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Review Article

Challenges of illegal, unreported and unregulated fisheries in Indian waters: Plausible mitigation measures

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Marine fisheries sector provides not only a major source of high-quality animal protein but also ensures food security for fish-consuming populations at reasonable costs. With ~200000 fishing crafts, including mechanised, motorised, and non-motorised crafts, marine fishing, landing, and sales activities employ close to 4 million fisherfolk in recent years. India, with a mainland coast length of over 7000 km and 3000 km of island coastline, is among the top 10 marine fishing nations in the world. The annual contribution of marine fisheries to India's GDP is about 1.1 %, and 5.4 % of agricultural GDP. India, being a leading seafood exporter, the marine export earnings accounted for about 3.5 % (≡ 9.30 billion US$) of total exports in 2021. Notably, there has been a double-digit average annual growth rate of 10.87 % since 2015. Using the relevant datasets of 1950–2023 marine fish landings, this paper attempts to compile information on reported, unreported, and discarded catches. In addition to adverse climate change impacts, illegal, unreported and unregulated (IUU) fishing and coral reef degradation are crushing the nearshore fisheries. To provide a reasonable inference on IUU fishing aspects, literature-based data of Indian oil sardine and Indian mackerel, together accounting for close to 25 % of total landings, along with their pertinent biological characteristics, are used to showcase the IUU fishing for 2000–2023. A careful estimate reveals a revenue loss of over Rs 4 billion to the state of Kerala alone from unreported and discarded catches of Indian oil sardine and Indian mackerel. In view of the SDG 14 target of the subsequent withdrawal of diesel/fuel subsidies, a few steps, in particular strategies for offshore patrolling and the modification of the Marine Regulation Act to revise the minimum legal mesh size of certain gears that could reduce overall IUU, are discussed.

[**Keywords**: Fuel subsidies, Illegal Unreported Unregulated (IUU) fishing, Indian mackerel, Indian oil sardine, SDG 14, Marine fisheries, Maximum Sustainable Yield (MSY), Mesh size]

Introduction

The process of food production stands tall among the most vital ecosystem services provided by the marine ecosystem. Over 80 % of all life forms on Earth are living in the oceans, which provide protein-rich food to people of all strata of society across the globe. The other important ecosystem services of the oceans are the deep ocean system as a major heat sink, slowing anthropogenic global warming[1]; biogeochemical cycling and recycling of elements and nutrients; recreational and spiritual benefits; and energy-efficient means facilitating transoceanic trade and transportation[2]. Over a third of emitted CO_2 is absorbed by the oceans[3,4] through its physical, chemical, and biological processes. A large portion of this CO_2 is photosynthetically transformed into marine biomass that sustains the food web in marine ecosystems. While this phenomenon of CO_2 absorption by the oceans at the surface is vital for its pivotal role in climate-regulating services[5], the marine biomass production revealed by microscopic autotrophic phytoplankton and a gamut of macrophytes/ plants, nurtures all heterotrophic life forms, from bacteria to fish to whales and seabirds. Climate regulation, including carbon sequestration, will remain a critically important service provided by the deep sea as CO_2 emissions continue to increase[6]. Thus, the global ocean is the largest carbon sink and a key source of food and economic security for billions of people[7].

Furthermore, oceans drive global systems that make Earth habitable for humanity by providing and regulating rainwater, drinking water, weather, climate, coastlines, food, and the oxygen we breathe[4]. While the services provided by global marine ecosystems are valued at US$ 29.5 trillion annually[6], they are reported to contribute US$28 trillion annually to the global economy. While the ocean's relevance to

humanity's future is undisputed, it is not always fully appreciated[9]. The ocean has much greater potential to drive economic growth and equitable job creation, sustain healthy ecosystems, and mitigate climate change than is realised today[9]. The annual market value of marine and coastal resources and industries amounts to ~US$ 3 trillion (nearly 5 %) of global GDP.

Fish is among the most widely consumed foods in the world. As economies expand and individuals earn more money, the preference is to consume fish from a healthy life viewpoint. As such, the worldwide preference for seafood has been growing, particularly in recent decades. Up from 184.6 million metric tonnes in 2022, the global fish production expanded to 186.6 million metric tonnes in 2023. The seafood market worldwide is expected to grow considerably over the next several years. The global seafood market was valued at USD 358.68 billion in 2023 and is expected to more than double to USD 837.17 billion by 2032(ref. 8). The country that catches the highest volume of fish is China, followed by Indonesia and India[9]. China is also home to the largest fish and seafood processing industry in the world, generating USD 31.6 billion in revenue in 2018.

The global marine fisheries are experiencing tremendous fishing pressure. The 2017 fish catch, with and without attuning, respectively, indicated 6 % underfished stocks, a significant 60 % maximally fished, and up to 34 % overfished in a scenario without adjusting the harvested weight. With the weight adjustment, it was evident (Fig. 1) that 79 % of stocks were sustainably fished and 21 % overfished. Illegal, Unreported, and Unregulated (IUU) fishing results in long-term unsustainability due to environmentally destructive fishing methods, damage to marine ecosystems, threats to food security, and detrimental socio-economic impacts for structured and legal fishing.

The embroglio of IUU

Illegal, Unreported, and Unregulated (IUU) fishing is a global problem that violates lawful and mutually compatible fishing regulations both nationally and internationally[10]. The IUU threatens economic security and destroys natural resources that are critical to local populations and fishers, apart from hampering food security and the global seafood supply chain[10]. Notably, the IUU poses both long- and short-term disadvantages to law-abiding fishermen, marine farming, and seafood-producing communities.

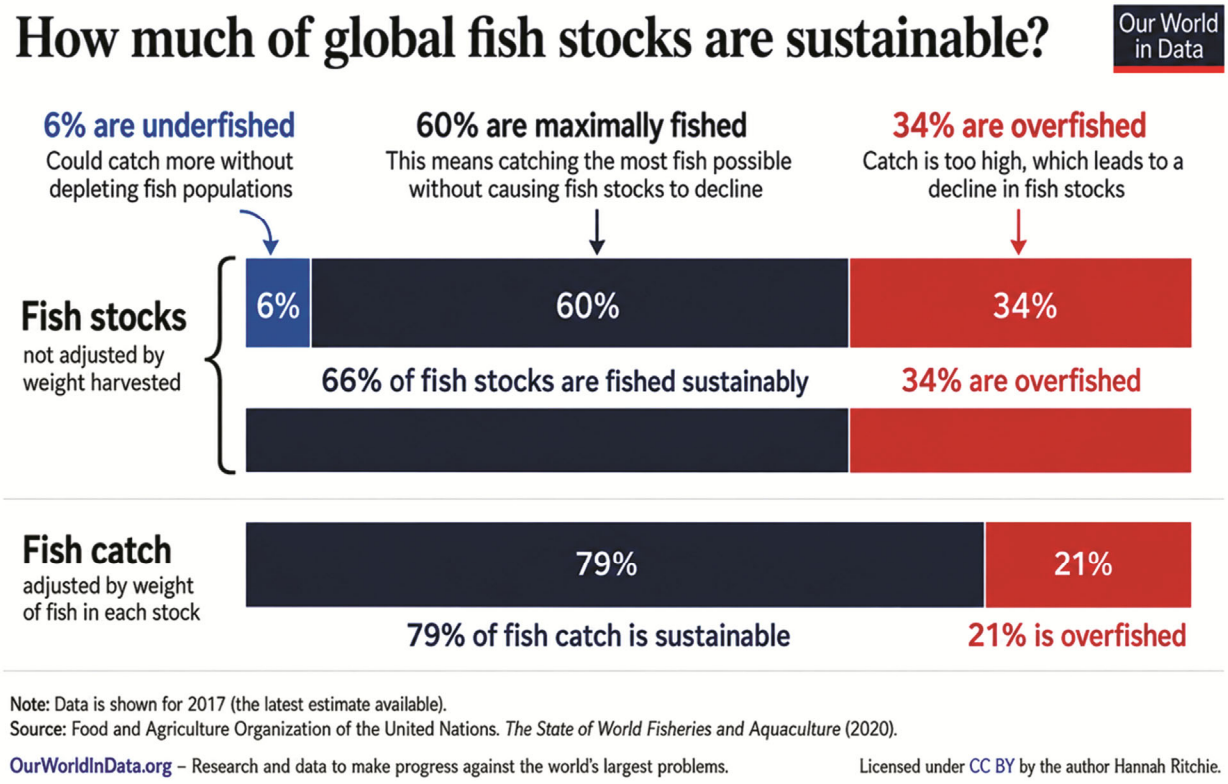

Fig. 1 — Summary of sustainable global fish stocks according to FAO, 2020(ref. 77). Figure taken from *Our World in Data*[77]

The IUU practices can be summarised as those that are quite detrimental to both the sustainable and continued harvesting of marine fish resources. NOAA (2021)[10] highlights the following as IUU activities: Fishing without a license or quota; not reporting catches or providing false reports; capturing undersized fish and those that are protected by regulations; fishing during closed seasons, fishing in protected areas; use of prohibited fishing gear; unauthorised transshipments of catch at sea to cargo vessels or overseas. Therefore, the direct threats posed by IUU fishing activities are manifold and global. Socio-economic solidarity, seafood security, and export income for many developing countries, including India, are most at risk from IUU fishing[9].

