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Review

Review on Fisheries Resources and the Effect of Marine Pollution in Coastal Waters of Pakistan

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Abstract

The people who reside in the Balochistan and Sindh Provinces rely on the abundant fish and shellfish resources in Pakistan's coastal waters for food and a living. The fish populations in the two marine provinces are at different levels because of their very different topographies. Fisheries make a minimal contribution to the national GDP (0.32%), and their contribution to Pakistan's agricultural GDP is 1.4%, whereas 0.01% of employment is derived from fisheries. Fish production reached 800,000 metric tonnes in 2022, with varying production from marine waters. Just 25% of the country's total fishery production was exported, with 496 million US dollars. The stagnant trend in fish production, especially in Sindh province, indicates that fish stocks are being overfished. The Government of Pakistan's Marine Fisheries Department and the FAO worked together from 2009 to 2015 to conduct a number of fish stock assessment surveys. The final evaluation report states that large fishing fleets and current fishing practices amount to "fishing for catastrophe," with the principal fish populations in Pakistani seas being overfished and decimated by 60-90 percent. Prominent ecological changes include the decrease of large-bodied, slowly growing, highly valuable predatory species; an increase in short-lived, fast-growing, small-sized species with low commercial value; a wide variety of cephalopods, mainly squids and cuttlefish (an opportunistic, fast-growing group); and an abundance of jellyfish, which further disrupts resources severely. The fishing fleet's overcapacity, harmful fishing gear, inadequate storage on fishing vessels, lack of cool chain maintenance, inadequate landing place infrastructure, and destruction of mangroves are some of the major problems facing marine fisheries. Along the Karachi shore, the primary effects of pollution are habitat loss, eutrophication in some areas due to deteriorating water quality, hazardousness to aquatic life, particularly to the commercial species' larval stages, suffocation of intertidal marine vegetation and animals, sub-lethal effects on development and reproduction, red tides, pathogen-contaminated fish and shellfish, and the bioaccumulation of hazardous substances, especially heavy metals. Ultimately, these factors lead to the nearshore ecosystem depleting its marine life resources.

Keywords: Marine fisheries, living resources, coastal waters, marine pollution, Northern Arabian Sea

1. Introduction

Fisheries resources are crucial to the economic development of a country and the well-being of its people. It is well known that fish stocks are prone to fishing pressures and environmental deterioration. From the beginning, the Marine Fisheries Department has participated in the fish stock assessment. This has been done as part of an international cooperation program or with the assistance of the department's own research vessels. There have been signs that several important resources, such as shrimp, lobster, sharks, crabs, etc., have already been overfished and are at risk of becoming unsustainable. Therefore, there was a need to have updated information about fish stocks was essential for the nation's fisheries to be managed sustainably [1]. In an effort to bridge the information gap, a series of fisheries resources survey surveys were carried out from 2009-2015 with the technical assistance of FAO and NORAD. For the first time, the complete EEZ of the country was surveyed to estimates the major small pelagic and mesopelagic fisheries resources by using the acoustic echo-integration. Oceanographic observations pertaining to the marine environment and fisheries

resources were also acquired. Trawl net sampling was done for the demersal fish populations at pre-selected random locations [2; 3].

In 2016, the Ministry of Maritime Affairs received a Full Evaluation of Pakistan's Marine Fisheries Resources until 2015, in addition to voyage reports [2]. The report was distributed to legislators, stakeholders, and other interested parties, including the Public Account Committee and subcommittees reviewing the depletion of fish stocks. The summary of the report was also discussed with stakeholders in several meetings to reach a consensus on the report's recommendation to reduce fishing efforts in order to recover fish stocks. This study examines key facets of the 2016 FRAPP report, which holds importance for sustainable management. The final evaluation study described current fishing methods are as 'fishing for catastrophe' due to unsustainable practices.

There are 1,001 kilometres of coastline in the Islamic Republic of Pakistan, which forms the northern border of the Western Indian Ocean [4, 3, 5]. Different values of coastline are provided in the literature, such as: 1,050 km [6]; 1,120 km [1, 7]; 1,100 km [8]; 1,046 km [9]; 990 km [10; 11; 12]. The Indian Ocean monsoons largely influence Pakistan's maritime environment. The monsoon season in the northeast (winter) runs from December to February, whereas the monsoon season in the southwest (summer) is from mid-May to mid-September [9]. Pakistan coast is divided in to two zones:

a) The North-western Region, also known as the Makran coastal zone, is around 734.5 km long [4], and stretches from the Hub River to the Iranian border. The continental slope, or 200-meter isobaths, is rather narrow, extending only approximately 6 km in Gwadar and 70 km at Sonmiani Bay. The bottom is often rocky and the shelf is uneven [9]. The coast of Balochistan is typified by a number of noteworthy peninsulas at Ormara, Pasni and Gwadar, as well as large bays at Jiwani and Sonmiani. There are sporadic, sharp rocky outcrops scattered over the sand-covered shoreline. There are two deserted islands which include Churna and Astola, and two lagoons at Miani Hor and Kalmat Hor. There is no significant river discharge on this shore, except a few transient streams. Mangrove may be found in small areas at Jiwani, Gwadar Bay, Kalmat Khor, and Miani Hor [9]. The Balochistan Sea Fisheries Ordinance 1971 prohibits trawling using trawl nets in the territorial waters of Balochistan [13].

