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Article

Protecting the High Seas from Illegal, Unregulated, and Unreported Fishing with Overarching Management

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Abstract: Food and Agricultural Organisation estimates from 2014 suggest 64% of the high seas migratory stocks are either overfished or undergoing overfishing. Illegal fishing exacerbates the damage to marine ecosystems, human rights, and food security, and is yet to be included in the recent United Nations (UN) draft agreement to protect high seas biodiversity. We used catch data from the Sea Around Us Project to determine trends in fishing gear use and the catches of countries fishing in the high seas. Using Two-way ANOVA, Principal Coordinates Analysis, and SIMPER Test, we found that Spain, Taiwan, Japan, Indonesia, and Ecuador had the highest catches in 2004-2014. Each decade, only 1 in 10 countries (10.8%) caught over 500,000 tonnes, leaving the remaining 90% of countries catching less than 500,000 tonnes. Further analysis showed the mean high seas catch per fishery decreased 55% between the 2000s and the 2010s. Purse seine and longline were increasingly used towards the 2010s. Catch from purse seine and longline accounted for 70.5% and 78.4% of total high seas catch in 1950-2014 and 2004-2014, respectively. Discards were unreported throughout 1950-2014, and the reporting levels of landings varied greatly between countries and gears. We call for immediate action and recommend (1) including international, overarching high seas governance to end illegal and unsustainable fishing in the high seas in the UN draft agreement, and (2) using large mobile marine protected areas in high seas fisheries management through the UN draft agreement.

Keywords: high seas, illegal fishing, marine resource management, marine protected areas, subsidies, sustainable fisheries

Key Contribution: Key findings from our analysis highlight that (1) regional fisheries management organisations (or RFMOs) are inadequate for high seas fishery management (2) certain countries contribute significantly to illegal, unregulated and unreported (IUU) fishing (3) high seas catch has decreased by more than 50% in a 10-year period (4) purse seine and long-lining account for 70 to almost 80% of all high seas catch and (5) discarded catch has largely been unreported. These findings are globally important and call for strict and immediate management strategies to mitigate loss of fishery value, fish biomass, and ecosystem function.

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1. Introduction

High seas account for over 60% of the ocean [1]. Despite the wide area they cover (see Figure 1), fisheries on the high seas contribute only 5 to 10% towards global catches [2,3]. High seas fisheries exist due to the expansion of fishing from depleted exclusive economic zones (EEZs) to distant waters, expanding the global fished area from 60% to 90% [4,5] with the help of industrialised fleets [6,7]. One example of this is the largest and the most funded distant water fleet in the world: China has around 17,000 vessels dedicated to high seas fisheries that are funded with $7.2 billion USD [8]. The extensive removal of biomass by high seas fisheries is not the only concern, as high seas fish stocks

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have other important roles: being highly connected to fish stocks and biodiversity within EEZs, the high seas support more ecosystems than its area entails [9]. High seas are also a key in global carbon storage, and exploitation and disruption of its ecosystems can reduce its ability to sequester carbon [10].

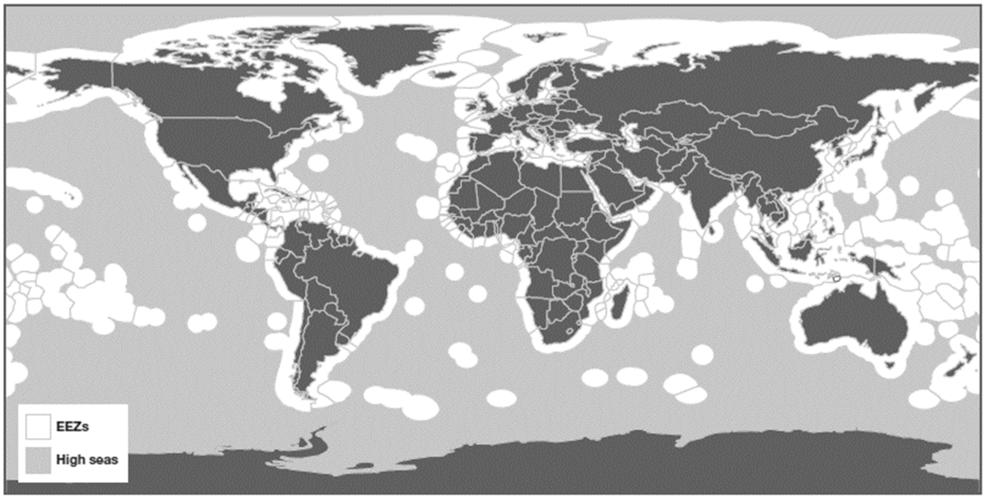

Figure 1. Map of the global high seas [1].

High seas fisheries and the support they provide to EEZs have been under threat due to increasing fishing pressure and destructive fishing practices since 1950 [6,7]. A few marine protected areas (MPAs) exist protecting only 0.8% of the high seas [11]. Most marine MPAs in general lack no-take zones, or resources for enforcement and effective fisheries management and risk becoming "paper parks" instead of protecting the biodiversity [12,13]. Moreover, the current regional fisheries management organisations (RFMOs) have displayed incongruous roles on the high seas; the RFMOS show a disconnection between their objectives and implementations [14–16]. This disconnection benefits neither the high seas fisheries nor ecosystems.

1.1. High Seas Biodiversity

Key biodiversity areas and ecologically or biologically significant areas, such as seamounts and hydrothermal vents in the high seas, have been highlighted as significant areas of interest by international organisations such as the International Union for Conservation of Nature (IUCN) and by the Convention on Biological Diversity (CBD) as reported by [17] and [18], respectively. These unique ecosystems are good examples of the great habitat diversity of the open ocean and deep-sea environments [19,20]. High seas fishing gears, such as purse seine and longline, have high catch rates that come at the cost of high levels of bycatch [21–24]. Other high seas fishing gears such as deep sea trawls significantly damage these significant areas of interest [25,26]. Sharks, seabirds, turtles, marine mammals, and benthic invertebrates are examples of vulnerable species and populations that often are collateral damage or severely damaged by high seas fisheries [24,27–29]. A large portion of high seas species have slow maturation and low fecundity that increase their vulnerability [9,30], and some of them can take years (sharks) to hundreds of years (deep-sea sponges) to replenish their populations [30,31]. In addition to increasing fishing pressure, climate change is slowly altering the demographics of these ecosystems [30,32–34].

1.2. Illegal, Unregulated, and Unreported Fishing in the High Seas

The catches from illegal, unregulated, and unreported (IUU) fishing account for roughly 20% of global catches [35]. The extent of IUU fishing differs between regions and over time, and generally increases with the overall fishing pressure [36]. On the high seas, the responsibility to monitor and govern the fleets rests mostly on the countries issuing flags for high seas vessels, i.e., flag states [37].

