Application of DPSIR framework in tuna fisheries management in the Indian Ocean with special reference to Sri Lanka

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A Social-Ecological System (SES) is formed when humans interact with their environment. Thus, an SES is an ecological system intricately linked with and affected by one or more social systems. Exclusive Economic Zones (EEZs) can be considered as vibrant SESs in which human societies and other organisms interact with the physical environments. Particularly human-fish interactions could also be considered as an SES and decisions for tuna fisheries management are mainly borne after the analysis based on fish and fisheries data that hardly addressed information on SES. Therefore, the present analysis was conducted for Sri Lankan tuna fisheries using the Driver-Pressure-State-Impact-Response (DPSIR) framework which was developed and used for the adaptive management of various SESs. "Driving forces" such as high dependency for fish, economies of the stakeholders, climate change, urbanization and industrialization through the "pressures"; increased fishing effort, overexploitation, use of destructive gears, Illegal, Unreported and Unregulated fishing practices, changing oceanographic conditions to "state" of, depleted fish stocks and low fish production deviation of fish distribution and fishing grounds, and more warm pools and 'impacts' on declining catch, loss of early life stages, marine environment degradation and eventually leading to 'responses' of fisheries and environmental laws and regulations as well as novel technological applications. This showed that the important steps in the process where catch data analysis, could not support alone to support the system. Therefore, a comprehensive analysis using DPSIR is recommended to find out the facts for fisheries management both in terms of regional and national scales.

Introduction

The Indian Ocean holds the world's second largest tuna fishery, contributing significant potential for countries and fishing communities in terms of providing food to hundreds of millions of people and is also an important contributor to food security, poverty alleviation, job creation and income generation. The migratory species of tuna and tuna like species form the most important resources of the offshore pelagic fishery in both eastern and western regions (Obura et al, 2017).

Indian Ocean Tuna Commission (IOTC) is the Regional Fisheries Management Organization (RFMO), mandated to manage and conserve tuna and tuna-like resources in the Indian Ocean and adjacent seas. Species-specific management measures are being covered for the major commercial tuna species, billfishes, and several shark species. As a management tool conservation and management measures (CMMs) for bycatch species particularly for sharks have been adopted subsequently with the implementation of Resolution 12/09, Resolution13/05 and 13/06 (IOTC Compendium, 2022). Since the end of 2016, a rebuilding plan for the currently overfished yellowfin tuna has been in place and fishing limits for total allowable catches (TACs) have been introduced. However, these are not being fully implemented due to the lack of compliance of contracting parties since the fishing effort are still being maintained at a very high level (WWF, 2020).

Despite efforts, the latest stock assessments conducted by the IOTC revealed that stocks of yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*) (IOTC–WPTT24 2022), striped marlin (*Tetrapturus audax*), blue marlin (*Makaira nigricans*) (IOTC–WPB20 2022), Longtail tuna (*Thunnus tonggol*), Narrow barred Spanish mackerel (*Scomberomorus commerson*) (IOTC–WPNT12 2022) are overfished or subjected to overfishing. This further revealed that the necessity of criteria focusing beyond species-based fisheries approaches for fisheries management while understanding the fisheries as a complex social-ecological system.

Fisheries management involves multiple stakeholders at various levels, from local fishing communities to national governments, regional Indian Ocean organizations, and NGOs. Managing tuna fisheries is complex because tuna is a multi-species resource that crosses territorial boundaries, including exclusive economic zones and high seas. This complexity results in intricate relationships among and between users and the mobile tuna populations (Andriamahefazafy and Kull, 2019).

Most management strategies and recovery plans are focused on fishing as the primary factor that inhibits the recovery of resources. While this seems logical, especially because fishing is always strongly implicated in a population's initial decline, the support for this idea is surprisingly ambiguous (Hutchings and Reynold, 2004).

Regardless of international, regional and national ambitions to halt biodiversity loss, recent studies show that globally poor progress has been made toward fulfilling the targets to prevent extinction and improve the conservation status of threatened species (Kyrkjeeide et.al, 2021).

Stopping human-induced extinctions and the disappearance of iconic species will require strong policy commitments (Bolam et al, 2020) which provide provisions for international level policies translated into national level actions (Mace et al, 2018) that comprehensively address threats to species.

Natural resource management frameworks which concern the Social-Ecological System (SES) in which an ecological system intricately linked with and affected by one or more social systems are important in generating information that promotes the development of appropriate policies and regulations for effective management and utilization of different aspects of ecosystems (Dzoga, 2018). Exclusive Economic Zones (EEZs) can be considered vibrant SESs in which human societies and other organisms interact with the physical environments. The Drivers-Pressure-State-Impact and Response (DPSIR) framework developed in 1990s provides a nexus between the causes of environmental problems and the resultant pressures, associated impacts and responses needed to resolve and manage specific environmental issues and challenges (Dzoga, 2018). The framework provides a structure that present the indicators needed to enable feedback to policymakers on environmental quality. However, the approach is presently less used in fully marine systems than in coastal systems, where there are greater populations and environmental problems (Patrício, 2016). In addition, Gari et al. (2015) mentioned that the DPSIR framework is a useful adaptive management tool for analyzing and identifying solutions to environmental problems. However, the framework has been used to solve issues in fisheries management on many occasions (Dzoga et al., 2020) Since the framework mainly attributed to challenges in understanding the scope of Drive-Pressures-State-Impact as it could be expected regional scale while the successfulness of Responses always comes at the national level.