The unlawful and irresponsible nature of IUU fishing makes it difficult to accurately estimate the full global economic impacts resulting from IUU activities. For example, total catches in West Africa are estimated to be 40 per cent higher than the reported catches[12]. Many crew members on IUU fishing vessels are from poor and underdeveloped regions of the world, and they often work in unsafe conditions. The United Nation's Food and Agricultural Organization (FAO) estimates that IUU costs tens of billions of dollars each year to global fisheries. Indeed, there is little disagreement among the various studies that assessed regional levels of IUU fishing and estimated global losses in the billions. The FAO is currently developing regional IUU estimation tools and methodologies that can be regularly updated in view of changing patterns in fishing practices and to provide tactical insights into how to deal with contemporary IUU wrongdoing. Implementing the outcomes of the recommendations in the FAO action plan, based on recent research, will help gauge the actual level of activity and impacts so that they can be appropriately addressed.

Adverse impacts of IUU fishing

The primary victims of IUU fishing are conservation and management measures; all fishers and fishing companies participating clandestinely in IUU fishing circumvent the regular norms. This process could be used to save on the licence fee and to avoid incurring certain allied operational costs[12]. Besides hampering sustainable fishing practices, the very intent of IUU is to derive economic benefit from exceeding harvesting limits without reporting them either accurately or responsibly. As a result, their illegally caught products can be sold at cheaper rates. Perceivably, this would help unlawful fishers and companies engage in unfair competition in the marketplace for the seafood industry as a whole and law-abiding fishermen in particular. Additionally, IUU fishing is certain to cause an imbalance by 'dumping' lower-quality fish products into the markets of the seafood-importing nations. This can be a two-pronged serious threat: firstly, by challenging the sustainability of global marine fisheries, and secondly, by encouraging law-abiding fishers and companies to indulge in IUU activities, at least occasionally[13].

An overview of India's marine capture fisheries

With the recalculated coastline length of 11098 km coastal line (incorporating bays, estuaries, inlets, other geomorphological features and replacing the straight-line measurement approach[13]), about 2.02×10^6 sq km of exclusive economic zone (EEZ) and over half a million sq km of continental shelf, India's estimated fisheries potential is 4.41 million tonnes. Not with standing some interannual fluctuations in the marine fish stocks, the fish landings have increased from around 0.5 million tonnes in the 1950s to around 4 million tonnes in recent decades (3.53 million tonnes for 2023[(ref. 14)]). This coastline is shared by nine maritime states, and two union territories in the mainland and two island territories *viz*., Andaman and Nicobar, and Lakshadweep. The marine fisheries resources remain spread along the country's vast coastline of about 8118 km, and over the 2.02 million km^2 Exclusive Economic Zone (EEZ) and 0.53 million km^2 continental shelf[15]. The total fish production in the country rose from 0.75 million tonnes in 1950–51 to 14.16 million tonnes in 2019–20, owing to over 11 million tonnes of fish produced inland almost exclusively through culture fisheries. Situated in the tropical belt, the nation's marine fisheries are typical multi-species systems. Due to this, the management is manifold, fishing methods are diverse; tackle gear and fleet are of various types. Close to 3 million fishermen go to sea and an equal number support the supply chain of the marine fish and shellfish harvests, including the processing units. As a result, formal and countless informal agreements and conflict management systems are in practice in the islands, union territories and maritime states as highlighted by Pido *et al*.[12]. From a socio-economic perspective, marine capture fisheries are an important national priority activity. India is the third-largest producer of fish in the world. Apart from generating and employing mostly non-skilled and/or semi-skilled

youth and traditional fisherfolk, India's marine fisheries sector is a notable contributor to foreign exchange earnings. Indeed, marine fish and fisheries are unique primary sources of livelihood for a section of the population steeped in tradition and fishing skill.

Since its inception in 1950, the Central Marine Fisheries Research Institute (ICAR-CMFRI), with its primary mandate of continuous Research & Development in marine fisheries, has been the repository of information, various types of data, and knowledge sources on marine fisheries and aquaculture. The institute monitors and evaluates India's exploited marine fish resources to derive management measures to keep the harvest of these resources at sustainable levels[14]. As has been the continuing practice, the process of monitoring fish, shellfish, and seaweed resources and their harvesting/exploitation includes national-level sample surveys that are conducted regularly and are improvised. For instance, the institute recently employed a two-stage stratified random sampling design enabled by the online data collection app, namely, Fish Catch Survey and Analysis (FCSA). In this data collection approach, these devoted 'harbour-based observers' with species identification skills are mandated to visit the landing centres according to work schedules generated under the sampling scheme and record different aspects of the fishery from sampled boats. Using such methods and by intensive training and deploying such trained/skilled technicians, the institute compiles datasets from 1250 landing centres all along the coast, which would be processed to derive species-wise, zone-wise, gear-wise and month-wise marine fish landings along the Indian coast, covering the nine maritime states and union territories.

As in other maritime countries, marine fisheries are an important source of food, employment and income in India too. Marine fisheries provide and sustain the livelihoods of ~16 million fishers and fish farmers at the primary level itself. This number doubles along the fish value chain. In this article, the focus is on the IUU and its disadvantages faced in Indian Marine Fisheries Sector with a view of highlighting how this problem is a challenge in deciphering the shortcomings faced on the way of meeting up the targets put forth under the SDG 14.6, which has an ultimate task of eliminating subsidy provisions to fuel purchases for marine vessels used by certain groups of fishers engaged in sea fishing. The activities in contravention of applicable legal norms, stipulated laws, and traditionally practised rules can be termed illegal. The missing diligence and practice of documenting the quantum of available resources and/or their harvests can be termed unreported. Missing management and/or conservation steps for resource protection and sustainable harvesting qualify as unregulated. The unlawful, undocumented, and non-managed activities are best exemplified in the marine fisheries sector.

IUU fishing in India's waters

Fish, being an affordable and rich source of animal protein, is one of the healthiest options to mitigate hunger and malnutrition. India is the third-largest fish producer in the world. Fish production in the country has shown continuous and sustained increases since independence (1947). The annual average growth rate is about 8 %. While freshwater or inland fish production was either non-existent or unrecorded/ unreported at the time of independence, about 74 % now comes from inland sources in recent years, and the rest is contributed by marine capture fisheries. The total fisheries potential of India has been estimated at 22.31 million metric tonnes; of this, the marine fisheries potential stands at an estimated 5.31 million metric tonnes[16]. The landings of marine fish during 1950–2023 are displayed in Figure 2. Indeed, during the decade of 2003–2012, the marine landings were very high vis-à-vis the occasional peaks in 3 or 4 years previously as visualised in Figure 2.

Specific IUU fishing practices occurring in India

The FAO and IMO outline concrete instances of IUU fishing that occur in Indian waters and adjacent seas and group them into three categories, namely: 1. Illegal practices; 2. Unreported practices; and 3. Unregulated practices.

Among the illegal practices, cross-border incursions into foreign EEZs are a major issue. Unauthorised fishing across maritime boundaries is reported to result in arrests and seizures in Sri Lankan and Bangladeshi waters[39,40]. Another unlawful practice is fishing during seasonal closures. Despite state-specific monsoon fishing bans intended to protect spawning fish stocks, violations by mechanised fleets continue to occur along both coasts, with repeated enforcement actions documented by state authorities and local media[41,42]. The use of prohibited or destructive gears also poses serious threats to fish stocks. Although bottom trawling and

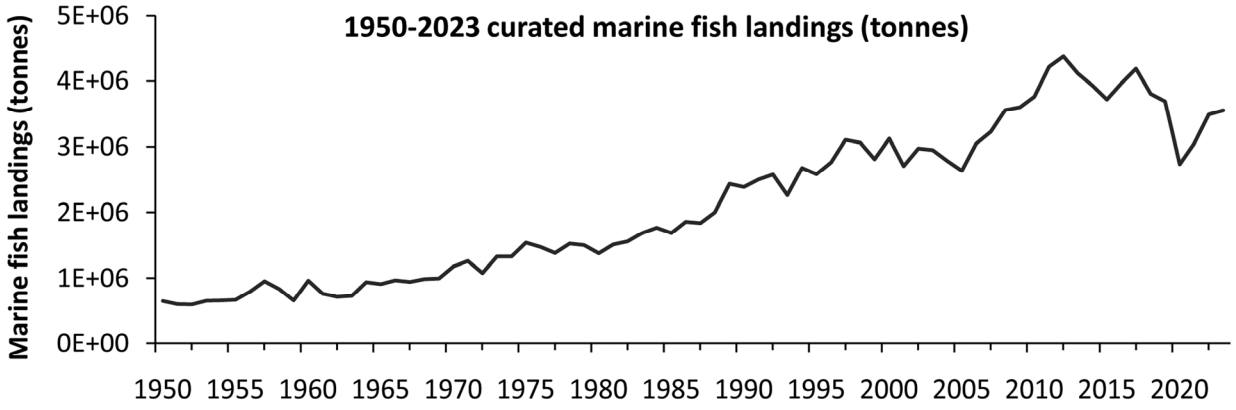

Fig. 2 — Annual landings of marine fish from India during 1950–2023

certain small-mesh nets are prohibited or restricted in several states, reports indicate continued use of such gear in nearshore and estuarine habitats, causing seabed degradation and ecological harm consistent with global assessments of destructive fishing methods[43,44].