Since the 1950s there have been at least 143 different flag states sailing and enforcing the high seas [38]. IUU fleets often operate under flags of convenience that allow them to navigate through a sea of jurisdictional loopholes; vessels flying under flags of convenience can fish against the regulations of an RFMO by choosing a flag state that is not a member of that RFMO [39–42]. Back on the shore, however, only 76 of the high seas countries have agreed to monitor their ports through ratifying the Port States Measures Agreement (PSMA) since its implementation in 2016 [43]. Along with the United Nations Convention on the Law of the Sea [44], PSMA is a key agreement to curb IUU fishing, and the more flag states ratify and enforce it effectively, the harder it is for IUU vessels and their catches to enter ports [45]. If the PSMA is not ratified, the ports of those flag states can be classed as ports of convenience with bribery cases and inefficient or lacking inspection measures [46,47].

Furthermore, IUU catches are labour-intensive to track. Some IUU operators mislabel their catches for markets to hide the endangered or highly regulated species caught, but this can be detected with DNA identification [48,49]. Some ports with Port States Measures Agreement, however, might receive IUU landings mixed with legal landings, known as fish laundering [50]. Fish laundering is facilitated by transshipment [41,50–52]. Transshipment vessels (reefers hereafter) used for fuel shipments and collecting processed catches, are also used in fish laundering [40,41]. In their recent report Greenpeace [41] identified 416 reefers, 381 of which are owned by 8 high seas countries, that are potentially involved in IUU fishing, discrimination of human rights, and other risky operations. The use of flags of convenience by reefers to avoid consequences of discriminatory actions was also highlighted in their report. In addition to such discriminations, trafficking is thought to be prevalent within IUU fishing operations especially through transshipment [52].

1.3.Governance of IUU Fishing on the High Seas

The draft agreement published in March 2023 marked the beginning of concerted international action to protect marine biodiversity beyond national jurisdiction (BBNJ; United Nations General Assembly {UNGA) [53]. Sitting under the United Nations Convention on the Law of the Sea (UNCLOS, 1982) – previously updated in 2020 to include high seas habitats in addition to living resources, i.e. fisheries – the objectives of the BBNJ agreement cover 1) marine genetic resources, 2) area-based management tools such as MPAs, 3) environmental impact assessments, and 4) capacity building and technology transfer [54]. The draft agreement does not directly include IUU fishing although it recognises "the need to address, in a coherent and cooperative manner, biodiversity loss, and degradation of ecosystems of the ocean, due to [...] unsustainable use" [54] (p. 2). Sustainable use of high seas resources, on the other hand, is defined in the agreement as "the use of components of biological diversity in a way and at a rate that does not lead to a long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations" [54] (p. 4). IUU fishing activities in the high seas go against this very definition and are not currently governed.

Patchwork fisheries governance is one of the key underlying reasons why IUU fishing has spread from coastal areas to the high seas; the prevalent lack of surveillance and enforcement, overfished EEZs, wide-spread use of forced labour, and substantial government subsidies are key facilitators of IUU fishing on the high seas [40,55–58]. Overfished EEZs and extensive use of harmful subsidies in particular have increased IUU fishing as seen in Senegal [28,59]. High seas fleets are subsidised by governments for almost three times the amount of actual net profit, leaving over half of the high seas fleets unprofitable should subsidies be stopped (Table 1) [2]. This alone questions the socio-economic motives of some high seas fisheries and brings attention back to IUU fishing. IUU vessels do not comply with gear restrictions, set quotas, or EEZ boundaries, thus depleting the stocks many depend on and causing both socioeconomic and ecological damage with their operations [46,60]. A review of the global extent of IUU fishing [58] revealed that 8-14 million tonnes of fish are caught illegally within EEZs annually. With both revenue and tax revenue losses put together, this can lead to losses of up to US$ 18 billion according to their estimates [58]. With respect to the high seas portion of 5 to 10% of global catch [58], the same figures for the high seas would amount to 0.42-1.56 million tonnes of IUU catch and combined losses of US$ 6 billion annually (Table 2).

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Table 1. Top 10 of subsidised high seas fleets, adapted from Sala et al., (2018).

Country	Subsidies (Million us$)	% of Global Subsidies
Japan	841	20.1
Spain	603	14.4
China	418	10.0
South Korea	409	9.8
United States	256	6.1
Taiwan	244	5.8
France	195	4.7
Indonesia	102	2.4
Mexico	32	0.8
Panama	25	0.6

Table 2. IUU fishing scenarios adapted from Sumaila et al. (2020) according to the estimated contributions of high seas catches (5% and 10%) towards the global catches of fisheries (Sala et al., 2018).

High Seas	5% Scenario	10% Scenario
IUU catch(million metric T)	0.42 - 0.74	0.88 - 1.56
Gross IUU revenue (billion US$)	0.47 - 0.89	1.0 - 1.89
Tax revenue loss (billion US$)	0.11 - 0.21	0.22 - 0.44
Economic loss (billion US$)	1.37 - 2.63	2.89 - 5.56

1.4.Large Mobile Marine Protected Areas to Combat IUU Fishing?

Large mobile marine protected areas (large mMPAs) are an innovative new approach for marine spatial planning in the high seas. Large mMPAs are enabled by developments in the use of artificial intelligence and other technologies such as remote sensing in MPA governance [61,62]. The pertinence of the role large mMPAs can play in high seas governance was emphasised in a recent study [63] which showed that less than 1% of the existing, non-mobile MPAs can protect key transboundary and highly migratory species with large ranges.

The potential benefits of large mMPAs include their flexibility to accommodate the complexities of marine species and ecosystems. The protection of key transboundary and highly migratory species is a challenge for the international community, while several high seas species face additional stressors and risks due to IUU fishing (e.g. penguins [64]; turtles, bluefin tunas [29]). Large mMPAs should be coupled with "climate-smart" thinking for MPA networks around the world, whereby the design of marine protection measures, including MPAs, would include a vast database of multi-species data and modelling for different climate scenarios [65]. Further, at least 64% of the high seas should be protected instead of the current 30% target, which large mMPAs could help achieve [65].

While area-based management tools such as large mMPAs would not be able to govern transboundary and highly migratory species and their habitats within EEZs, or recompense insufficient and ineffective monitoring, enforcement, and management [29], they can provide elemental protection to the species and habitats, the protection of which in the high seas is at present non-existent.

1.5. Aims & Objectives

Eliminating IUU fishing through international governance and mMPAs would work towards important global goals, namely the Aichi Biodiversity Target 11 (10% of the oceans protected by 2020; [66]) and the United Nations Sustainable Development Goal (SDG) 14 'Life Below Water' [67,68]. It would also further not only the 2030 Agenda for Sustainable Development under the new UN Decade of Ocean Science for Sustainable Development to protect 30% of the ocean by 2030 (the "30x30 goal" [69]), but also the recently drafted BBNJ agreement.

This paper explores the Sea Around Us Project (SAUP) catch reconstruction dataset for high seas provided by Pauly and colleagues [28]), spanning from 1950 to 2014, and aims to highlight trends in amounts of landings and discards of countries, and their respective reporting statuses. Notably, this paper did not conduct stock assessments in the high seas using catch reconstructions as some scientific debate exists around this particular aspect [70–72]. Several studies have used SAUP data to examine, inter alia, the impacts of marine heatwaves on fisheries [73], extinction risks in oceanic sharks and rays [74], and global fishery subsidies [75]. The last decade of the dataset (2004-2014) was analysed in more detail with statistical analysis to identify recent country- and gear-specific trends of the global high seas' fisheries. Reporting statuses of catches and countries are examined, as unreported catches are thought to be potential indicators for IUU fishing activity [36,40]. The results are then discussed along with the existing studies. The overarching international governance and large mobile MPAs (mMPAs) [29,76] are explored as solutions in protecting the high seas from IUU fishing and overcapacity.