Being one of the oldest and important tuna fishing island nations in the Indian Ocean (Maldeniya, 1998) with its significant contribution to the livelihood and foreign exchange earnings (MOF, 2020), during this analysis we discuss the tuna fisheries management through the steps of DPSIR framework to understand the socio-ecological scenarios both in regional scale and national scale with special focus on Sri Lankan context.

Drivers -Pressures-State-Impacts-Responses (DPSIR) in Tuna Fisheries Management

Understanding the underlying forces or factors that influence or contribute to tuna fisheries is very essential. Since the "Drivers" can be natural or human-induced, we have identified three major "Drivers" namely

1. High dependency on fisheries due to economic status and nutritional requirements,

2. Climate change, and

3. Industrialization and urbanization

1. High dependency on fisheries due to economic status and nutritional Requirement

Economic status and nutritional requirements are significant driving forces in marine fisheries in Sri Lanka, which is also valid for many coastal tuna fishing nations in the region.

The nutritional needs of a population drive the demand for fish. In Sri Lanka a developing state, malnutrition is more prevalent among rural poor and estate households especially children under 5 years old, along with pregnant and lactating women (Amarasinghe, 2014; Jayasekara et al., 2022). Fish play a crucial role in Sri Lankan's protein intake, accounting for 50-60% of total dietary protein needs (Munasinghe et al., 2015). On the other hand, the economic status of a region or community plays a critical part in shaping the demand for fishery products. Socio-economic issues, also pose significant challenges in management. The active fishers (fishermen and women) in the marine sector of Sri Lanka in 2021 account for 224,190 (MOF, 2022) and reveal the importance of marine fisheries in terms of income generation sources. Moreover, tuna plays a key role in export earnings with an average contribution of 46% to the total exports of fish and fishery products in volume in Sri Lanka during the last five years (MOF, 2022).

Pressures

The above driving force puts “Pressures” on the tuna populations and associated ecosystems in the Indian Ocean in many ways. The phenomena of open-access fisheries in the Indian Ocean high sea, poses a significant challenge even the mandates of regulations by Regional Fisheries Management Organizations (RFMO). In the case of shared fish stocks like tuna, they are even more vulnerable to the tragedy of the commons. These collectively can lead to Illegal, Unreported and Unregulated Fishing (IUU) and overfishing as demands increase and fishing technologies become more advanced. In 2015, , it has been estimated that anywhere from 16 - 34 % of the catches in those stocks in the Indian Ocean are associated with illegal or unreported fishing activities (Salahuddin, 2015). Also, the high number of fishing vessels combined with the capacity along with diverse gear exerted considerable pressure on the resource in terms of recruitment overfishing and by catch.

State

The "State" of the tuna populations and marine environment is totally dependent on the various pressures inserted. The IUCN Red List criteria show that 21% of migratory marine species are classified as threatened, with sea turtles the most threatened group (85%), followed by seabirds (27%), cartilaginous fish (26%), marine mammals (15%), and bony fish (11%). Including the near-threatened 11%, approximately 50% of marine migratory species are threatened, Near Threatened or Data Deficient (Lascelles, 2014). As per the stock assessments conducted by the IOTC, two tropical tuna species; yellowfin and bigeye tuna (IOTC– WPTT24 2022); two billfish species; striped marlin and blue marlin (IOTC–WPB20 2022), two neritic species; narrow barred Spanish mackerel and long tail tuna (IOTC–WPNT12 2022) were identified as the stocks which are overfished and subject to overfishing.

The utilization of harmful fishing equipment and techniques contributes to an increase in the capture of young and undersized fish, as well as the unintentional capture of non-target species. The range of methods utilized to harvest more tuna could have resulted in a higher percentage of immature catch rates. For example, the deployment of fish aggregation devices (FADs) to attract surface tuna to improve catch efficiency has become common practice in the region, however, they often result in small juvenile bigeye and yellowfin tuna in addition to the target species (Scutt et al., 2017). Bycatch mainly marine mammals, turtles and sea birds from gillnet is also well documented and has been identified as an issue of increasing global concern (MRAG, 2012).

In Sri Lanka, Jayasinghe et al (2019) revealed that out of 4014 records of incidental catches of threatened and conserved species 73.1% were caught in gill nets while 16.0% were caught in long line and 10.9% were caught to ring nets. However, for all gear, the live release rate of incidental catch was around 90% and zero mortality was recorded for ring nets.