According to sustained research efforts[45,46], a substantial proportion of India's small-scale and artisanal fishers' land catches at informal beaches and minor landing sites where systematic reporting is absent, creating persistent gaps in national fisheries data and stock assessments. Additionally, non-reporting and under-reporting of catch, as well as misreporting of species and their quantities, are apparently serious issues. High-value species such as tuna, sharks, and seer fish are sometimes misreported or aggregated under generic categories, undermining accurate monitoring within India's national systems and regional frameworks, such as the Indian Ocean Tuna Commission[47,48]. Further, significant numbers of small motorised vessels continue to operate without complete registration or valid licences in several maritime states, thereby enabling fishing effort to remain outside official monitoring and reporting mechanisms[47].

Kumar & Bhatt[49] and Valli[47] list (a) Distant-water fleets near India's EEZ and on the high seas, (b) Gaps in RFMO coverage, stateless, and (c) AIS-dark operations as unregulated practices. Notably, remote-water fishing fleets, including vessels linked to China and other extra-regional actors, operate close to India's EEZ or in high-seas areas with weak regulatory coverage, posing indirect but significant risks to Indian fish stocks. Parts of the Indian Ocean remain outside comprehensive regional fisheries management regimes, enabling unregulated exploitation of migratory species such as tuna and squid beyond national jurisdictions[50,48]. According to Polepalli[51] and IMO[44], some vessels deliberately disable AIS transponders or operate with obscured identities, significantly hindering detection, attribution, and enforcement, and increasing the likelihood of IUU fishing activity.

Data and Methods

For the analysis of IUU fishing, the following published data/data sources are used. Total reconstructed or curated marine catches were estimated by Ansell *et al*.[17] for the Indian mainland EEZ during 1950 to 2018. The annual landings data published by the CMFRI for the years 2019 to 2023 were used. Curated catch data of reported, unreported and discards reported by Ansell *et al.*[17] were used.

Species-specific landings data on Indian oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) from 2000 to 2023, as published in CMFRI annual reports, were used for the various determinants listed later. The landing data and many biological characteristics of these two species were considered to provide a possible overall impact of IUU fishing on the whole. This is because these two fish species often form very large shoals running into tens of tonnes and are caught using purse seines/trawls with smaller mesh sizes that trap undersized, immature, and juvenile or under-aged stocks. Notably, they contribute year on year to 15 to 25 % of total marine landings and close to 50 % of all pelagic fish harvested from the seas around India. Using these data, it was rationalised that unregulated and illegal aspects of marine fisheries could be inferred.

An extensive review of existing studies revealed a lack of long-term or time-series data on size variations for over 10 predominant fish species that constitute the bulk of Indian marine landings. The exception is the study by Kripa *et al*.[18] on the Indian oil sardine, which provided valuable insights into size ranges over time. An attempt is made in this analysis to determine if the sizes of both oil sardine and mackerel landed could be useful in suggesting the legality of their harvestable sizes/ages. Thus, the inferences drawn in this paper rely heavily on the insights provided by that study.

Fishing fleet data from publicly available datasets on various types of fishing fleets were analysed to understand the costs associated with diesel subsidies. This analysis aims to explore how subsidies could be restructured to align with Target 6 of the United Nations Sustainable Development Goal (SDG) 14, which focuses on prohibiting certain forms of fisheries subsidies that contribute to overcapacity and overfishing. In order to provide an overview of the number of licensed fishing vessels and to establish their possible relationship with the IUU fishing, the available information in the public domain for the years 2016 (CMFRI) and 2022 (MPEDA) are made use of.

Salient features of India's marine fish landings and IUU impacts

In Figure 2, the 1950–2023 annual landings of marine fishes comprising pelagic, demersal and shellfish are presented. In the years from 1950 to 1969, the average growth in landings, the marine fish harvests grew from about 1.1 million tonnes in 1969 to 1.87 million tonnes by 1988. It was in the range of two million plus tons during the mid-1980s, with quite high reported landings in 1988. Further, the highest landings were reported in 2008, with the trend continuing to remain high until 2012. On a decadal scale, beginning with a low of 0.65 million tonnes in 1950, the first million tons of landings were in 1968. The fish landings, while on an increasing trend, fluctuated inter-annually between 2 and 3 million tonnes during 1987–1998. Gradually, the landings increased to 3.75 million tonnes by 2010. Most notably, the highest landings happened during the period from 2011 to 2019. Afterwards, the landings showed a decreasing trend from 2019–2023. In terms of percentage variation, during 1950–1970, the overall increase was 23.5 %. From 1971–1990, a close to 200 % rise was seen. From 1991–2010, the increase was 1.5 times (or 150 %) growth over the 1971–1990 period. From 2011–2023, there was a 16 % decline relative to the growth seen during the previous years from 1991–2010. Overall, a decline was seen from 2013 until 2018. The recovery can be inferred from the post-COVID years of 2020 and 2021.

Unreported and discarded fish percentages during 1950–2023

In Figure 3, the percentages of reported, unreported, and discarded harvests are presented. The data used to draw this figure are from Ansell *et al*.[17] who had ascertained the "high trust in the quality of the CMFRI data as the best estimates available" for the reported period, which produced low overall uncertainty

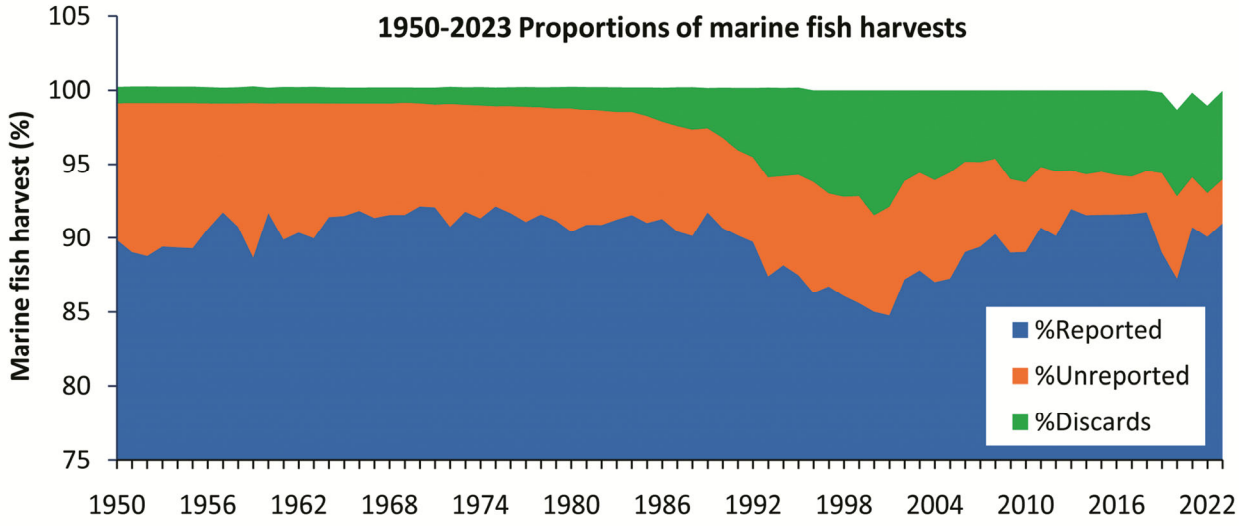

Fig. 3 — Proportions of reported, unreported and discarded marine fish harvests during 1950–2023

estimates for catch-weighted total reconstructed/ curated data of catches from 1950 to 2018. For the 2019 to 2023 landings data, the published data available in the corresponding annual reports of CMFRI were used, and the percentages of reported, unreported and discards were estimated following Ansell *et al*.[17] in this analysis. Briefly, the reported catches invariably varied between 84.78 % (in 2001) and 91.97 % (in 2013). The percentage of unreported catch ranged between 2.54 % (in 2017) and 10.46 % (in 1959). During the first 30 years, the percentage of discarded catch was under 2 %. However, it increased gradually to as high as 6 % in 2010 and stabilised to around 5.5 % over the next 13 years.

A case study of the Indian oil sardine and mackerel fishery for assessing IUU fishing impact

The annual harvest of the commercially most dominant pelagic and shoaling fish species, the Indian oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*), were extracted from the CMFRI repository (CMFRI annual reports from 2000 to 2023). These data are presented in Table 1, and for ease of comprehension, the same are depicted in Figures 4 and 5.

Together, these two species contributed around 7.35 % in 2019 to as high as 21 % in 2007 (Fig. 5). Their proportions of reported, unreported and discarded catches are shown in Figure 6. The overall mean percentage for the 24-years (2000–2023) period is 16 % of the total marine landings. As mentioned previously, because of their sizable contribution to the marine fish landings, an analysis of their biological characteristics (Table 2) and for the State of Kerala their Maximum Sustainable Yields (MSY), the loss due to unreported and discarded catches and a possible gain in biomass if the immature juveniles are not netted and/or unreported/discarded are derived and, along with contextual/relevant socio-economic parameters are presented in Table 3.