2. Materials and Methods

Google Scholar, Web of Science, and PubMed databases were used as research platforms in the literature review part of this paper. The keywords applied included, inter alia, the following: 'high seas', 'ABNJ' 'biodiversity', 'fisheries management', 'illegal fishing', 'IUU fishing', 'high seas conservation' and 'large MPA' as several combinations. A total of 102 peer-reviewed or organisational sources were reviewed. The SAUP catch reconstruction dataset by Pauly et al. [38] spanning from 1950 to 2014 was used in some of the references of this paper, which allowed for some comparison of the results [1,2,5,7,26]. Table 3 lists the variables in the SAUP dataset. Table 4 lists all gear types of the dataset.

Table 3. SAUP dataset and the variables for years 1950-2014 (Pauly et al., 2020).

Variable	**Key**
Year	*Year of fishing*
Fishing entity	*Country with active HS fishery*
Fishing sector	*Industrial, artisanal*
Gear type	*See Table 4*
Catch type	*Landings, discards*
Reporting status	*Reported or unreported catch*
End use type	*Direct human consumption, discard, fish meal and oil, other*
Sum of tonnes	*Sum of catch in tonnes (t)*
Landed value	*Value of catch (US$)*

Table 4. Gear types used by high seas fleets in 1950-2014 (Pauly et al., 2020).

Gear class	Gear type
Mobile	*beam trawl*
	bottom trawl
	dredge
	otter trawl
	pelagic trawl
	purse seine
	shrimp trawl
	encircling nets

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Static	*longline* *gillnet* *pots or traps* *small scale trammel net* *pole and line* *hand lines* *artisanal fishing gear*
Unknown or other	*mixed gear* *other* *other industrial* *other nets* *unknown by source* *unknown class*

For clarity, 'catch' refers to overall catch including both landings and discards. 'Landings' refer to catches that are either target or non-target species but have been reported as landings. 'Discards' refer to all non-target species that have been either bycaught and then discarded, taken onboard and sold for fishmeal or oil, taken onboard and sold for human consumption, or non-target species reported in category 'other', for which there is no further explanation in the dataset [38].

2.1. Statistical Analysis

The SAUP dataset [38] was analysed for trends over time, descriptive statistics, and percentiles. Landing values were not included or analysed in this paper. The statistical analysis focused on the last decade of the dataset (2004-2014) and only on the countries with active high seas fisheries during that time.

For preliminary data-screening, a Shapiro-Wilk test was applied for the normality of the catch data of all countries and gears together. Levene's Test was conducted to determine the homogeneity of variance within the catch data. Differences in catch data between countries and gear types were analysed using two-way analysis of variance (ANOVA) (IBM SPSS v. 25). A Shapiro-Wilk test showed the catch data to be non-normally distributed, $W(2438)=0.447$, $P<0.001$. A Levene's Test showed no homogeneity of variance in the catch data, $F(310,2100)=9.74$, $P<0.001$. As the catch in metric tonnes (t) is measurement data and would, thus, require parametric tests, the catches were transformed by adding 1 (+1) to each datapoint. Country- and gear-specific catches below 10 tonnes were also excluded. These allowed for lognormal distribution of the catch data when applying a two-way ANOVA. Tukey's Honest Significant Difference (HSD) comparisons were applied as the post hoc test.

Non-parametric multivariate analyses were conducted using PRIMER 6.1 (Primer-E Ltd: Plymouth Routines in Multivariate Ecological Research, Version 6.1). For the last decade (2004-2014), a principal coordinate analysis (PCO) and PERMANOVA tests were applied for the catch data of the countries catching more than 1 million tonnes to determine the extent of variation caused by country and by gear type. The limit of 1 million tonnes was chosen to distinguish between small-to-medium and larger fisheries with considerably higher catches. In addition, a similarity of percentages (SIMPER Test; [77] was conducted using PRIMER-e to reveal the gear- and country-specific variations in catches of over 1 million tonnes in 2004-2014. All PRIMER 6.1 tests were based on square root (data + 1) transformed data in S17 Bray Curtis similarity matrices [78] with 9999 permutations.

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3. Results

3.1. General Observations of High Seas Fisheries And catches in 1950-2014

A total of 143 individual countries fished on the high seas. The numbers of active countries varied, but nonetheless increased (Figure 2). The total high seas catch increased more rapidly and almost concomitantly with the number of active fisheries from the mid-1980s (Figure 2) until the 2000s. From the 2000s onwards, the number of active fisheries declined slightly, while the total annual high seas catch was fluctuating. There was no concomitant increase in the number of fisheries and the total high seas catch after the 2000s. The SAUP dataset [38] revealed that approximately 1 in 10 countries (10.8%) caught over 500 thousand tonnes, leaving the remaining 90% of countries fishing in the high seas with catches of less than 500 thousand tonnes each decade.

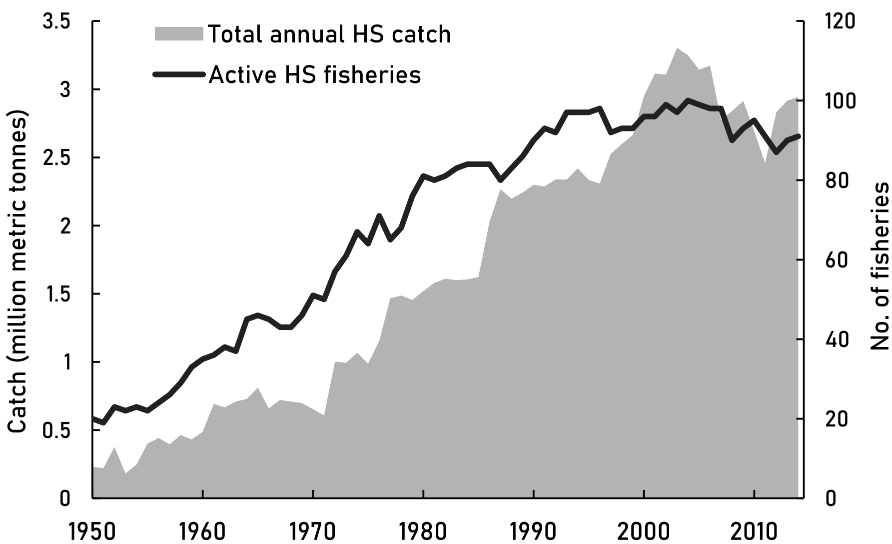

Figure 2. The catch reconstructions data (Pauly et al., 2020) of the high seas through 1950-2014. Changes in total annual catches of active high seas fisheries over time along with the number of active high seas fisheries.