Impacts

The state of the tuna and sea leads to various "Impacts" not only to the marine environment but also to stakeholders including coastal communities, The depletion of tuna stocks resulting in low catch rates could negatively affect the long run of the tuna fishing industry in the Indian Ocean which is also valid for all the coastal and distant water fishing nations. IUU fishing has emerged as a significant global problem, posing threats to ecosystems, food security, and livelihoods, and is jeopardizing the organized and strategic efforts aimed at restoring the world's oceans, which have been severely depleted of fish stocks. It has detrimental effects on a wide variety of marine species, with a particular focus on tuna and other large pelagic fish sought after for their significant market value (Liddick, 2014). The impacts of IUU fishing on developing countries like Sri Lanka involve multiple extents, including financial, economic, social, and ecological effects. Illegal fishing disrupts the market, reducing the price of legally caught fish, which harms legal operators. Additionally, when national authorities reduce fishing quotas in response, it also affects legal fishing operators negatively (Liddick, 2014). It also strains national budgets for monitoring and enforcement. In places where fish is the key protein source, illegal fishing adds to hunger, malnutrition and poverty. In past periods Sri Lanka faced devastating experiences from IUU fishing, when the European Union imposed a fish import ban on Sri Lanka during 2015-2016 due to non-compliance with the standards of the Indian Ocean Tuna Commission (IOTC). The ban was causing severe impacts on offshore fisheries and the economy of the country (Sandaruwan and Weerasooriya, 2019).

Response

Since the fish, environment and people get negatively affected by the "Impacts" the "Responses" refer to the actions taken by society, governments, and organizations to address the issues identified in the DPSIR framework. These responses mainly addressed the "Drivers" to control the "Pressures".

The Resolutions based on conservation and management measures by the IOTC play a key role in managing the fish stocks in the Indian Ocean (IOTC Compendium, 2022). In Sri Lankan context, the Fisheries and Aquatic Resources Act No. 2 of 1996 (amended by Acts No. 4 of 2000, 4 of 2004, 22 of 2006, 35 of 2013 and 2 of 2015) is the prime code of rule for fisheries management in the country providing management, regulation, conservation and development of fisheries and aquatic resources.

The High Seas Fishing Operations Regulations No. 1 of 2014 (with 2015 amendment) has directly focused on management of high seas tuna fisheries in the country while the stated conservation and management measures have adopted in keeping with the United Nations Convention on the Law of the Sea of December 10, 1982, IOTC and Fish Stocks Agreement 1995 and United Nations Food and Agriculture Organization (FAO) Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing 2009. According to the regulation, possession of species such as marine mammals, turtles, thresher shark species, and sea birds are prohibited. Paper log book on board and installation of satellite based Vessel Monitoring System (VMS) have been made legally mandatory. The maximum length of gill nets in the high seas shall not exceed two point five kilometers in length. De-hookers, line cutters and, dip nets are mandatory on board by the longliners and purse-seiners respectively in order to ensure the minimum impacts on prohibited species. Catch, retaining on board, tranship, land, store or sell of prohibited shark species and landing detached shark fins both within EEZ and high seas areas is prohibited (Hewapathirana et al., 2022). Moreover, in order to minimize the undersized catch rates of marlins and sailfish, smaller than 60 cm Lower Jaw Fork Length individuals are prohibited in the High Seas, and have been included in the High Seas fishing operation license.

The Sri Lanka National Plan of Action to Prevent IUU (SLNPOA-IUU) ensures that measures against IUU fishing are consistent with the conservation and sustainability of fisheries resources and protection of the marine environment while providing relevant provisions of the International Plan of Action to Prevent, Deter and Eliminate IUU Fishing (IPOA-IUU) (DFAR, 2020).

In line with the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) developed by the Food and Agriculture Organization (FAO) in 1999, Sri Lanka National Plan of Action for the Conservation and Management of Sharks (SL-NPOA-Sharks) was initiated in 2013 and updated in 2018. The long-term goal of the SLNPOA-Sharks (2018-2022) is to ensure the conservation and the sustainable management of key Shark species from directed and non-directed fisheries in Sri Lankan waters and BEEZ, by 2029 (SLNPOA–Sharks 2018 – 2022).

The efforts also focused on the need for a policy, and accordingly the Ministry of Fisheries and Aquatic Resources Development, in association with the departments and agencies under its purview has formulated the National Fisheries and Aquaculture Policy in which also includes highly migratory species within Sri Lanka's Exclusive Economic Zone (EEZ) and beyond the EEZ (BEEZ) (MOF, 2022).

Furthermore, in recent years sustainable aquaculture is promoted to reduce the pressure on wild fish populations in the Indian Ocean (Ateweberhan, et al., 2018) including Sri Lankan waters to cater to the increasing demand (EDB, 2023).

Research studies are also focusing on the feasibility of the use of environmentally friendly gear like pole and line fishery as an alternative to gill net (Bandaranayake et al, 2023). Further, research is needed to find alternative protein sources such as plant-based and lab-grown alternatives to replace fish demand. Reducing wild fish fishing pressure is a complex and multifaceted challenge that requires coordinated efforts from governments, industry, and consumers.

2. Climate change

Climate change is a significant "Driver" of change in marine fisheries, especially profound to migratory fish stocks. Consequently, alterations in oceanographic parameters driven by climate change have extensive implications for various aspects of the marine environment, including marine biodiversity, health of marine ecosystems, fisheries production and pose significant challenges to fisheries management strategies (Brander, 2010; Pentz et al., 2018).