Briefly, the oil sardine in Kerala, known as *Kutumbampularthi* (a livelihood option for coastal fishermen), is a significant fish with a maximum life span of 2.5 years, attaining a reported maximum length of up to 23 cm. It is reported to grow to a maximum weight of 94 g. The fecundity of adult (> 18 months old) females averages around 1.82 lakh oocytes[19] (see Table 2 footnote for references). However, the mean length and weight in the landings are 15.7 cm and 42.43±15.19 g, respectively. The

Table 1 — Total landings (in tons) of marine fish in 2000–2023: Indian oil sardine and mackerel

Year	Total landings	Oil sardine	Indian mackerel	% Oil sardine	% Indian mackerel
2000	3120024	367537	172040	11.78	5.51
2001	2704155	267790	90130	9.90	3.33
2002	2968710	347743	95628	11.71	3.22
2003	2945478	403952	113444	13.71	3.85
2004	2785856	381448	143333	13.69	5.15
2005	2629846	328636	125172	12.50	4.76
2006	3043949	394598	141918	12.96	4.66
2007	3227671	497264	178734	15.41	5.54
2008	3556565	444593	158913	12.50	4.47
2009	3599701	414767	185932	11.52	5.17
2010	3757710	488205	267250	12.99	7.11
2011	4211651	609111	278503	14.46	6.61
2012	4368165	720270	170410	16.49	3.90
2013	4111789	595392	202218	14.48	4.92
2014	3924064	544684	237056	13.88	6.04
2015	3717578	265667	237876	7.15	6.40
2016	3962807	244992	249641	6.18	6.30
2017	4184591	337390	288516	8.06	6.89
2018	3801059	155450	286056	4.09	7.53
2019	3690100	145083	165226	3.93	4.48
2020	2730000	21600	179000	0.79	6.56
2021	3047485	87195	214441	2.86	7.04
2022	3490299	251257	328000	7.20	9.40
2023	3548872	245420	343095	6.92	9.67

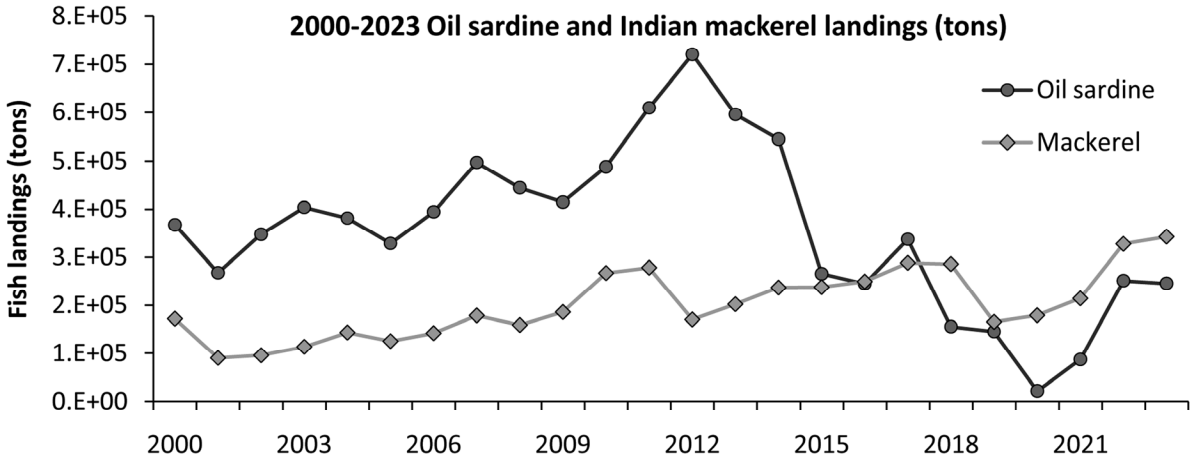

Fig. 4 — Oil sardine and Indian mackerel landings (in tons) during 2000–2023

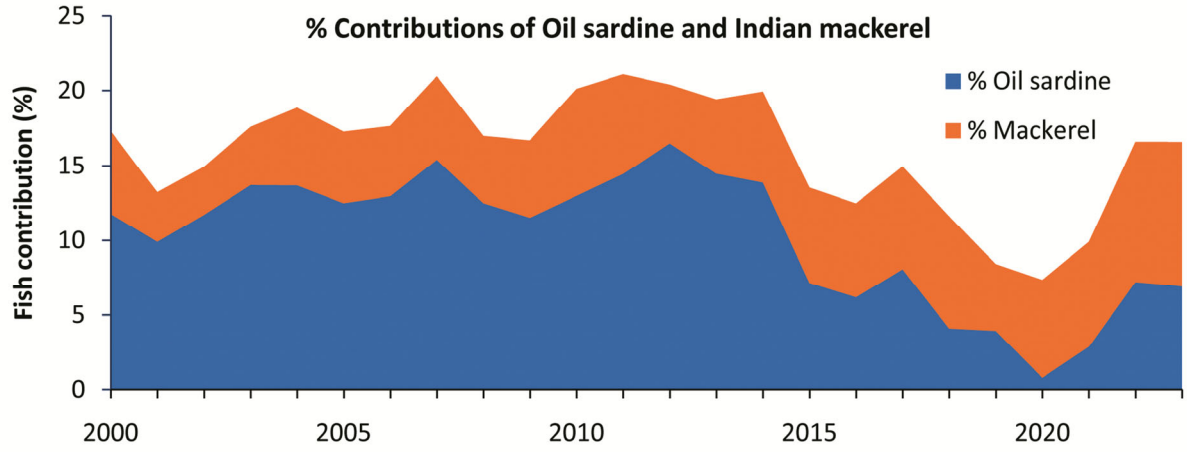

Fig. 5 — Percentages of Oil sardine and Indian mackerel landings in total landings during 2000–2023

major size modes in the landings are < 10–12, 10–14, and 15–18 cm. Usually, the Indian oil sardine is caught when the fish is about 8–9 months old, with mostly immature juveniles. The length composition of oil sardine catches is reported to range from 5.0 to 22.0 cm[19]. First time spawners of 14–16 cm length enter the fishery on the Malabar coast during June/July, and as per Kripa *et al.*[18], with progressing season, adult quantities reduce by September–December and the later catches are dominated by juveniles/immatures of 12–14 cm size. This small-sized catch, perhaps, explains the increased trashing/discarding of juvenile fish with hardly any flesh for consumption. In addition, recently, seafood taste preferences have narrowed down to quality flesh among many consumers these days who can afford to buy the high-priced larger-sized carnivorous fishes, mostly in the Order Perciformes.

Similar details of biological characteristics for the Indian mackerel are also presented in Table 2. Indian mackerel is a large-sized pelagic species with a much longer reported life span of 4 years and weights up to 270 to 280 g, and the fecundity of 2+ years old is close to 3 times that of smaller-sized and shorter-lived Indian oil sardine[20] (see Table 2 footnote for references). Yohannan & Sivadas[20] reported the average length frequency distribution of mackerel in the size group 110–150 mm with a mode at 145 mm along the west coast of India, which perhaps requires reanalysis owing to the increased percentage of discards observed in the last two decades.

The capture fisheries details of Indian oil sardine and Indian mackerel from Kerala (Table 3) estimate an MSY of 150000 tonnes for Indian oil sardine[21]. However, because of the excessive fishing, the recent (2008–2023) mean landings for the 16 year period

