed of plastics (Dunlop et al., 2020), it can be inferred that the impact of marine plastics on Scottish net fisheries was 4%.

Table 1: Overview of data from Scottish net fisheries in 2008 (Source: Scottish Government statistics, 2008)

Vessels	Annual catch (tonnes)	Value (in £ 2008)	Fishing zone (km^2)
653	331,440	315,203,000	462,263

Amount of plastics present in Scottish EEZ

Every year, there is a certain amount of plastic that is leaked into the ocean due to the factors such as inadequate waste management system, illegal waste disposal, littering, urbanization etc. This leaked plastics impact many economic activities including fisheries (Boucher et al., 2019). The estimated amount of plastics present in the EEZ of Scotland was 24,161 tonnes in 2008 (calculation based on the estimates in GRID-Arendal, 2018). Thus, the assumption is that in 2008 the impact on Scottish fisheries of 4% was due to the presence of estimated 24,161 tonnes of plastics in their EEZ.

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