b) The South-eastern Region, often known as the Sindh coast, stretches 266.5 km [4] between Hub River to the west and India to the east. The Indus River delta formed a network of winding channels that make up much of the Sindh coast. Some of these canals have mangrove stands (Avicennia marina) surrounding them. The Sindh coast's western section includes a mix of long, sandy beaches and steep cliffs. The Swatch, a well-known Indus submarine canyon, is located on the 150 km wide continental shelf and reaches a maximum depth of almost 700 m [9]. Numerous fish and shellfish, which are important to the economy and spend a portion of their life cycles in the creek area, are among the many species that find home in the large wetland and soft sediments [14; 9; 15].

The Exclusive Economic Zone (EEZ) of Pakistan is about 240,000 square kilometres (Figure 1A). It includes all of continental shelf and slope as well as a section of the Arabian Sea's deep-sea floor, which is 3,250 metres at its deepest point [16]. The EEZ is divided in half by the Murray Ridge, which stretches southwest from the Baluchistan continental shelf to the Carlsberg Ridge [2]. The Exclusive Economic Zone (EEZ) was extended from 200 to 350 nautical miles in 2015, as per Pakistan's proposal approved by the UN. Pakistan was granted exclusive access to resources on the seafloor over an area of around 50,000 square kilometres, including both living (benthic) and non-living components [17].

Federal government authority over fisheries development, management, and control extends to the EEZ beyond 12 nautical miles [18]. As per the guiding principles, the Federal Government bears the responsibility of providing support to the fishermen's capacity building in fish harvesting, on board handling, onboard fish storage to reduce postharvest loss, food hygiene, and personal hygiene and safety at sea [19].

Approximately 0.32% of the GDP was derived from the fishing industry in 2022–2023; 1.4% of the agriculture GDP [20].

Fisheries contribute just 1.0% of the total employment in the country [19; 20]. An estimated 800,000 metric tonnes of fish was produced in 2022, of which 170,000 metric tonnes come from inland aquaculture [21]. Over the past five years, the amount of fish produced by marine capture has varied between 450 and 500 thousand tons. The value of Pakistan's fisheries exports peaked in 2022–2023 at 496 million US dollars, the highest amount ever [22]. Exports account for only 25% of the overall fish production [23]. Pakistan's average export value per kilogramme of fishery products is between 2 and 2.5 USD, which is less than the global average of 5.0 USD per kilogramme [24].

2. Material and method

The basic methodology and data of this study has been derived from the final report of the Fisheries Resources Appraisal in Pakistan Project (UTF/PAK/108/Pak) and submitted to the ministry in 2016 [2], fisheries statistics on fish production and number of active fishing fleets, was additionally gathered from the Handbook of Fisheries Statistics [25]. Statistics about export of fisheries products was obtained from the web sites of Trade Development Authority of Pakistan and Pakistan Bureau of Statistics. The information about the aquaculture production was taken from the web site of FAO Fishery Country profile.

3. Results

3.1. Fish production

The fish production by provinces and zones (inland and marine) from 1973 to 2021 is shown in Fig. 1B, the total fish production increased from 214,231 tonnes in 1973 to 737,025 tonnes in 2021. There are several significant peaks in 1980s, 1990s and 2000, after that, there is a declining trend that lasts until 2005, although from 2020-2021, there is some recovery. The fish production from marine waters was 196,614 tons in 1973 which increased to 426,025 tons in 2021 and following a similar trajectory of the total production. The fish production from Inland waters was 17,617 tonnes in 1973 and increased steadily to 307,000 tonnes in 2021.

The fish production by provinces in the marine sector is also shown in Fig.1C, the Sindh province produced 158,892 tonnes in 1973 which increased to 230,314 tons in 2021 and following the trajectory pattern of marine sector and overall production. The province of Balochistan produced 37,722 tons of fish in 1973, and it rose gradually to 195, 711 tonnes in 2021. Fish produced from the EEZ began in 1982 with 2,314 ton, and reached a peak in 1985 with 9,986 tons and then again in 1992 with 25,338 tons and 1993 with 30,677 tons, respectively. Before it was entirely discontinued in 2009, a minimum of 78 tonnes was recorded in that year.

3.2. Export of fish and fishery products

Figure 1D shows data on fish exports, their value, and the average unit price per kilogramme from 2000–01 (July–June) to 2022–23, as reported by the Trade Development Authority. Exports were at 82,045 tons in 2000–01 and rose to 214,367 tonnes in 2022–2023 with varying trend. In 2000–01, the value of fisheries exports was $135 million USD; by 2022–2023, that figure had increased to 496 million USD, and the trend had maintained. The typical unit price of exported fisheries products varies from 2 to 2.5 USD per kg.