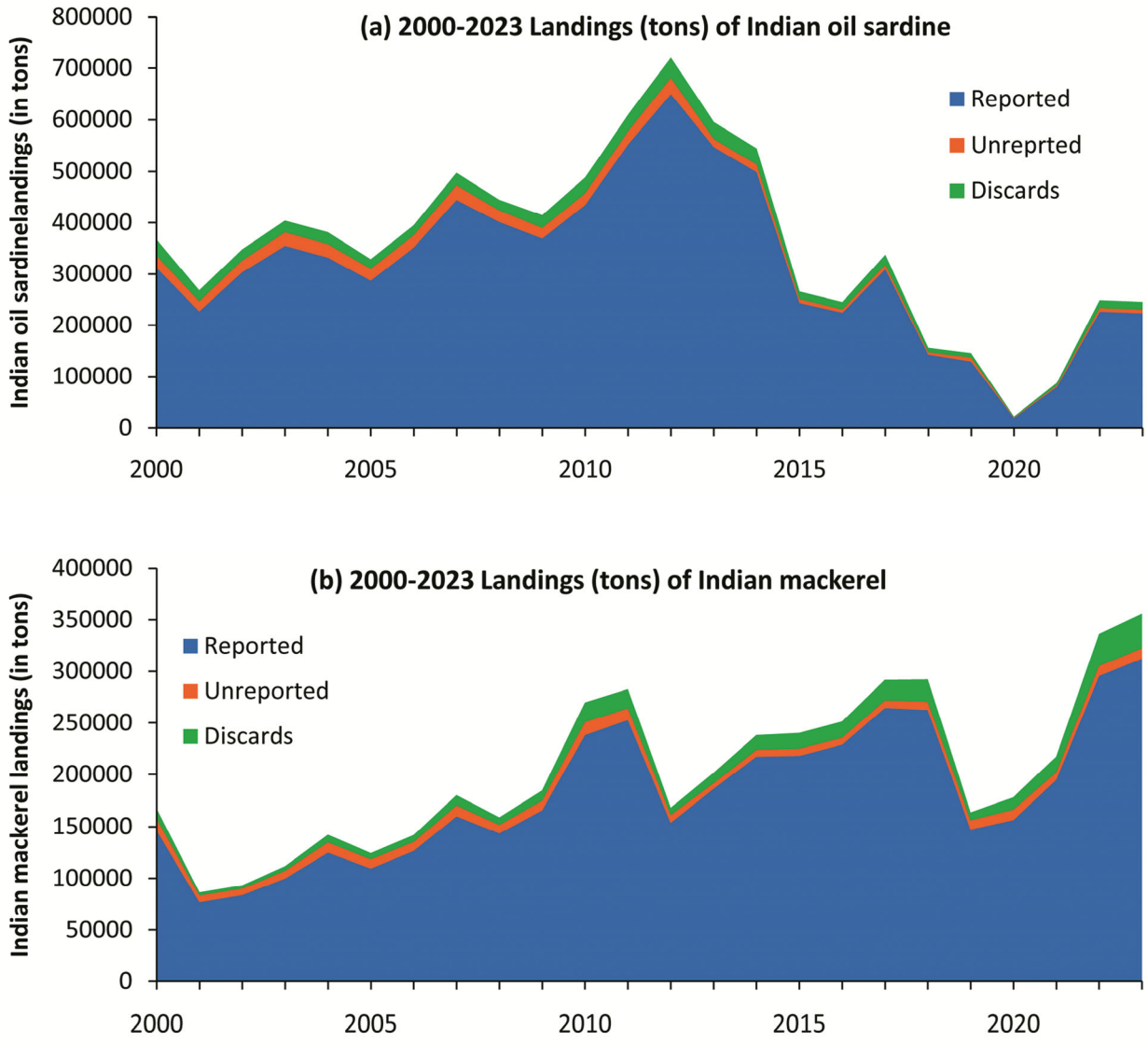

Fig. 6 — 2000–2023 landings (in tons) of reported, unreported and discarded catches of (a) Indian oil sardine, and (b) Indian mackerel

from 2008–2023 were as high as 348192 tonnes. The decadal growth patterns in landings and their mean percentage contribution to total fish landings in the state of Kerala, along with many other details for both oil sardine and mackerel are provided in this Table. These figures are arrived on the basis of the vital biological parameters of maximum possible growth for these two species reported from the coastal waters of Kerala. The important point to recognise is that the annual discards of sardines exceed 20000 tonnes per year from the mean reported landings of over 319000 tonnes. Further, over 168000 tonnes of the sardine catch off the coast of Kerala go apparently unreported every year in this period of 24 years considered in this analysis. Hence, the economic losses due to discards/trashed and due to unreported oil sardine catch exceed Rs. 2.2 billion. Similarly, the losses from the discarding of undersized mackerel and its unreported catches (presented in Table 3) total to over Rs. 1.35 billion. Vivekanandan *et al.*[22] highlighted that, back in the 1980s, the large-scale exploitation of juvenile Indian mackerel is a major factor limiting the yield of the fish stock.

To estimate the loss in the number of immature/juveniles of both oil sardine and mackerel, an analysis is conducted in this study. It is important to note that as many as 749 million juveniles of oil sardine of an average weight of ~27.24 g each are lost

Table 2 — Some biological characteristics of Indian oil sardine and mackerel from coastal waters of Kerala state

Characteristic	Oil sardine	Indian mackerel
Maximum life span (longevity; years)	2.5	4
Maximum reported length (cm)	23	35
Mean length of first year recruits (cm)	15	10–14
Mean length of second year recruits (cm)	18.8	18–23
Peak spawning period	May–August	March–September
Mean length at Ist maturity (mm) male: female	152.0:157.0	172.7:174.7
Fecundity (no. of oocytes/female)	15836–182237	27027–370607
Size of immature fish	Up to 15 cm	Up to 16 cm
Mean weight in grams of 15 cm juvenile	14	21
Mean weight in grams of adults	89.4–94.6	270–280
Mean length and weight in landings	15.7 cm; 42.43±15.19 g	17.2 cm; 55.7 grams
Major size modes in landings (cm)	< 10–12; 10–14; 15–18	9.5–10; 13.5–14; 22.5–23
Mean weight of landed catches (grams)	42.43	55.7
Age at first capture (months)	8–9	5

*Data compiled from CMFRI Annual Reports (2000–2023), Central Marine Fisheries Research Institute, Kochi, India

Table 3 — Capture fisheries details of Indian oil sardine and Indian mackerel

Characteristic	Oil sardine	Indian mackerel
Maximum sustainable yield (tons)	150000[#]	637667[#]
Maximum economic yield (tons)	107000[#]	578012[*]
16-year (2008–2023) mean landings (tons)	348192.3±204985.7[+]	237008.3±58177.7[**]
Decadal growth pattern in landings (%)	1985–1996: -15.80[#] 1997–2006: 12.19[#] 2007–2016: 35.55[+] 2017–2023: -63.19	1985–1996: 12.19[*] 1997–2006: -5.15[**] 2007–2016: 67.01 2017–2023: 18.97
2000–2023 mean % of total fish landings	10.22±4.39	5.77±1.68
2000–2023 mean reported landings (tons)	319270.9±154109.8	181718.6±66462.78
2000–2023 mean unreported catch (tons)	16860.39±9363.4	8574.96±1856.32
2000–2023 mean discards/trashed (tons)	20396.59±9390.75	12725.53±8001.55
2000–2023 loss from trashing @Rs100/kg	Rs 2039.66 million	Rs 1272.56 million
2000–2023 unreported catch loss @Rs100/kg	Rs 168.61 million	Rs 85.75 million
No. of individual fishes lost/year due to immature individuals trashed	748773495 @27.24 g/fish	244510600 @avg 50 g/fish
Biomass gain (tons/yr) by landing adults	50632.06 by landing 67.62 g adults	15496.18 by landing 139.15 g adults
Fishing pressure	Strong post-2013	Moderate to high
Major gear/s used	Ring/beach seines; gillnets	Purse seines, trawlers
2000–2023 mean catch/seagoing fisher (t/yr)	1.45	0.99
Total number of boats in use in 2022[#]	43812 for all types of fish harvests	
Total number of marine fisherfolk in 2022[#]	812223 doing fishing sales and household jobs	
Number of seagoing fishermen in 2022[#]	240867 for all types of fish harvests	
Amount of Diesel subsidies in 2021–22[#]	Rs 450 million for all types of fish harvesting	

Data from: [#]CMFRI annual reports; [+]Sivadas *et al.*[21]; [*]Ashwathy & Narayankumar[23]; [**]Kripa *et al.*[18]

every year due to netting and discarding them either at sea or by selling clandestinely (?) to some fish meal plants. Supposing that these individuals were allowed to grow to the landing-sized adults of 67.62 g[23], the total biomass gain would be an additional value of 50632 tonnes. Similarly, Indian mackerel immature individuals of close to 250 million, 50 g each, are trashed. If the trashing had been avoided, the biomass of these individuals, if allowed to grow to 139.15 g, would have amounted to an additional 15500 tons every year. From many other pertinent details provided in Table 3, it is worthwhile to note that apart from harvesting 1.45 tonnes of Indian oil sardine and about one tonne of Indian mackerel, every one of over 2.4 lakh sea-going fishermen might end up harvesting close to 4 tonnes of fish and shellfish.

While there were some years of decreased sardine landings prior to 2013, for instance, the ones seen post-2013 in the oil sardine landings stand out. Notably, the oil sardine catch of 3.9 lakh tonnes in 2012 was the highest in the last two centuries[18]. The decline started almost immediately, as can be seen in the data presented in Table 1. Indeed, landings from Kerala declined by 46 % in 2013, then by 61 % in 2014, and by a whopping 82 % in 2015, as reflected in the analyses conducted in this study (Table 3). Thus, over a span of 5 years, the state witnessed the highest and lowest catches.

The main cause of this continuous decline could be attributed to both climate change impacts[52] and unregulated fishing practices. While details of what percentage of fisheries is affected by the adverse impacts of climate change are yet to be ascertained, back in the late 1990s, there was already precautionary information available on how the netting of small-sized immature oil sardine and mackerel could affect the fishery in the following years. Vivekanandan *et al*.[22] reported that the estimated landings of young fish (< 15 cm) using ring seines during the May–July 2000 period along the Kerala coast were 11,138 tonnes, which formed nearly 38 % (in weight) of the total sardine catch of the period. The worst, still, the rest of the 62 % "being constituted mainly by virgin spawners", as per Vivekanandan *et al*.[22]. Similar observations on small-sized mackerel from off the Mangalore coast were also highlighted by Vivekanandan *et al.*[22].

Relevance of fuel subsidies to reduce the IUU impacts

During 2022, at the WTO Ministerial meeting, the Agreement on Fisheries Subsidies (Agreement), prohibiting the provision of subsidies for Illegal, Unreported and Unregulated (IUU) fishing and overfished stocks, was signed[24]. However, under the Special and Differential Treatment, Developing Countries and Least Developed Countries were allowed a transition period of two-year from the date of entry into force of this Agreement. The Agreement will eliminate the subsidies granted to fishing vessels or fishing operators engaged in IUU fishing. Such disciplining will check large-scale IUU fishing, which deprives coastal countries like India of fisheries resources, thereby significantly impacting the livelihoods of our fishing communities. This Agreement also provides flexibility to extend subsidies for overfished stocks if measures are taken to rebuild fish stocks to a biologically sustainable level, thereby supporting fishing communities. Developing countries and least developed countries have been allowed special and differential treatment, with no obligation to implement disciplines for a period of two years from the date of entry into force of the Agreement.