Pressures

The climate change "Driver" provides various "Pressures" to the marine environment such as rising sea surface temperature (SST), ocean acidification, sea level rise, intensified storms and altered ocean circulation ultimately leading to both direct and indirect consequences in fisheries (Johnson and Welch, 2009). Recently Dalpadado et al., (2021) showed that the Indian Ocean is undergoing remarkable change as a significant expansion of the Indian Ocean Warm Pool (IOWP), which is characterized by SST values exceeding 28 °C. This expansion is particularly prominent in the last decade and approximately 74%, has been observed in the south-central basin. Across most regions, there has been an average temperature increase of 0.4–0.7 °C over the past two decades (Karim, 2023). Studies further revealed that the western tropical Indian Ocean has been warming for more than a century, at a rate faster than any other region of the tropical oceans while experiencing anomalous warming of 5°C difference in summer SSTs (Roxy et al., 2014; Durei, 2017).

Additionally, the rapid warming of the Indian Ocean is expected to lead to more extreme weather conditions such as strong positive Indian Ocean Dipole (IOD) in a more frequent manner (Vinayachandran et al., 2009; Dalpadado et al., 2021). Warming temperatures can bring about changes in ocean currents, either rising or weakening local nutrient-upwelling processes (Hallegraeff, 2010).

State

The pressures due to climate change alter the "State" of the marine environment and fish populations. Ocean warming leads to adverse consequences on fisheries industries in countries bordering these affected regions. Migratory fish like Tuna and billfish are strongly influenced by environmental conditions as they have a suitable habitat, mainly determined by temperature and oxygen concentrations. Changes in ocean temperatures can affect the distribution of prey species, which, in turn, can impact the availability of food for fish populations (Selden et al. 2017) including tuna. Some tuna species are highly sensitive to water temperature, affecting their distribution and migration patterns (Lan et al., 2013). Danovaro et al. (2016) pointed out that increased water temperature can promote the growth of harmful bacteria, viruses, and parasites. Climate change projection studies show that yellowfin tuna reaches the upper limit of its current favourable spawning temperature range in many places in the Indian Ocean (Dueri, 2017). Also, increased temperature affects the recruitment of Indian Ocean skipjack tuna and detected a significant negative correlation between SST and CPUE of Skipjack tuna in the tropical regions of the western and central Indian Ocean (Liu et al., 2023). Moreover, ocean acidification may also affect tuna to reduce sound absorption creating a noisier environment, which might affect the ability to detect prey and predators (Ilyina et al., 2010). Due to rising sea levels and increased coastal erosion can reduce the availability of essential fish habitats, such as seagrass beds, mangroves, and coral reefs (Munday et al. 2008; Short and Neckles, 1999; Field, 1995). The oxygen minimum zones (OMZs) in the Indian Ocean are primarily found in the Arabian Sea and the Bay of Bengal, where warming intensifies the reduction of oxygen concentrations in OMZs by causing a decline in the solubility of oxygen (Azhar et al., 2017). Considering ocean warming, the Gill Oxygen Limitation Theory (GOLT) predicts a decrease in fish size (stunt) because they may be unable to compensate for the elevated metabolic rate caused by higher temperatures through their gill surface area (Pauly and Cheung, 2018; Pauly, 2021).

A recent analysis of skipjack tuna catch distribution in Sri Lankan waters revealed that the fishing grounds of skipjack tuna are mostly distributed mostly beyond the range of 7-10 NM perhaps climate change could be one reason (Bandaranayake et al., 2023).

Climate change can contribute to recruitment changes leading to fish stock depletion. Fishermen often exert higher efforts to maximize their catch, and in some cases, this can lead to unsustainable fishing practices. Excessive fishing efforts can deplete fish populations beyond their ability to recover and lead to long-term declines in fish stocks. Increased efforts may result in higher levels of bycatch, where non-target species, including endangered or protected species, are caught unintentionally contributing to ecosystem degradation.

Impacts

"Impacts" are the effects or consequences of the changes in the "state" of the marine environment on human health, well-being, and ecosystems. Impacts can be positive or negative and may include effects like reduced fish yields, increased health problems, loss of biodiversity, or extreme weather events linked to climate change.