Regarding changes in mean catches per active fishery; a steady increase concurrent with the number of active fisheries continued until the 2000s up to a mean catch of 259 thousand tonnes (Figure 3 and Table 5). However, we observed a pronounced decline in mean catch per fishery between the 2000s and 2010s; it declined close to the 1970s mean catch (133 thousand tonnes) with the mean of the 2010s being 134 thousand tonnes (Figure 3 and Table 5). In effect, the mean catches per active fishery declined by almost 55% between the 2000s and the 2010s, although over 100 fisheries were still active.

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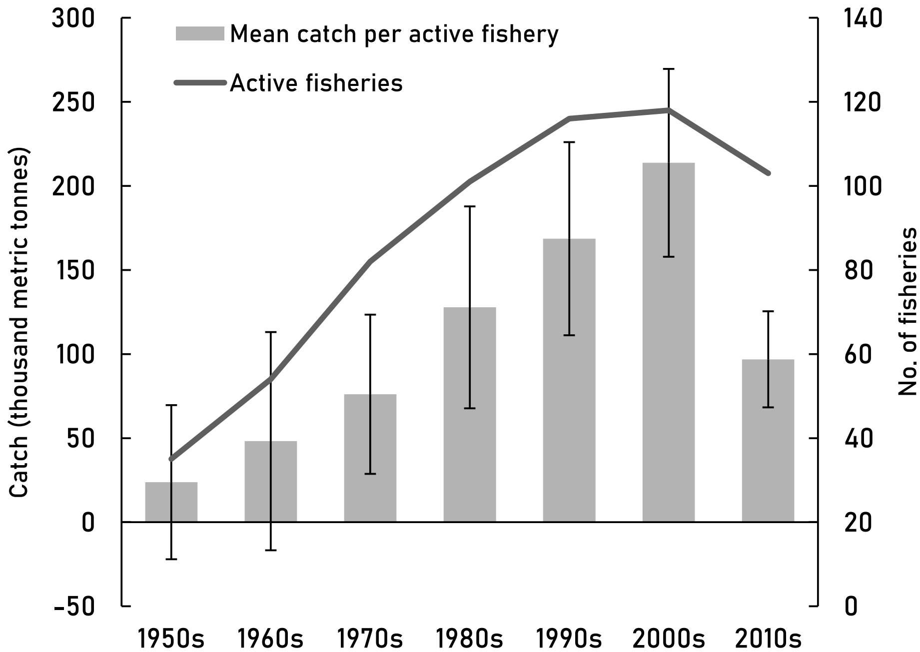

Figure 3. The catch reconstructions data (Pauly et al., 2020) of the high seas through 1950-2014. The mean high seas catch (± 1 SEM) and the number of active fisheries per decade.

Table 5. Descriptive statistics of high seas catch by decade, SAUP data (Pauly et al., 2020). All tonnages in thousand metric tonnes.

Decade	Active fisheries	Mean catch	StDev	SEM	Total catch
1950s	35	97	± 271	± 46	3395
1960s	54	128	± 477	± 65	6885
1970s	82	133	± 429	± 47	10877
1980s	101	181	± 604	± 60	18271
1990s	116	208	± 619	± 57	24113
2000s	118	259	± 607	± 56	30568
2010s	103	134	± 290	± 29	13843

3.2. Observations of High Seas Fisheries in 2004-2014

Despite the increase in mean catches for fisheries during 2004 to 2014 ($r^2 = 0.40$), the amount of total high seas catch was declining ($r^2 = -0.32$) (Figure 4). During 2004-2014, only 81% of the countries had active high seas fisheries (N=116). Spain, Taiwan, and Japan had the highest catches in 2004-2014 (3.2, 2.9, and 2.8 million tonnes, respectively), followed closely by Indonesia and Ecuador with respective catches of 2.4 and 2.3 million tonnes (Figure 5). Furthermore, a two-way ANOVA demonstrated significant differences between countries that caught over 1 million tonnes in 2004-2014, ($F[107,2098] = 38.58$, $P < 0.001$). These differences are elaborated in the following sections.

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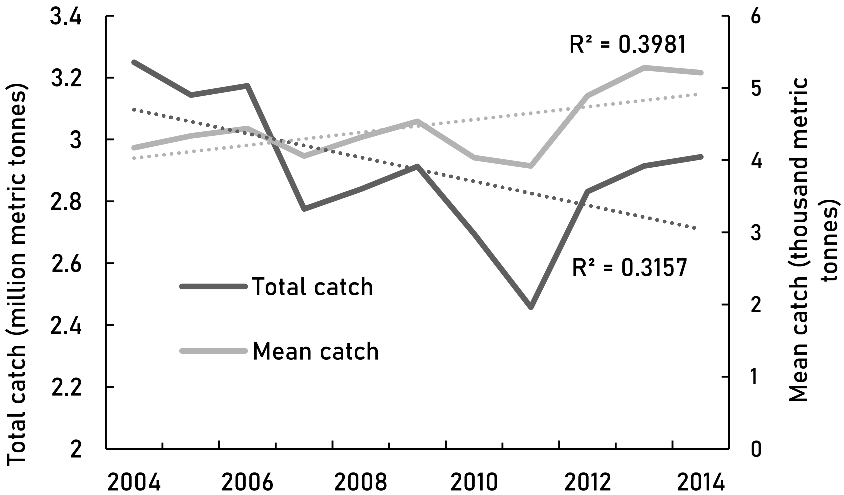

Figure 4. The trends for high seas catch from SAUP data [38]. and B) Top 5 high seas fisheries in 2004-2014 [38].

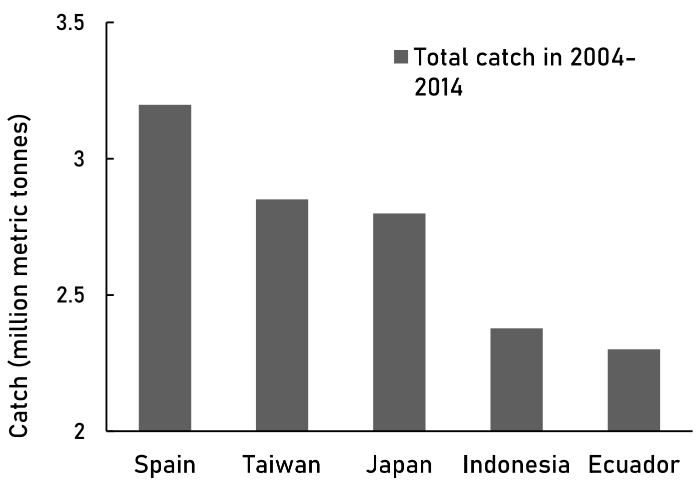

Figure 5. The top 5 high seas fisheries in 2004-2014 [38].

3.2.1. Principal Coordinate Analysis (PCO) and PERMANOVA

Principal coordinate analysis (PCO) demonstrated that 55.5% of the variation in catches was due to gear types and the countries using them (Figure 6a). The 10 countries catching more than 1 million tonnes in 2004-2014 (Figure 6b; not in order: Philippines, Indonesia, Taiwan, Ecuador, Japan, Spain, Mexico, South Korea, France, and Norway) caught the most with purse seine, longline, pelagic trawl, gillnet, and pole and line gears, as well as with two other, more unclear gear types ('unknown class' and 'other') (Figure 6a). Furthermore, PERMANOVA indicated a significant difference in amounts of catch between gear types ($F_{20,21} = 2.7$, $P \leq 0.001$) for the countries that caught over 1 million tonnes in 2004-2014.