The Agreement also prohibits providing subsidies for fishing on high seas, which are outside the jurisdiction of coastal countries. Apparently, such exclusion from providing subsidies has not been imposed for fishing in India so far, even though there are indications of overfished stocks for oil sardine[18]. As such, India's stand is that "we are one of the lowest fisheries subsidisers despite such a large population and one of the disciplined nations in sustainably harvesting the fisheries resources". India does not exploit its resources indiscriminately like other advanced fishing nations, and India's fisheries sector primarily depends on several million small-scale and traditional fishers. Therefore, those WTO Members who have provided huge subsidies in the past, and engaged in large-scale industrial fishing, which is responsible for the depletion of fish stocks, should take more obligations to prohibit subsidies based on the 'polluter pays principle' and 'common but differentiated responsibilities'[24].

Raju *et al.*[25] reported that mechanised vessels accounted for up to 75 % of total fishing operating costs, and motorised vessels for 12 to 33 %. For comprehension, the number of fishing crafts in India, as reported on the Registration and Licensing of Fishing Craft (ReALCraft, 2024)[38] website, is provided in Table 4. This is because the ReALCraft[38] is a workflow-based online application system for Vessel Registration under the MS Act and License Certificate under the MFR Act for fishing vessels operating along the Indian coast. Such authenticated information could be relied upon to ascertain the actual marine fish harvests, without leaving any scope for unreported catches.

Imminently, fuel subsidies are the most substantial type of government support sought by and provided to marine fisheries[26]. In fiscal year 2019, such subsidies accounted for an estimated 32 % of total government support to the sector. India provided Rs. 15.5 billion in subsidies to the fisheries sector in 2016, which increased to Rs. 22.25 billion in 2019, reflecting a 43 % increase, according to an estimate by the International Institute for Sustainable Development[26]. The state of Kerala provided subsidised diesel and kerosene worth Rs. 450 million in the year

Table 4 — Various types of fishing vessels in use along India coasts

State	Deep sea fishing vessel	Motorised non-mechanical	Motorised mechanical	Non-motorised	Total
Andaman and Nicobar	0	1868	117	1365	3350
Andhra Pradesh	0	19896	1860	10557	32313
Daman & Diu	2	320	2070	0	2392
Goa	0	0	2528	270	2798
Gujarat	51	11770	16607	76	28504
Karnataka	0	9670	4576	7224	21470
Kerala	10	30881	5979	2676	39546
Lakshadweep	0	1530	52	408	1990
Maharashtra	0	0	21075	7790	28865
Orissa	0	12962	1876	13640	28478
Puducherry	0	1848	646	813	3307
Tamil Nadu	0	36301	5796	3351	45448
West Bengal	0	6151	3335	6510	15996
Total	63	133197	66517	54680	254457

Table 5 — Fishing crafts in operation during different years along India's coast

Year	Traditional	Non mechanised	Motorised	Total	Reference
2008	107448	59743	76748	243939	Hofs[31]
2010	52982	73749	73410	199141	Hofs[32]
2016	25689	42985	97659	166333	CMFRI[35]
2018	65876	66198	136920	269047	Hofs[33]
2020	65876	67254	136920	270050	Hofs[34]
2023	NA	NA	NA	194490	Gopal & Edwin[37]

2020-2021[ref. 26]. With the severely dwindling catches after 2013, fuel subsidies increased considerably, by 142 %, between 2016 and 2019, which decreased slightly between 2019 and 2021. Central Government support for marine fisheries grew by 40 % from INR 458 crore (USD 68.2 million) in FY 2016 to INR 643 crore (USD 91.4 million) in FY 2019, some portions of which were diverted for fuel subsidies.

Subsidised diesel is provided to mechanised fleets, and subsidised kerosene to traditional and smaller-scale motorised vessels. Both types of boats have their respective annual limits for purchasing subsidised fuel. From the perspectives of sustainability and accountability in most states, the sale of subsidised fuel is tracked through a fuel passbook owned by the fisher of a vessel holding a fishing certificate. It is apparent from the data compiled in Table 5 that an increasing number of fishing fleets operating in Indian waters in recent years seem to possess the requisite licenses. From the SDG 14 target perspective of withdrawing fuel subsidies, albeit in a phased manner, it would be imperative to ensure certification of fishing permits for those who comply with bringing all catch ashore and complete reporting of the harvest by using permitted gear with legally permitted mesh sizes.

Marine Fishing Regulation Act (MFRA)

India's MFRA stipulates provisions for regulating fishing and conservation measures in the territorial waters. These Acts are aimed at (a) regulation of gear to avoid over-exploitation of certain species, (b) reservation zones for traditional fishermen, and (c) declaration of closed seasons. The Act also provides stipulations for each maritime state to earmark, for each category of fishing vessels (non-mechanised, motorised, and mechanised types), in the territorial waters. Commonly, across all the states, between 5 and ~10 km is reserved for operations by artisanal (non-mechanised) fishers.

The MFRA, created by the central government in 1979, sets mesh size regulations and specifically includes sizes to avoid catching juvenile fish. Mesh size regulations are important for the long-term sustainability of fisheries and the seafood export industry. They help exclude small fish, which generally lack swimming speed and stamina[24]. Though there are variations in policy across states, current mesh size regulations in practice in the coastal states of India are as follows. In the state of Gujarat, the minimum mesh size is 40 mm. In Kerala, the minimum mesh size is 35 mm for finfish trawl nets

and 25 mm for shrimp trawl nets. The minimum mesh size allowed in Karnataka is 35 mm. Further, the recommended minimum mesh sizes for different types of fish are: sardine - 33 mm, mackerel - 50 mm, croaker - 40 mm, pomfret - 126 mm, tuna - 80 mm, seer fish - 104 mm, and shrimp - 38 mm. In general, all the states are advised to follow these regulations for all seine nets and cod-ends of trawl gears. However, there are no reports or reliable indications of whether these regulations are in practice across different states and Islands. Also, there are MFRA stipulated rules, which state that (i) the area up to 9 km from the shore is reserved for non-mechanised/traditional fishing vessels and beyond 9 km for mechanised vessels; (ii) in case of trawl net, square mesh of minimum 40 mm size at cod ends need to be used; and (iii) gill net with mesh size 150 mm cannot be operated in nearshore waters.

Jurisdictional gaps in the implementation of MFRAs in India

The marine fisheries governance in India is shaped by a federal constitutional arrangement that divides legislative authority between the Union and the States. There are constitutional and legal context of Marine Fisheries Governance. Under Entry 21 of the State List, states possess jurisdiction over fisheries within territorial waters extending up to 12 nautical miles (nm) from the coast[53]. Beyond this limit, Entry 57 of the Union List vests exclusive control over fishing and fisheries in areas beyond territorial waters with the Union government[54].

Recently, Vachaparambil[55] and Correya[56] observed that in response to a model bill circulated by the Union government in 1979, coastal states enacted their own MFRAs to regulate fishing activities within their state maritime boundaries. While these Acts introduced licensing systems, gear restrictions, zonation, and seasonal fishing bans, their regulatory reach ends at 12 nm, creating structural discontinuities in marine fisheries governance.

This condition of Centre-State Jurisdictional Discontinuity Beyond 12 Nautical Miles is a major jurisdictional gap arising from the lack of continuity between state-level MFRAs and the central authority in the Exclusive Economic Zone (EEZ). Although Indian fishing vessels particularly mechanised and deep-sea fleets frequently operate between 12 and 200 nm, state laws do not extend into the EEZ[57]. Though the Maritime Zones of India Act, 1976, empowers the Union government to exercise sovereign rights within the Exclusive Economic Zone (EEZ), it does not establish a comprehensive fisheries management regime comparable to state-level Marine Fisheries Regulation Acts (MFRAs). This regulatory gap has been repeatedly acknowledged in national fisheries policy discussions, particularly regarding the absence of a dedicated EEZ-level fisheries law. Repeated attempts to address this structural deficiency most notably through the Draft Indian Marine Fisheries Bill (2017) have not advanced, largely due to resistance from coastal states and small-scale fishing communities, who have expressed concerns regarding central overreach and the potential erosion of state autonomy over marine fishing rights[58]. As a result, fisheries management within India's EEZ continues to remain fragmented and operationally weak, with inadequate monitoring, control, and surveillance mechanisms. This fragmented governance framework has enabled regulatory evasion, contributed to weak enforcement capacity, and complicated conservation efforts across the EEZ, as documented in a recent analysis of India's offshore fisheries governance[59].

Institutional fragmentation at the central level

Overall, the jurisdictional gaps and responsibility fragmentation undermine effective governance of fisheries beyond territorial waters. Vachaparambil[55] reported that the jurisdictional ambiguity is further aggravated by the multiplicity of central agencies involved in marine fisheries governance. Responsibilities are divided among the Department of Fisheries, the Indian Coast Guard, the Navy, port authorities, and research bodies such as the CMFRI, each operating within narrowly defined mandates. Thus, the absence of a single coordinating authority results in (a) weak monitoring, control, and surveillance (MCS) mechanisms, (b) limited integration of scientific stock assessments into regulatory decisions, and enforcement overlaps and delays in responding to IUU fishing[59].