Ocean warming can significantly affect the life cycles, species distributions, community structure, productivity, connectivity, organism performance, and recruitment dynamics. Warmer waters can affect fish behaviour, making them more vulnerable to fishing. Fish may be forced to move closer to the surface or shore, where they are easier to catch. Based on the high seas longline fishery catch data in Sri Lanka, a clear decrease in the extent of the distribution and the catch rates of swordfish (*Xphius gladius*) has been experienced with the increased SST and probably be associated with the deepening of thermocline with respect to the depth of longline operations (Bandaranayake et al., 2018). In addition, due to the loss of habitats like mangroves, sea grasses and coral reefs which provide spawning and breeding grounds for many fish species, the fish may not survive during the early stages of their life cycle. This may lead to lower fish catches and overfishing causing socio-economic impacts as well. Further, extreme weather events due to climate change can result in more frequent and severe storms, which can damage fishing infrastructure, disrupt fishing activities, and even lead to the loss of fishing vessels (Rezaee et al. 2017). Also, altering the distribution of prey species, for tuna populations may show low growth performances, migratory route alternations and poor reproductive success which connect to ecosystem health and the economy of fishers. Furthermore, warm water has a high probability of spreading disease and parasites can affect fish health, reducing the overall fish population (Danovaro et al. 2016). Cumulative impacts for the regions that are heavily dependent on tuna fisheries, the changes can have serious economic consequences, including the loss of jobs and income gaining socio economic issues. Not only that, due to changing geographical areas of fish and fishing grounds, regulatory challenges may arise in fisheries management. Highly migratory fisheries resources, along with the organizations responsible for their conservation and sustainable utilization, will face growing challenges due to the magnitude of climate change impacts. Therefore, it is necessary to alter fishing practices and regulations that are suitable for the shifting distribution of fish stocks and changing environmental conditions.

Responses

In the coming century, climate change will pose considerable challenges for marine environments, especially for the high seas and shared fisheries resources. Therefore, “Responses” are addressed in multiple ways since climate impacts are considered as a main factor while drafting management measures. Also, it is important to point out that certain “Drivers” and “Pressures” cannot be directly addressed by the “Responses”. Tackling the impacts of climate change on tuna fishing is a complex and ongoing challenge. It requires a collaborative effort among governments, the fishing industry, scientists, and the public to ensure the long-term sustainability of tuna populations while mitigating and adapting to the effects of climate change.

The complex governance surrounding transboundary stock fisheries management under the influence of climate change highlights the significance of the biodiversity status beyond national jurisdictions’ agreements. Addressing the responses to climate change on tuna fishing management requires a multifaceted approach that combines adaptation and mitigation strategies. Here are some steps and strategies to address these impacts.

- Scientific Research and Monitoring:

Invest in research and monitoring programs which include tracking changes in migration patterns, habitat shifts, and population dynamics to better understand the specific effects of climate change on tuna populations (Dedman et al., 2023).

- Reducing Greenhouse Gas Emissions:

Take steps to reduce greenhouse gas emissions in terms of transitioning to cleaner energy sources, increasing energy efficiency, and adopting sustainable transportation practices that contribute to climate change (UCAR, 2020).

- Protected Areas and Sanctuaries:

Establish marine protected areas and sanctuaries to safeguard critical tuna breeding and feeding habitats. These areas can serve as refuges for tuna populations (Mees et al., 2009).

- Climate-Resilient Fishing Techniques

Develop and promote fishing techniques that are more resilient to changing ocean conditions (Bolin et al., 2021).

- Capacity Building:

Invest in training and capacity-building programs for fishermen and fisheries managers to enhance their ability to respond to and mitigate the impacts of climate change.

- Resilience Planning:

Develop climate adaptation plans specific to the tuna fishing industry, which should consider potential impacts, risks, and mitigation strategies.
Prioritize scientific performance evaluation with a focus on climate change, continue improving enforcement and monitoring strategies., expanding the establishment of marine protected areas (MPAs), incorporate political analysis into decision-making processes within RFMOs are some of the key strategies road toward the maintain the sustainability (Pentz et al, 2018). Leading on that way, IOTC passed a climate change resolution (referred to as the IOTC Climate Change Resolution). This resolution falls under the "Conservation and Management Measures" (CMM) outlined in Article IX of the IOTC Agreement in May 2022 (Karim, 2023).

The fishing ground forecasting system is one of the important techniques in Sri Lanka for offshore tuna fisheries as it supports increasing catch efficiency reduces the searching time and conserves the additional fuel burning by vessels. Forecasting initiated in 2008 and has seen on-going improvements. A more precise method for estimating yellowfin fin and skipjack tuna has been developed using satellite data on sea surface temperature, chlorophyll and sea surface height (Gunasekara and Rajapaksha, 2017; Gunasekera, 2022).

Coastal blue carbon ecosystems in Southeast Asia are diverse and productive where seagrasses and mangroves play as key components. They hold great potential as a nature-based solution for combatting climate change, serving as a significant global hotspot for carbon sequestration and storage (Stankovic et al., 2023). Restoration and conservation of this blue carbon ecosystem are essential for ecological, economic, and social reasons. In Sri Lanka, the restoration of 1,200 ha of mangroves has had significant effects, and there is a plan to restore an additional 10,000 ha. However, the restoration of sea grass remains unattempt (Gorman et al., 2022).

Since 2016, Sri Lanka ratified and became one of the 195 countries that signed the Paris Agreement which is a legally binding international treaty on climate change (Zylva, 2017). Fisheries have been identified as one of the vulnerable sectors in the National Adaptation Plan for Climate change Impact in Sri Lanka. In 2022, the National Environment Policy (NEP) and the National Environment Action Plan (NEAP) 2022- 2030 were adopted in Sri Lanka. The NEP clearly states that human-induced adverse impacts on the environment, such as climate change, could derail the process of sustainable development (MOE, 2022).