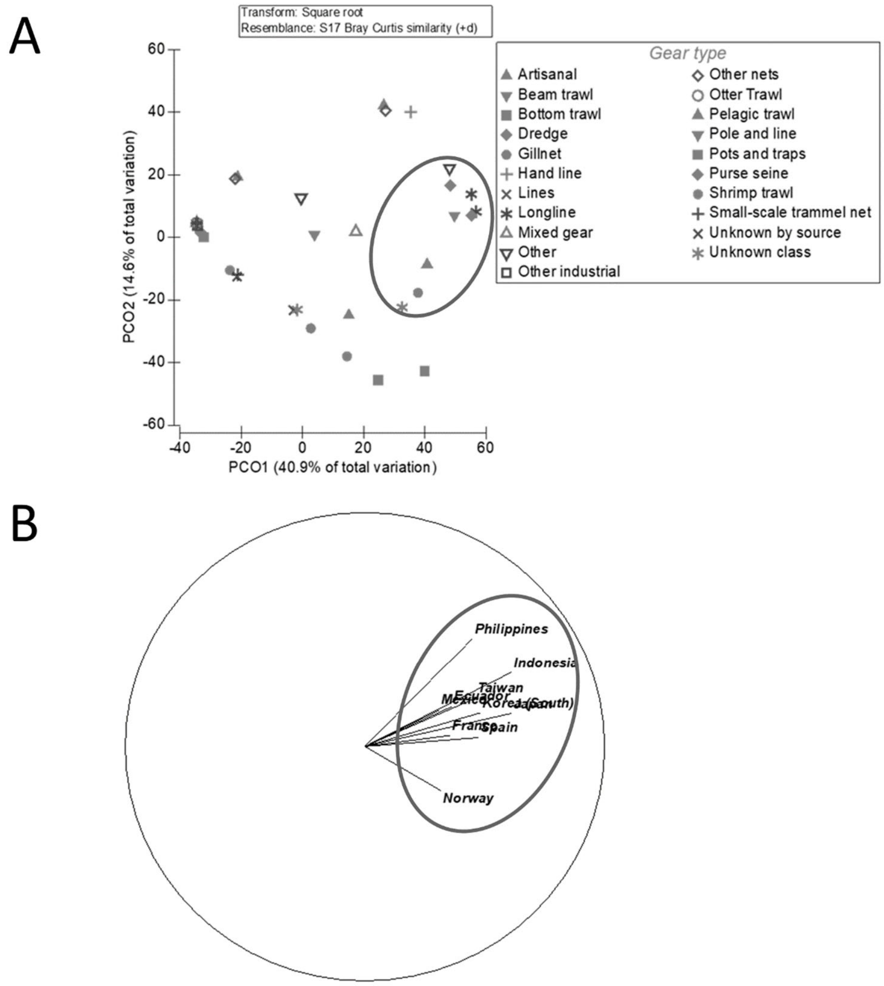

Figure 6. The PCO (A) and country ordination (B) regarding variation in catch by countries that caught over 1 million tonnes in 2004-2014, and the fishing gears those countries used. Blue circles illustrate strong relationships with gear types (A) and country (B).

3.3. *Trends of High Seas Fishing Gears*

The most common fishing gears of high seas fleets both in 1950-2014 and 2004-2014 were purse seine and longline. Purse seine and longline had the highest catches and the highest numbers of countries using them (Table 6). Together, purse seine and longline accounted for 70.5% and 78.4% of the total high seas catch in 1950-2014 and 2004-2014, respectively. The catches might vary depending on the combination of the fishing country and the gears they used. Firstly, a two-way ANOVA revealed significant (α=0.05) differences between catch amounts of different gear types ($F[17,2098] = 138.980$, $P < 0.001$) in addition to the significant differences between countries as stated earlier. Moreover, the interaction effect of those two variables was also significant, $F(215,2098) = 30.573$, $P < 0.001$, indicating that the within-gear differences in catch varied by country. This was further supported by PCO and PERMANOVA analyses (Figure 7). Tukey's HSD comparisons showed that in the case of the most common high seas gears, purse seine catches were slightly higher than those of longline ($P < 0.001$, 95% CI of the difference = 0.45 to 0.62; Table S1). The countries with the most catches (Figure 5) used primarily both purse seine and longline (Figure 8). Other gears were used to a lesser degree amongst the countries catching over 1 million tonnes in 2004-2014 (Figure 8).

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Table 6. Descriptive statistics of purse seine and longline fisheries for both 1950-2014 and 2004-2014. All catches in thousand metric tonnes.

Time period	Gear type	Avg catch	StdDev	Total catch	Catch (% of total)	No. of user countries	User countries (% of N)
1950-2014	*Purse seine*	8.7	± 27.9	42,424.2	39.3	82	57.3
	Longline	5.6	± 23.4	33,634.1	31.2	107	74.8
2004-2014	*Purse seine*	13.2	± 33.8	16,659.5	52.2	64	55.2
	Longline	4.1	± 16.1	8,363.0	26.2	92	79.3

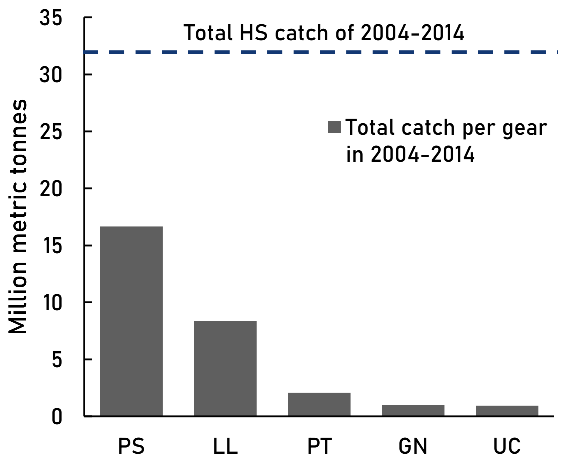

Figure 7. Fishing gear trends of the countries with catches of over 1 million tonnes in 2004-2014 - Gear-specific catches compared to the total catch of 2004-2014. Gear abbreviations: ‘PS’ = purse seine, ‘LL’ = longline, and ‘BG’ = all benthic gears. ‘Other’ includes gears with smaller contributions towards the total catch of countries.