In addition to inter-state jurisdictional conflicts arising from migratory fisheries[56], zonal overlaps between traditional and mechanised fisheries[60,61], there is regulatory disconnect with environmental and coastal laws[57], as well as limited legal space for community based governance[56,59]. In essence, the marine ecosystems do not conform to administrative boundaries, yet state MFRAs are territorially rigid. Fish stock migration and the seasonal movement of fishing fleets frequently lead to vessels licensed in one state operating within another state's territorial waters[56]. In essence, though the MFRAs have established a foundational regulatory framework within India's territorial waters, their

effectiveness is largely constrained by fragmented jurisdictional authority, weak centre-state coordination, and limited integration with environmental and community governance systems. The most significant regulatory gap persists in the EEZ, where institutional and legal inadequacies remain unresolved despite repeated reform efforts. A cooperative federal approach to EEZ fisheries regulation, harmonisation of MFRA standards across states, stronger linkages among fisheries, environmental, and coastal governance, as well as formal incorporation of community based management institutions, is necessary[62].

India's ways forward in dealing with IUU

The IUU Fishing is a collective term for a broad range of fishing activities considered illegal, unreported, or unregulated in law[28]. It is a genuine public policy issue for India. IUU fishing depletes fish stocks, destroys marine habitats, puts fishermen at a disadvantage and impacts coastal communities, especially in developing countries. The Government of India, through its public admittance, stated in August 2021 that *"Illegal, Unreported and Unregulated (IUU) fishing remains one of the threats to marine ecosystems due to its potential to undermine national and regional efforts to manage fisheries sustainably as well as endeavors to conserve marine biodiversity. Presence of unregistered boats in Indian waters can be a potential threat to national maritime security".* However, the India-centric examinations of IUU fishing as a domestic policy issue remain limited[36] and are indeed neglected in favour of other issues that might appear more obviously related to matters of maritime security.

Mishra[28] has provided some insights into solutions to address complex issues related to IUU. In this regard, the explanations offered using the 74-year curated and trusted CMFRI data sets in this study would be of relevance for strict implementation of the MFRA and advisories on rigorous compliance with reporting all netted catches. This study, using the examples of Kerala state oil sardine and mackerel data, demonstrates the opportunities for implementing the same in other regions and for many dominant commercial species caught in Indian waters. By compiling and collating curated data on marine landings, this attempt to address the impact of IUU fishing can be useful in deriving insights into how to improve the incomes of coastal fisherfolk and the benefits to Indian economy.

As many as 392 incidents of illegal, unreported and unregulated fishing were noted by the Indian Navy in 2021 and 379 in 2020. Apparently, most of these incidents are from outside the Indian Exclusive Economic Zone (EEZ). According to Vajiram & Ravi[29], mostly Chinese, European Union, and other countries' fishing vessels were observed to be illegally fishing, especially in the Northern Indian Ocean region. Chinese deep-sea trawlers have been a matter of concern for countries in the region, including India, due to their impact on local marine ecology. Additionally, such IUU fishing activities are certain to deplete fish stocks in the waters adjoining India's EEZ, which could traverse inside. Any stealthy fishing practices can result in economic loss for local fishermen and, more so, as Bisen[30] infers, threaten national security.

Policy mapping for overriding the IUU fishing issues

The framework of the revised National Fisheries Policy 2020 (NFP 2020) is expected to serve as a model framework for states and UTs to develop location-specific legislation and policies with regulatory and developmental features. It envisages export growth, enhanced fishers' income and better choices for consumers through sustainable development of the fisheries sector. Salim & Anuja[14] commented that encompassing elements of 'blue growth initiative', Ecosystem Approach of Fisheries (EAF) management and the set SDG targets for India, the NFP 2020 is committed to consolidating the sectoral gains and ensuring sustainable growth through policy support to enable and accelerate fisheries development responsibly and inclusively. Pertinently, NFP 2020 aims to support government initiatives to double fishers' and fish farmers' incomes and double exports through improving the lives and livelihoods of fishers and their families. Many aspects of the governance structure of NFP 2020, as well as impending challenges, are reviewed and documented by Salim & Anuja[14]. Since the social behaviour and/or responses to the enactment of the NFP 2020 by fisherfolk and the industry as a whole can be complex and may be resisted, arriving at a harmonious policy framework with inclusivity across policy elements is necessary as stated by Salim & Anuja[14]. These issues can pose serious apprehensions in policy formulation and implementation. Therefore, many reiterations, revisions, and modifications are underway not only to suit locally specific concerns but also to envisage those that may be problematic in the future. In this regard, many inferences from current analysis on how biomass gains in marine fisheries can be achieved by avoiding the netting of small-sized fishes and how the

increased catches and revenues are possible are useful. In all likelihood, this first attempt is indeed highlighting the need to sensitively elucidate the biological characteristics of all commercially important finfish and shellfish along both coasts and within the island territories of India. On the whole, there is an urgent need to conduct further studies on IUU fishing in India, on its risks to marine ecology and the national economy, as well as to strengthen governance and regulatory frameworks.

Need for international efforts in handling IUU issues

Combating IUU fishing must be a top priority for all nations. In this effort, communication, collaboration, and strategic coordination will be key to achieving tangible results. International working groups, regional cooperation, and information sharing are some of the key features essential for successful, highly effective, and pragmatic steps in combating IUU activities. This is particularly true for safeguarding the fish and fishery resources within the exclusive economic zones of all maritime nations. Establishing frequent focused interactions between the interagency working groups of marine fisheries and ecosystem experts on IUU fishing would facilitate arriving at long-term solutions to eliminate this scourge. As a consequence of establishing such agencies, an integrated, worldwide government network would be in place to respond to the exigencies of IUU fishing globally. These agencies, as is the case in the United States[13], can consolidate coordination efforts to tackle IUU fishing practices and set the conditions under which IUU fishing becomes unacceptable and is eliminated in the near future.

The genuine interests of traditional, illiterate, lowly skilled and economically weak fisher communities must be considered when it comes to framing the rules and compliance mechanisms for IUU fishing. Taking the examples of the United States, which leads in preventing the IUU scourge, has certain treaties in place with many Pacific Northwest Indian tribes, "reserving their right to fish in "Usual and Accustomed" fishing places that include important marine and freshwater fish. Created by executive order, these tribes participate and contribute to several management decisions related to hatchery production, habitat conservation, hydropower, and fisheries harvest. Indeed, they are the designated co-managers of the fisheries. Such pragmatic, fisher-friendly stipulations need to be in place to ensure sustainable and productive management of Indian marine fisheries.

Possible mitigation measures by India against IUU fishing

India's ability to counter IUU fishing depends on an integrated strategy combining maritime security, port controls, legal reform, regional diplomacy, digital traceability, and livelihood-sensitive fisheries governance[49,47]. The main features which can help counter IUU fishing are provided in Table 6.

Technology and market-oriented instruments in marine fisheries governance

Best practices for effective marine fisheries governance in India include establishing Vessel Monitoring Systems (VMS), Electronic Logbook Systems (e-logbooks), Fisheries Improvement Projects (FIPs), and Marine Stewardship Council (MSC) Certification. A brief description of these aspects is included for comprehension.

Vessel Monitoring Systems (VMS)

The Vessel Monitoring Systems (VMS) are satellite-enabled tracking mechanisms that periodically transmit data on a fishing vessel's geographical position, speed, and course to designated authorities. Internationally, VMS has become a foundational element of fisheries Monitoring, Control, and Surveillance (MCS). The FAO strongly promotes this VMS as a primary tool for addressing Illegal, Unreported, and Unregulated (IUU) fishing[63].

Globally, in many major fishing nations and regions including the European Union, the United States, and Australia the use of VMS is mandatory for industrial fishing fleets. In particular, the Regional Fisheries Management Organisations (RFMOs), governing tuna fisheries such as the Indian Ocean Tuna Commission (IOTC), and the International Commission for the Conservation of Atlantic Tunas (ICCAT), require compulsory VMS reporting for authorised vessels. In general, empirical assessments indicate that VMS significantly enhances compliance with spatial restrictions, facilitates enforcement of marine protected areas and closed seasons, and enables more accurate regulation of fishing effort[72]. Recent global practice has involved integrating VMS datasets with Automatic Identification Systems (AIS), expanding possibilities for public transparency and independent monitoring of fishing activity at sea[64].

In India, the deployment of VMS remains partial and selective, primarily concentrated on deep-sea fishing vessels and larger mechanised boats operating beyond coastal waters. The Government of India, through initiatives such as the Pradhan Mantri Matsya Sampada

Table 6 — Essential mitigation measures against IUU fishing in Indian waters

IUU fishing counter-measures	Action plan
Strengthening Monitoring, Control, and Surveillance (MCS)	Develop a unified maritime domain awareness architecture that links many stake holders[(A) 47]. Rigorously patrol all known sustained patrols are required in known IUU hotspots[(B) (30,49)]
Leveraging port state measures	Access and fully implement the FAO Agreement on Port State Measures[(C) 73]. Designate all major ports PSMA-compliant inspection hubs[(D) (73,74)]. Participate in PSMA to protect India's seafood export reputation[(E) (74)]
Legal and institutional reform	Modernise national fisheries legislation and harmonise state-level laws to explicitly criminalise IUU fishing practices[(F) (47,49)]. Reframe IUU fishing as both a maritime security and conservation challenge[(G) (49)]
Regional and international cooperation	Leverage platforms such as IORA, BIMSTEC, and IFC-IOR[(H) (49)]. Lead the regional dialogues and multilateral seminars in the Indian Ocean Region[(I) (75)]. Engage strongly within the Indian Ocean Tuna Commission[(J) (47)]
Data, traceability, and compliance	Adopt electronic catch documentation and traceability systems from vessel[(K) (76)]. Ensure universal registration of all mechanised and motorised fishing vessels, along with affordable tracking solutions[(L) (47)]
Livelihood-sensitive approaches	Address all economic drivers of IUU fishing[(M) (49)]. Enforce community-based fisher cooperatives and harbor associations[(N) (47)]