3. Industrialization and Urbanization

Urbanization in coastal areas is a common process throughout the world which show population growth, infrastructure development, and the expansion of cities and towns along coastlines. . The trend of urbanization along waterways (natural or man-made) has continued since the Industrial Revolution and around 75% of the world's largest urban areas are in the coastal regions (World Bank, 2010). The expansion of urban areas combined with industrialization in the coastal belts can be considered as one of the most key "Drivers" pressurizing the Indian Ocean.

In Sri Lanka also,, the majority of the country's population concentrated along the coastal areas especially in the western-southern area where more than 40% of the country's population resides.

Pressures

Together with industrialization technological advancements, which can improve the efficiency and effectiveness of fishing operations, it may pressure to the extent of over exploitation. On the other hand, urbanization and industrialization can lead to habitat destruction along coastlines through land reclamation, pollution, and coastal development. Marine pollutants, include runoff from industrial areas and sewage from urban centers, thermal pollution from power plants and noise and vibration from offshore constructions. The destruction of mangroves, seagrass beds, coral reefs, beaches, mudflats, sand dunes etc which serve as vital spawning grounds and habitats for fish and other organisms protect coastal ecosystems, along with the generation and disposal of waste resulting from domestic and industrial activities, have both played significant roles in the decline of coastal marine water quality and coastal fisheries (Singh and Somvansi, 2004; Chouhan et al., 2017). In Sri Lanka, discharging untreated liquid effluents into water bodies probably end up with the ocean but with exceptions that employ central treatment systems, as well as a handful of medium and large operations that can afford treatment facilities (Nuwanka and Gunathilaka, 2023).

Industrialization and urbanization increase the nutrient pressures to the environment, especially by adding Nitrogen and Phosphorous. Nutrient inputs, and changes in stoichiometry (N:P:Si) promote phytoplankton growth and change species composition sometimes leading to Harmful Algal Blooms that may release toxins. Bacterial decomposition of phytoplankton-derived organic matter consumes dissolved oxygen, especially in bottom waters. Phytoplankton blooms also increase turbidity, decreasing light penetration through the water column for submerged aquatic vegetation (SAV) such as seagrasses and macrophytes. The eutrophication process causes deterioration in the "State" of the marine environment and also changes in marine biodiversity. In addition to that, land-based pollutants such as plastic waste are being deposited in the ocean. Apart from these concerns, industrialization has lead also the Indian Ocean to become home to major sea routes connecting the Middle East, Africa, and East Asia with Europe and the Americas with a fourfold increment of container traffic from 2000 to 2017 (Kannangara, et al., 2018) accelerating oil and heavy metal pollutions

State

Industrialization often leads to advancements in fishing technology, increased capacity and efficiency of tuna fishing vessels can lead to overfishing and the depletion of tuna stocks. This is often worsened when the drive for profit takes precedence without sufficient consideration for sustainability (Chouhan et al., 2017). On the other hand, pollutants from various sources such as industrial chemicals, agricultural runoff, sewage discharge, and thermal plant hot waters can contaminate coastal waters, leading to reduced water quality and habitat deterioration. Mannage et al, 2022 revealed that the western south coastal area has begun the degradation particularly due to fecal contamination and tributyltin pollutant due to anthropogenic activities (Mannage et al, 2022).

Over the recent years, there have been three major maritime accidents in the Indian Ocean: (1) oil spill along the eastern coast of Mauritius (MV Wakashio) that affected local coral reefs and mangrove systems; (2) oil spill along the eastern coast of Sri Lanka (MT New Diamond) that was mainly restricted to deeper water; and, (3) plastic pellets ('nurdles') spill along the western coast of Sri Lanka (X-Press Pearl) that severely affected the whole coastline of Sri Lanka and other countries.

Nutrient availability changes the composition and succession of phytoplankton and thus the species composition of zooplankton and increasing gelatinous plankton. Hypoxic conditions cause changes in species composition and community collapse including mass mortalities of zoobenthos. Fish abundance, species composition and distribution because of behaviour changes occur to avoid low dissolved oxygen areas; loss of feeding grounds, breeding grounds and nursery grounds such as seagrass meadows; increased mortality of larvae and juveniles. Mortality of marine mammals, sea birds and turtles occurs due to changes in the food web and toxins.

Impacts

Poor water quality can harm fish health and growth. Some pollutants, like heavy metals and persistent organic pollutants can accumulate in the tissues of marine organisms over time. When tuna-like fish consume contaminated prey, the pollutants can accumulate in their bodies, potentially reaching levels harmful to human consumers. Also, urbanization can contribute to habitat degradation that leads to the destruction of critical habitats such as mangroves, coral reefs and seagrass beds. Particularly harmful to fish larvae and juveniles, these critical stages can reduce survival rates and recruitment to adult populations. This can be profound in Sri Lankan coastline as findings from Dr Fridtjof Nansen survey in 2018 revealed that Sri Lankan waters act as valuable nursery grounds for a wide range of fish species including *Auxis thazard*, *Euthynnus affinis*, *Katsuwonus pelamis*, and *Thunnus albacares* (Rathnasuriya et al., 2021). Mangroves have a remarkable capacity for sequestering large amounts of carbon, surpassing many other types of forests. When mangroves are destroyed, there is a higher likelihood of carbon accumulating in the ocean, contributing to ocean warming and further environmental impacts (Macintosh et al., 2012).