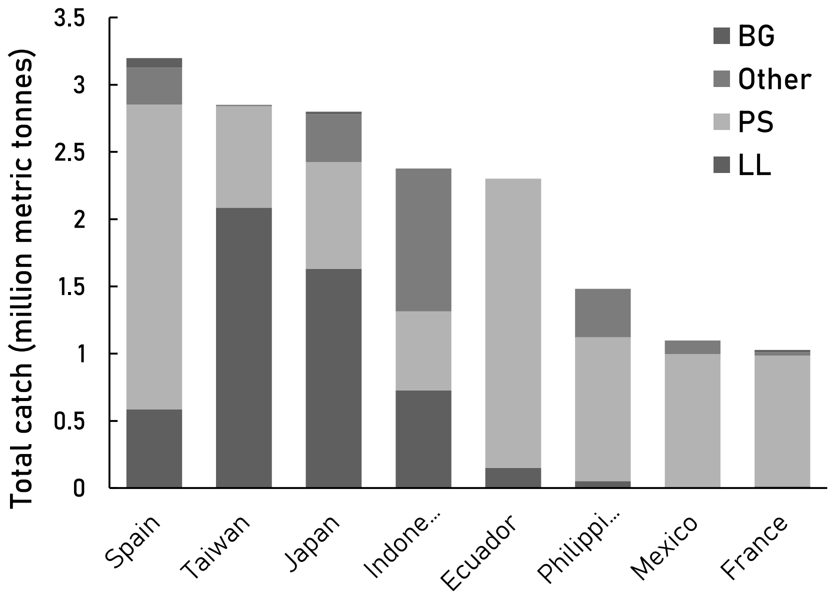

Figure 8. Fishing gear trends of the countries with catches of over 1 million tonnes in 2004-2014 - Gear-use distribution within countries. Gear abbreviations: 'PS' = purse seine, 'LL' = longline, and 'BG' = all benthic gears. 'Other' includes gears with smaller contributions towards the total catch of countries.

3.3.1. Similar Percentages Analysis (SIMPER Test)

Regarding the most used gear types, namely purse seine and longline, the SIMPER Test showed that Spain, Ecuador, South Korea, and France accounted for 54.2% of purse seine catches, while Japan and Taiwan together were responsible for nearly half (49.7%) of longline catches. In terms of the less common gear types, France, Japan, and Norway were the only countries using gillnets. Only Indonesia, Philippines, and Japan used gears categorised as 'other'. France was the only contributor to both dredge and 'other industrial' catches. Philippines accounted for 100% of catches caught with 'other nets' and artisanal fishing gear. France and Spain were the only countries in 2004-2014 to use unknown gear types, namely 'unknown by source' and 'unknown class'. Norway and South Korea were the only users of pelagic trawl. Norway and Spain accounted for 100% of shrimp trawl catches.

3.4. Reporting Statuses of High Seas Fisheries

3.4.1. Reporting in 1950-2014

The majority of high seas fisheries reported all their landings in 1950-2014. Only 0.01% of discards were reported, starting from the 2000s (Table 7). Regarding unreported gear-specific catches in 1950-2014, longline and bottom trawl dominated in 'all catches' and 'discards' with respective contributions of approximately 45% and 30% in both categories (Table 8). 'Unknown class' and bottom trawl both accounted for approximately 50% of all unreported landings (Table 8). As the other most common gear of the high seas, unreported purse seine landings accounted for approximately 20% of all catches, but less than 1% of the landings (Table 8). Longline, purse seine, and bottom trawl were associated with all unreported catches more often than other gears with approximately 45%, 30%, and 20%, respectively (Table 8).

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Table 7. Tonnages of reported and unreported discards by decade.

	Discards	
Decade	**Reported (t)**	**Unreported (t x 1000)**
1950-1959	-	857
1960-1969	-	2862
1970-1979	-	2780
1980-1989	-	3122
1990-1999	-	3174
2000-2009	23	2603

Table 8. Top 5 unreported gear-specific catches for 1950-2014. All tonnages in thousand metric tonnes. Contribution (%) of gear-specific catch was calculated from total catch of each catch type category. The number of fisheries in each category: N(all catches)=131, N(landings)=39, and N(discards)=131.

Catch type	***Gear type***	***Mean catch***	***StdDev***	***Total catch***	***Catch (% of total)***	***No. of user countries***	***User countries (% of N)***
All catches	*Longline*	3.5	± 12.6	7818.4	45.0	82	62.6
	Bottom trawl	2.7	± 11.2	5188.4	29.9	45	34.4
	Purse seine	1.9	± 8.5	3406.0	19.6	75	57.3
	Unknown class	0.9	± 2.6	602.5	3.5	15	11.5
	Gillnet	0.2	± 0.7	141.1	0.8	31	23.7
Landings	*Unknown class*	0.962	± 2.890	386.5	49.60	4	10.3
	Bottom trawl	0.539	± 1.753	385.7	49.49	24	61.5
	Longline	0.014	± 0.056	5.2	0.67	19	48.7
	Purse seine	0.004	± 0.014	1.0	0.13	4	10.3
	Other nets	0.004	± 0.021	0.3	0.04	2	5.1
Discards	*Longline*	4.2	± 13.8	7813.2	47.1	82	62.6
	Bottom trawl	4.0	± 14.0	4802.8	29.0	45	34.4
	Purse seine	2.1	± 9.0	3405.0	20.5	75	57.3
	Unknown class	0.8	± 2.1	216.0	1.3	15	11.5
	Gillnet	0.2	± 0.8	141.0	0.9	31	23.7

Note: smaller data points have three decimal points in place of one for increased precision.

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3.4.2. Reporting in 2004-2014

Only four countries reported their discards from the 2000s onwards, namely Japan, Norway, South Korea, and South Africa (South Africa not included in the table; Table 9). Mexico and Spain had the most unreported landings in 2004-2014, approximately 66% and 22%, respectively (Table 9). Although all the high-catch fisheries in 2004-2014 had some unreported discards, Japan, Taiwan, and South Korea had notably higher proportions, approximately 50%, 20%, and 12%, respectively (Table 9). Moreover, Spain did not report any discards in 2004-2014. However, when we looked at all the active fisheries of 2004-2014, Dominica, Georgia, and Sierra Leone reported neither their landings nor their discards (Table 10). In addition, some of the total catch of Saint Pierre & Miquelon (66%) as well as Fiji (28%) were unreported. Bottom trawl had the highest levels of unreported catches (28%) of the overall total catch, followed by 'other industrial', dredge, longline, and 'unknown by source' (Table 10).

Table 9. Reporting rates of high seas fisheries that caught over 1 million tonnes in 2004-2014. Note: Two decimal places were included in the percentages for added accuracy as some countries had smaller values.

Country	Landings			Discards		
	Reported (%)	*Unreported* (%)	*Total* (%)	*Reported* (%)	*Unreported* (%)	*Total* (%)
Ecuador	5.60	0.00	5.60	0.00	2.57	2.57
France	7.04	0.07	7.04	0.00	2.98	2.98
Indonesia	8.60	0.00	8.59	0.00	2.58	2.58
Japan	28.52	2.98	28.51	82.63	49.68	49.68
Mexico	4.65	65.86	4.68	0.00	1.32	1.32
Norway	3.30	4.88	3.30	4.76	1.73	1.73
Philippines	5.59	0.00	5.59	0.00	1.26	1.26
South Korea	8.41	4.43	8.40	12.61	12.16	12.16
Spain	14.72	21.78	14.72	0.00	6.05	6.05
Taiwan	13.58	0.00	13.57	0.00	19.65	19.65
Total %	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

Table 10. Top 5 high seas fishing gears and countries with highest rates of unreported catch in 2004-2014. Percentage of unreported catch was derived from the overall catch, which included both reported and unreported catches, as well as both 'landings' and 'discards' categories).