[(A)]The stakeholders are Indian Navy, Coast Guard, IMAC, and state fisheries departments, supported by satellite-based AIS, radio-frequency detection, VMS, and anomaly-detection analytics; [(B)]Palk Strait, Bay of Bengal, Andaman Sea, and Lakshadweep waters, supplemented by coordinated patrols with neighboring countries to address cross-border violations; [(C)]To deny port entry, landings, and services to foreign vessels implicated in IUU fishing, thereby cutting off market access for illegally caught fish; [(D)]*e.g.*, Kochi, Chennai, Visakhapatnam, and Mumbai to strengthen risk-based inspections, information exchange via FAO's Global Information Exchange System, and enforcement capacity; [(E)]By preventing illegal fish from contaminating supply chains and by increasing India's leverage in international fisheries governance; [(F)]Such as AIS manipulation, organised violations, and repeat offences, backed by consistent and deterrent penalties; [(G)]To improve inter-agency coordination and elevate the issue within national security planning; [(H)]To share vessel blacklists, surveillance data, and enforcement intelligence, while coordinating diplomatic and operational responses to extra-regional distant-water fleets; [(I)]To help standardise enforcement practices and close governance gaps exploited by IUU operators; [(J)]Majorly to enhance conservation and compliance for highly migratory species vulnerable to IUU fishing pressures; [(K)]To reduce under-reporting and mislabelling while safeguarding India's access to international seafood markets; [(L)]To significantly reduce the scale of unreported fishing effort; [(M)]To cover all expanded deep-sea fishing transitions, buy-back schemes for destructive gear, and alternative livelihood options for near-shore fishing communities facing depleted stocks; [(N)]Community based cooperatives serve as a first line of monitoring and compliance if supported by capacity building, incentives, and social protection mechanisms

Yojana (PMMSY), has promoted the installation of satellite-based transponders, with pilot implementations reported in Tamil Nadu, Kerala, and Gujarat[65]. However, within the 0–12 nautical mile territorial waters, the enforcement continues to face operational limitations due to infrastructural and institutional constraints. The operational constraints on wider VMS adoption include high capital and recurring costs for installation and data transmission, particularly affecting small-scale fishers. Moreover, weak coordination and data sharing between state fisheries departments and central surveillance agencies are also challenges. There are forever ongoing concerns related to data security, ownership, and fisher privacy.

Electronic logbook systems (e-logbooks)

The electronic logbooks (e-logbooks) replace traditional paper-based catch records with digital systems that capture comprehensive, time-specific data on catch volumes, species composition, bycatch, fishing effort, and spatial location. International fisheries governance bodies increasingly recognise e-logbooks as essential for strengthening data integrity and evidence-based stock assessments[66].

Globally, the e-logbooks are legally mandated across European Union fishing fleets under the Common Fisheries Policy and are standard reporting tools in RFMO-managed fisheries, particularly in industrial tuna operations. Their integration with VMS data allows regulators to cross-validate fishing activity against reported catches, improve quota monitoring, and enhance compliance oversight. Evaluations conducted within the EU suggest that e-log-books substantially reduce underreporting, particularly when complemented by observer programmes and port inspection systems[67].

India's marine fisheries data collection remains largely dependent on shore-based, paper-driven systems, notably those managed by the Central Marine Fisheries Research Institute (CMFRI). The adoption of e-logbook in India is currently limited to experimental applications in industrial tuna and deep-sea fisheries and to pilot-scale integrations with VMS under PMMSY.

As such, the structural challenges include low levels of digital literacy, linguistic diversity among fishers, limited onboard power and connectivity, and the predominance of small-scale, multi-species fisheries, which complicates standardised digital reporting[59].

Fisheries Improvement Projects (FIPs)

Fisheries Improvement Projects (FIPs) are collaborative, nonbinding initiatives designed to guide fisheries toward sustainability when immediate formal certification is not feasible. They typically involve cooperation among fishers, processors, exporters, NGOs, and buyers, and are structured around incremental performance benchmarks consistent with FAO's Code of Conduct for Responsible Fisheries and Marine Stewardship Council (MSC) indicators[68].

Internationally, the FIPs have been widely implemented in Southeast Asia, Africa, and Latin America, particularly in tuna, shrimp, and small pelagic fisheries. Evaluations show that well -designed FIPs can strengthen stock assessments, improve traceability mechanisms, and enhance governance capacity over time. From a market perspective, multinational seafood retailers increasingly require sourcing from FIPs as an interim risk-management strategy while fisheries progress toward certification[69].

India too has seen the emergence of several FIPs, largely driven by export-oriented seafood supply chains. Important examples are Yellowfin tuna. In this case, the FIPs are aligned with IOTC conservation frameworks. The other example is shrimp and small pelagic FIPs, supported by domestic exporters and international NGOs. These initiatives have contributed to improved awareness of sustainability requirements, basic traceability practices, and dialogue between industry and regulators. However, their long-term ecological effectiveness remains contingent on alignment with statutory regulations and consistent stakeholder participation[70].

Despite their potential, FIPs are teeming with limitations and face several criticisms: Their voluntary nature limits enforceability. There is a risk of "checkbox" compliance without measurable stock recovery. Additionally, continued reliance on donor funding and buyer interest can undermine continuity.

Marine Stewardship Council (MSC) Certification

MSC certification is a voluntary, market-driven eco-labelling system for wild-capture fisheries. This certification is granted based on performance in maintaining sustainable fish stocks, minimising ecosystem impacts, and the existence of an effective fisheries management regime[71]. The certification is widely regarded as the most stringent and internationally recognised sustainability certification for marine capture fisheries.

Globally, over 500 fisheries have either achieved MSC certification or are undergoing assessment. Evidence from Europe, North America, and Oceania suggests that certification can generate price premiums, enhance access to high-value markets, and incentivise improvements in fisheries governance[72]. However, MSC certification in India remains relatively limited, mainly due to the dominance of small-scale, multi-species fisheries, and complex, fragmented governance arrangements. Additionally, high financial and administrative costs associated with assessment and compliance are challenging. Nevertheless, select export-oriented fisheries such as the tuna and shellfish sectors in particular have pursued pre-assessment and FIP-based pathways toward certification. This trend is increasingly driven by sustainability requirements in the European and North American seafood markets[70].

As of 2025, the MSC certification in India remains largely inaccessible to small-scale fisheries in developing countries. It still is primarily oriented toward export markets rather than domestic food security objectives. It is essential to highlight that the lack of MSC certification might risk excluding informal and marginal fishing communities on a global scale.

Need for an integrated governance approach for marine fisheries sustainability

Taken together, VMS, e-logbooks, FIPs, and MSC certification constitute a continuum of governance instruments ranging from state-led technological surveillance mechanisms to market-based sustainability incentives. International practice demonstrates its collective contribution to transparency, accountability, and ecological resilience. In India, however, their effectiveness remains constrained by jurisdictional fragmentation, fleet heterogeneity, and the socio-economic realities of artisanal fisheries. A coherent national strategy that links mandatory regulatory tools (VMS and e-logbooks) with voluntary improvement and certification mechanisms (FIPs and MSC) is essential to align Indian marine fisheries governance with global best practices while ensuring equity and livelihood security.

Conclusion

The impending adverse impacts of a changing climate along with IUU fishing leads to the drastic depletion of fish stocks, making it difficult for fish stocks to rebound and reach optimal levels. Law-abiding fishers incur economic loss due to the IUU fishing trade. Therefore, IUU fishing is both environmentally and economically detrimental. Furthermore, IUU fishing by foreign vessels in Indian EEZ has the potential to pose national security threats. Extensive studies need to be conducted on the current state of IUU fishing in Indian waters. Accurate reporting on species being fished and the numbers of fish caught is crucial. From the detailed analyses of over 70 years of marine landings data in this study, it is apparent that close to 10 % of the total landings are recognised as lost, either as unreported or as discarded catches. Taking the examples of two commercially predominant pelagic species, namely Indian oil sardine and Indian mackerel, it is clear that landings can be higher with mesh size regulation, provided that there is strict compliance and complete reporting. With higher landings, the economic prosperity of both fishers and fish consumers will help the governments to withdraw fuel subsidies, thus facilitating the achievement of SDG 14 targets. Withdrawing subsidies from parties engaging in IUU fishing has the potential to reduce IUU fishing. Further, applications of technologies such as GIS-based documentation of marine fish landing centres can be highly beneficial, as these centres serve as reference points for mapping marine fisheries harvests along the coast. Such mapping efforts can provide basic data for fisheries conservation and management. In addition to adapting modern technology in vessel monitoring systems, e-logbooks, fisheries improvement projects, and marine stewardship council certification, countering IUU fishing depends on an integrated strategy combining maritime security, port controls, legal reform, regional diplomacy, digital traceability, and livelihood-sensitive fisheries governance. Involving local communities and educating them about bioresources and environmental aspects can help drastically prevent IUU fishing.

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Conflict of Interest

None. All authors have approved the manuscript

Author Contributions

MR: Data collection, data curation, visualization, formal analysis, writing –original draft, review and editing, RV: Formal discussion and analysis. FD'S: Validation, methodology, formal analysis, and discussion. AG: Conceptualization and project implementation.

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