The New Diamond accident in 2020 followed by X Press Pearl incident in 2021 has resulted in significant environmental impacts to the Sri Lankan coastal water in terms of oil and plastic pellets. The X press pearl ship disaster greatly affected the coastal water quality, potentially harming ocean biodiversity, overall ocean health, fishery resources, and the local fishing and seafood industry.

Responses

Urbanization and industrialization, while bringing economic growth and innovation, can also lead to various challenges. Implementing sustainable urban planning practices, strengthen and enforcing environmental regulations to control pollution and resource depletion are key responses behind the consequences.

The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, an international treaty adopted in 1972, aimed at preventing marine pollution by regulating the dumping of waste and other materials at sea. The Ballast Water Management Convention (BWMC) was adopted by the International Maritime Organization (IMO) in 2004, addressing the environmental and ecological risks associated with the discharge of ballast water from ships. MARPOL Convention, adopted in 1973 is one of the critical instruments for the protection of the marine environment and the reduction of pollution from ships. The Bunker Convention is an important legal instrument to ensure that parties affected by pollution damage resulting from bunker oil spills have access to compensation for their losses.

In State level concerns, the Marine Environment Protection Authority (MEPA) and the Central Environmental Authority (CEA) are actively engaged in pollution prevention and sustainable planning through various measures and initiatives in Sri Lanka. The Marine Pollution Prevention Act No. 35 of 2008 is the main law that safeguards the marine environment in Sri Lanka. It provides clear guidelines for preventing, reducing, controlling, and managing marine pollution in the country's coastal and maritime areas. Additionally, MEPA, the authority tasked with minimizing environmental damage from coastal oil spills in Sri Lanka, created the "National Oil Spill Contingency Plan (NOSCOP)" in 1995.

The CEA is responsible for enforcing environmental laws and regulations in Sri Lanka. It sets standards for emissions, effluents, and waste disposal, ensuring that industries and activities comply with these standards to prevent pollution. The National Environmental (Amendment) Act, No. 56 of 1988, designates the CEA as the authority responsible for enforcing environmental laws and regulations in Sri Lanka. It establishes rules for emissions, waste, and effluent disposal, making sure that industries and activities adhere to these rules to avoid pollution. According to the National Environmental (Amendment) Act, No. 53 of 2000, the CEA mandates Environmental Impact Assessments (EIAs) for different development projects. This procedure evaluates possible environmental effects and ensures that projects include measures to reduce or prevent harm to the environment.

Section 27 of the Fisheries and Aquatic Resources Act No. 2 of 1996 makes it clear that it is strictly forbidden to use harmful substances like poisons or explosives to kill or harm aquatic resources, including fish. In accordance with the 1996 Act and its subsequent amendments and regulations, five fishing methods**;** push nets, harpooning, moxinet, trammel/gill nets on reefs, and monofilament nets are strictly prohibited Sri Lanka. Further, understanding the potential consequences on coastal fishery resources, a special gazette notification No. 2008/30 of 2017 has been issued specifically on protection of fish and aquatic resources where no person shall engage in industrial or domestic effluent discharge directly or indirectly to the Sri Lankan waters.

some steps and strategies to minimize the impacts resulted with urbanization and industrialization are listed below.

- Sustainable Urban Planning:

  Develop and implement urban and regional planning that takes into account the need to protect aquatic ecosystems, especially those that are important for fisheries. Use zoning and land-use policies to limit urban expansion into critical fishery habitats such as wetlands, estuaries, and mangroves.

- Protect Critical Habitats:

  Establish marine protected areas and reserves that safeguard essential fish habitats from development, pollution, and overfishing. Restore degraded habitats to improve breeding and feeding grounds for fish.

- Improved Waste Management:

  Implement effective sewage treatment and waste management systems in urban areas to reduce the discharge of pollutants into rivers, lakes, and coastal waters.

- Reduce Pollution:

  Enforce strict regulations on industrial pollution and runoff, including laws to limit the release of pollutants into water bodies. Promote sustainable agricultural practices to reduce nutrient and chemical runoff into aquatic ecosystems.

- Community Involvement:

  Involve local communities in decision-making processes related to fisheries management and urban development. Their traditional knowledge can be valuable for sustainable resource management.

- Research and Monitoring:

  Invest in research and monitoring programs to understand the impacts of industrialization and urbanization on fish populations and their habitats. Use this data to adapt policies and regulations as needed.

- Education and Awareness:

  Educate the public, especially urban populations, about the importance of sustainable fisheries and the role they can play in protecting aquatic ecosystems.

Minimizing the impacts of industrialization and urbanization on fisheries requires a holistic and multi-faceted approach that involves government agencies, local communities, businesses, and conservation organizations working together to balance economic development with environmental sustainability.

Do the responses successfully address the restoration of tuna resources and associated environment?