Gear type	**Unreported catch (%) of total**	**Country**	**Unreported catch (%) of total**
Bottom trawl	28	Dominica	100
Other industrial	25	Georgia	100
Dredge	23	Sierra Leone	100
Longline	20	Saint Pierre & Miquelon (Fr.)	66
Unknown by source	13	Fiji	28

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A closer look at the gear-specific catches of 2004-2014 showed that longline and purse seine accounted for most of the unreported catches with proportions of approximately 61% and 27%, respectively (Table 11). The proportion of unreported bottom trawl catches was not as high in 2004-2014 (5.8%; Table 11) as it was during the 1950-2014 (20%; Table 8). Nonetheless, bottom trawl had the most unreported landings in 2004-2014, when over a half (56%) of the bottom trawl landings were unreported (Table 11). Longline had relatively low amounts of unreported landings (approximately 5%) in 2004-2014 but nearly two thirds of the longline discards were unreported (Table 11). Unreported purse seine catches were more pronounced in 2004-2014 than throughout the data series; they accounted for almost a third of the overall unreported catches as well as of the unreported discards (Table 11). Although 'unknown class' had little overall contribution, nearly 40% of the 'unknown class' landings were unreported.

Table 11. Top 5 unreported gear-specific catches for 2004-2014. All tonnages in thousand metric tonnes. Contribution (%) of gear-specific catch was calculated from total catch of each catch type category. The number of fisheries in categories: N(all catches)=100, N(landings)=29, and N(discards)=100.

Catch type	*Gear type*	*Average catch*	*StdDev*	*Total catch*	*Catch (% of total)*	*No. of user countries*	*User countries (% of N)*
All catches	*Longline*	2.0	± 6.4	1644.4	60.7	69	69.0
	Purse seine	1.5	± 3.7	719.9	26.6	57	57.0
	Bottom trawl	0.5	± 0.9	157.9	5.8	27	27.0
	Unknown class	0.7	± 1.5	86.9	3.2	12	12.0
	Pelagic trawl	0.6	± 1.5	39.6	1.5	9	9.0
Landings	*Bottom trawl*	0.439	± 0.912	49.1	56.4	13	44.8
	Unknown class	0.642	± 1.302	33.4	38.3	3	10.3
	Longline	0.017	± 0.066	4.5	5.2	18	62.1
	Other	0.007	± 0.017	0.1	0.1	3	10.3
	Gillnet	0.003	± 0.002	0.026	0.03	2	6.9
Discards	*Longline*	3.0	± 7.7	1639.9	62.5	67	67.0
	Purse seine	1.5	± 3.7	719.9	27.5	57	57.0
	Bottom trawl	0.5	± 0.9	108.7	4.1	27	27.0
	Unknown class	0.8	± 1.7	53.5	2.0	12	12.0
	Pelagic trawl	0.7	± 1.7	39.6	1.5	8	8.0

Note: smaller data points have three decimal points in place of one for increased precision.

4. Discussion

According to the data from the Sea Around Us Project, the exploitation levels in high seas fisheries increased notably from the 1950s onwards. In 2014, almost 47% of the high seas fish stocks were either over-exploited or collapsed, and 37% were exploited at their full capacity [38]. Similar estimates from the FAO [79] suggest that 64% of high seas stocks are overfished or undergoing overfishing. High seas fish stocks have potential for much more than their 5 to 10% contribution towards global catches. Without the healthy high seas stocks replenishing those of the EEZs, the catches from national waters would more rapidly decline [9,80]. We demonstrate a potential negative trend in the high seas total catches from the 2000s onwards (Figure 4a) and suggest a decline in mean catches of fisheries between the 2000s and 2010s (Figure 3). This would support the findings of a global decline of 22% in catch per unit area since 1996 [9]. It also suggests that the adverse effects of intense fishing pressure of the EEZs [5,71] are slowly being replicated on the high seas. We found the catches to be highly variable among countries. This could be due to the diversity of countries fishing on the high seas; the economic background of the country defines the size and efficacy of their fishing fleets and the extent to which the fleets are subsidised [81]. Furthermore, the gear-specific catches differed significantly (Figure 6a). Contrary to the globally common gears (bottom trawl, seine net, and pelagic trawl [7]), purse seine and longline overpowered most of the other high seas gears such as gillnet and pole and line both in catch and popularity (Table 6). Longline was also recognised as the most common high seas gear by Sala et al. [2]. The wide use of these two gears demonstrates their fishing power; top fisheries opt for efficient gear with high catch levels at the cost of large amounts of non-target catch [21,23].

Similarly, we found that purse seine and longline were also the main fishing gears used by the high-catch countries such as Spain, Taiwan, Japan, Indonesia, and Ecuador in 2004-2014 (Figure 6b). In addition to Spain and Taiwan, South Korea and China were largely responsible for expanding the fisheries coverage from 60% to 90% globally [9]. Indonesia, Japan, South Korea, and Taiwan were also recognised as dominant high seas fisheries in 2006 [26] and accounted for most of the global catch in 2000-2010 [1]. In addition, all the above countries along with China comprised 77% of the high seas fisheries [2]. In respect to our case study, the distant water fleet of China, it is worrying that a leading (legal) industrial fishery is not only the highest-ranking illegal fishery in the world [82], but also pushes smaller high seas fisheries towards illegal fishing [83]. The displacement of legal fishing effort due to illegal fishing by top high seas fisheries can, thus, result in more illegal fishing when smaller fisheries are left without a choice, providing yet another reason for ending illegal fishing altogether.

The high seas pose a challenge to all stakeholders from the exploiters of its natural resources to the entities willing to preserve them. Acting on the issues affecting the high seas would be an important step towards the Aichi Target 11 and the SDG 14 [66–68], as currently only 5.3% of the aimed 10% ocean protection has been fulfilled and IUU fishing is still ongoing [11,58]. However, high seas fisheries are not currently comprehensively managed, nor are the high seas ecosystems properly protected [15,37,46,84]. Moreover, inequality prevails on the high seas; high-income nations perform 97% of the industrial fishing in the high seas, leaving a mere crumb of the fish stocks to low-income nations [84,85]. The findings of this paper confirm these inequalities: approximately 90% of the countries fishing in the high seas catch less than 500,000 tonnes each decade. Facilitating IUU fishing through inadequate enforcement and governance needlessly exacerbates the equality and sustainability issues of high seas fisheries [46,60]. The damage from IUU fishing in the high seas increases the economic burden for countries already losing billions of US dollars due to IUU fishing in their national waters and cripples conservational efforts [58,59]. Placing all the enforcement pressure on the flag states, while RFMOs are sending mixed messages seems to benefit neither the high seas ecosystems, nor curbing IUU fishing [15,16,37]. It is evident that tackling the IUU activity on the high seas requires transparent international effort [76,86]. Cooperation between global, regional, and national sectors underpins the success of that effort [86,87]. Implementing overarching international governance as the key element of high seas management has already been called for in the reports from the Global Ocean Commission [76] and Greenpeace [41].