Establishing a DPSIR framework in tuna fisheries management appears as complex task as the state of the resource and the inhabiting environmental changes have not been attributed to a single cause. At the same time, the result will be visualized neither with the attempts by a single country nor different ways of responses in accommodating the impacts and mitigating pressures. Therefore, the identification of Monitoring, Control and Surveillance (MCS) in a more practical manner based on the level of pressure in relation to the corresponding drivers is essential for the unifying DPSIR framework for the Indian Ocean.

Recommendation

It is vital to conduct a quantitative criterion of risk assessment for tuna species with an objective of understanding the major human-driven threats and origin, and the effective interventions which can be applied to mitigate the impacts. There is an urgent need to integrate the stock status and related management advice with climate change in the national as well as regional levels in order to determine good climate change resilience practices. Also, it is important to take into consideration socio-economic elements in management responses. Research toward the effective utilization of untapped marine fishery resources and seasonal alterations of nutritional resource preferences among the local community with the climate change adaptive pathway are also crucial to ensure food security. DPSIR gives a valid mechanism and support for such assessments.

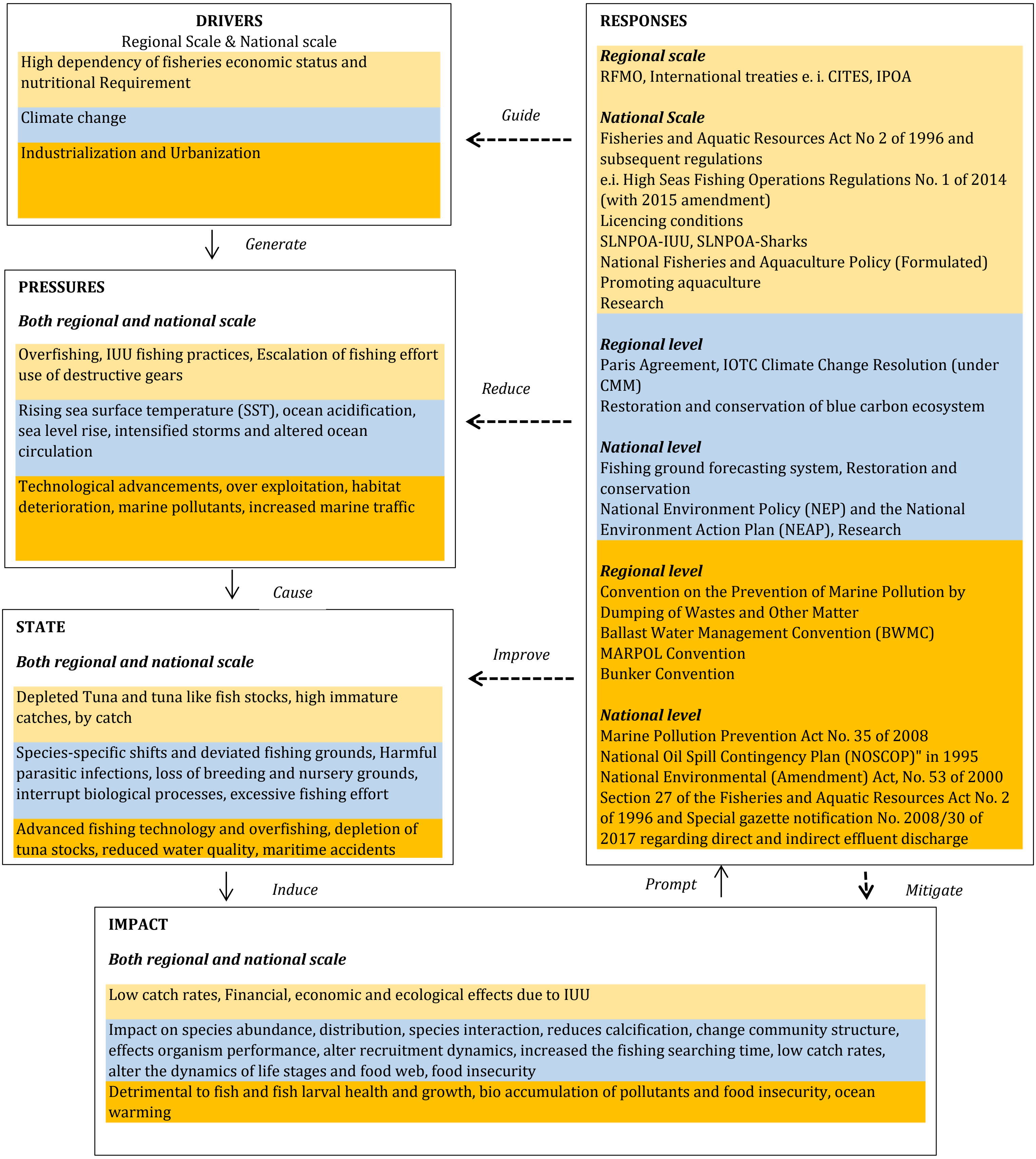

Figure 1: Schematic Diagram of DPSIR Framework for Tuna Fisheries Management

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