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The compliance of not only the flag states but their respective fleets is crucial in impairing IUU operations on the high seas and, therefore, effective surveillance of the high seas along with meticulous port inspections are of great importance [86,88]. Due to the vast area of the high seas, the surveillance would rely heavily on monitoring the high seas vessels remotely and improving port enforcement and governance. IUU catches are far less likely to be landed in ports of strongly governed countries, whereas busy ports with good access to markets are more likely to receive illegal catches [45]. IUU catches could be traced and simultaneously deterred with applying DNA test on landings and a rigorous traceability system based on sharing IUU fishing information, e.g., valid licences, and which areas are closed for fishing [48,89]. Fortunately, as the technology develops, it provides myriad of methods for monitoring fishing effort globally; automatic identification system (AIS) and vessel monitoring system (VMS) technologies are already widely used [61,90], while studies looking into using remote sensing and cross-matching of, e.g., VMS and AIS data are emerging to locate vessels at sea [91–93].

We found several issues in reporting levels of the high seas catches. Reporting levels of landings were higher than that of discards (Table 9), which were almost completely unreported apart from some exceptions in 2004-2014 (Tables 9 and 11). We detected further variation in reporting levels between countries and gear types. For example, although some fisheries such as Dominica, Georgia, and Sierra Leone were not amongst the high-catch countries of 2004-2014, none of them reported any of their catch to relevant authorities (Table 10). Furthermore, while bottom trawls caught less fish, almost a third of it was unreported (Table 10). Our results suggest that looking at the reporting levels of individual countries and gear types in addition to their respective catch quantities could provide valuable insights to the 'who' and 'how' aspects of IUU fishing, while pointing towards potential non-compliance cases in fisheries.

Nevertheless, merely solving the issues of patchwork governance on the high seas would not be enough as the threat of overfishing persists. To protect the high seas ecosystems and the fish stocks within, it is essential not to wait until holistic and sustainable management measures are in place. Including MPAs in high seas fisheries management could bring both economic and ecological benefits [94]. Due to the migratory nature of many high seas species, studies have suggested the implementation of MPA networks could be applied on the high seas [95,96]. However, we also consider an MPA concept that has only recently been explored; large mobile MPAs (mMPAs; [29]). The main principle of an mMPA of any size is having clear, mobile boundaries. Oceanographic boundaries such as sea surface temperature, or geographic features such as eddies and currents act as indicators for species presence [29]. The boundaries can be altered in almost real-time to benefit both the migratory species as well as the foraging grounds, nursery areas, and habitats. This would bring considerable benefits to many of the vulnerable high seas species: Key migratory routes as no-take zones would protect key species such as sea turtles, swordfish, and tunas. Large mMPAs would also improve connectivity between other MPAs and between the high seas and national waters, which would allow the species with wide home ranges to move freely without interruptions from fisheries [29]. Moreover, solutions such as environmental niche models for fleets could help predict the potential clashing spots between fisheries and marine wildlife [97]. High seas mMPAs would further increase the resilience of those ecosystems and protect them from overfishing and climate change as the species undergo home range shifts [9,29,32,33].

Finally, it is important to consider the livelihoods these management measures would affect. After all, in addition to the high seas ecosystems and fish stocks, it is the futures of the high seas fishers and fishing companies that are directly influenced. The concerns for future income are universally valid, when planning conservation measures [98]. While innovative solutions to high seas management arise frequently, only some of them acknowledge the sociological and societal effects in full [99,100]. Stakeholder engagement and satisfaction are important elements in fisheries management; without fishers marine conservation cannot go forward. Fishers are key stakeholders, and the ideal management solutions are 'win-win-win' situations, from which fishers, ecosystems, and communities benefit from. As studies of high seas stakeholder engagement are still scarce, studies from inshore fisheries could provide valuable insights as to how to activate that engagement and achieve those 'win-win-win' outcomes in high seas fisheries. For example, a study by Rees et al. [101] approached local pot fishers in the Lyme Bay Reserve, UK, with a suggestion: if the fishers reduced their fishing intensity and opted for more sustainable and low-impact fishing methods, their catches would increase with less effort. This would result in the preservation of their livelihoods, the ecosystem, and increase fished stocks. The suggestion later became reality: as a result, reducing the fishing impact and damage to the seabed, the Lyme Bay rocky and soft coral reefs and structurally complex benthic habitat increased the fish biomass by 4.5 times and the fishers began catching 2.5 times more fish with less effort than before [102]. The work of the DEFRA, the Blue Marine Foundation, and University of Plymouth in the Lyme Bay Reserve has shown that investing in local inshore fisheries and fishers can work. The need to subsidise high seas fisheries will decrease as the thriving economy and ecosystem support the communities closer to home. The money freed from subsidies could be put towards protecting, for example, nursery habitats.

4.1. Future recommendations

Although the Lyme Bay Reserve fisheries are coastal, they serve as an important example of the success of sustainable fisheries management, and similar approaches should be investigated in the context of the high seas fish stocks and ecosystems. The SAUP catch reconstructions [38] are an ample and comprehensive resource for studying the high seas fisheries in general and estimating the extent of IUU fishing occurring in the high seas. The scope of this paper was relatively broad and, therefore, more in-depth studies are required. For example, new studies could look further into the following aspects within the SAUP dataset in conjunction with the other available high seas data:

- Association between catch quantities of countries and their reporting levels; are fisheries with certain catch levels (low, medium, or high) more or less likely to have unreported catches?
- The role of subsidies in different catch levels of high seas fisheries; is the amount and type of subsidies (i.e., beneficial, harmful, or ambiguous; [2] connected with gear types and the reporting levels of catches?
- In addition to 'country' and 'gear type', what are the other drivers of catch variation in high seas, and are the other potential drivers natural or anthropogenic?
- The sustainability of high seas fishing gears; what are the fleet demographics (e.g., fleet size, employees, subsidies, and landing values) of different high seas gears, and could the use of purse seine and longline be restricted to reduce overcapacity?

5. Conclusions

As we have passed the deadlines for both the CBD and the UN global targets without achieving them, we have now entered into a new UN decade: the Decade of Ocean Science for Sustainable Development, 2021-2030. Meanwhile, the culture of inequality and unsustainability of high seas fisheries is becoming increasingly obvious. A handful of high-income countries with subsidy-fuelled fleets remove large quantities of biomass from the high seas, leaving the scraps for developing and smaller nations. While global fish stocks are declining, high intensity fisheries cause collateral damage to entire food webs, ecosystems, and non-target species. Prevalent IUU fishing worsens the damage both economically and ecologically. Governance issues and lack of high seas conservation measures delay the actions needed to protect the high seas ecosystems and fisheries. High seas fisheries are large-scale operations that require large-scale solutions, such as overarching, multijurisdictional governance, and large mMPAs as part of the new BBNJ agreement. While the contribution of high seas fisheries to global catches is small, it would seem the role of the high seas as a supporter of EEZs is not. Catch reconstructions can play a valuable part in high seas fisheries management and conservation; the trends and observations from papers such as this will benefit all high seas stakeholders.

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