3.3. Growth of fishing fleet

Fishing boats are divided into two categories: mechanised boats and non-mechanized boats (boats without inboard engine). Mechanized boats are further sub-divided in to Gillnetters and trawlers. Figure 2A displays the growth of fishing fleet from 1972 to 2021. It appears that trawlers increased from 535 in 1972 to 2,896 trawlers in 2021, with CAGR of 8.8%. The gillnetters increased from 366 to 5,949 during the same period, with CAGR of 30.5%, whereas, mechanised sailboats increased from 140 to 13,070, with CAGR of 184.7% during the same period.

A Marine Fishing Vessel Census of fishing boats and landing places was carried out in 1985 and again in 2010–2011 in cooperation with provincial fisheries agencies to gather data about the fishing effort that was really engaged in fishing. In 2012, the census data verification process was completed.. Enumerator training was organised by the FRAP project at MFD and different landing places at Balochistan. Table 1 displays the summary of the vessel census as well as the total

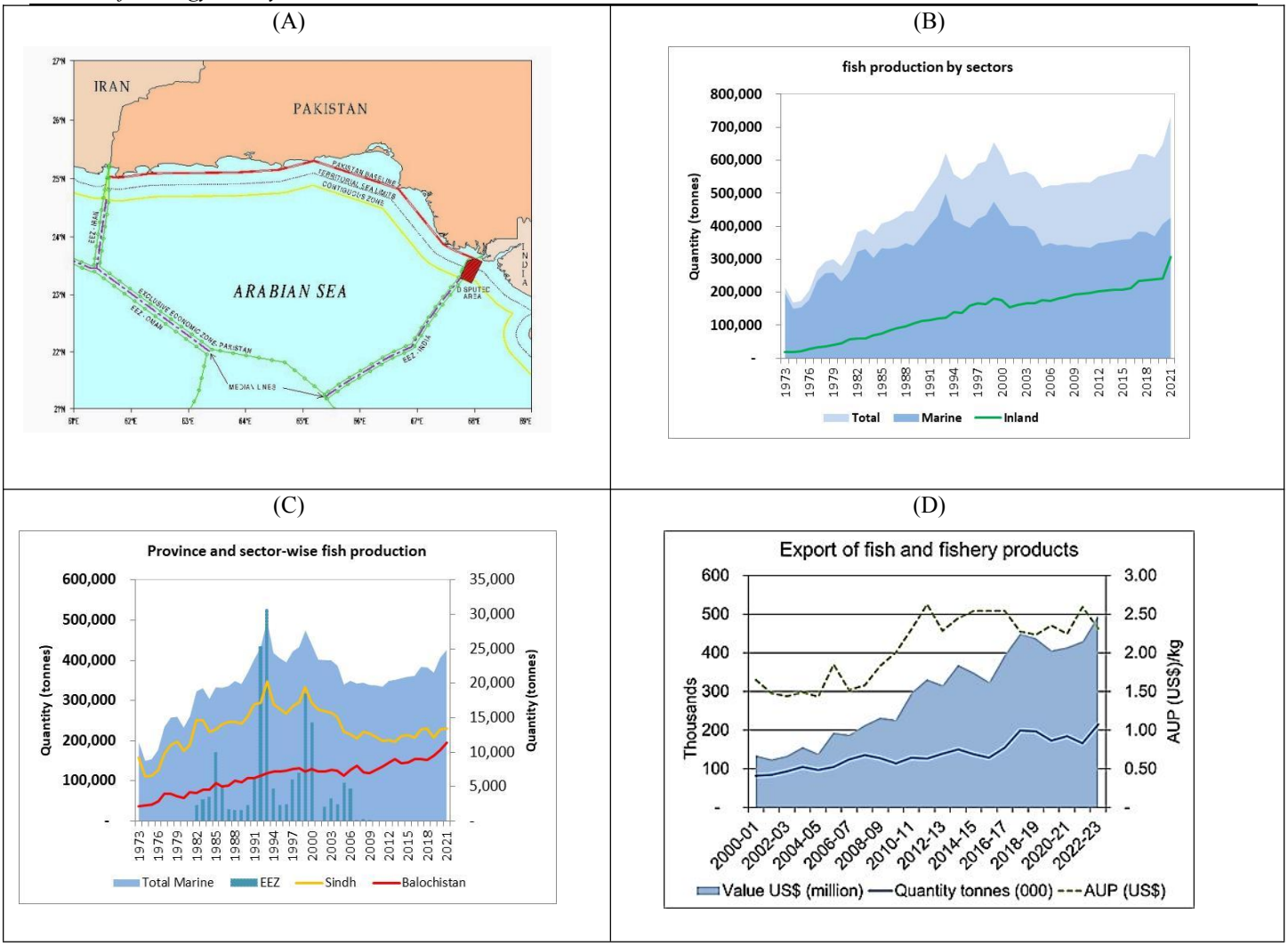

Figure 1. (A) The map displaying the borders of Pakistan's Exclusive Economic Zone (EEZ) with its neighbours, as well as the base line, territorial waters, and contiguous zone [26]; (B) Fish production by sectors [25]; (C) Provincial fish production [25]; and (D) Export of Fish and fishery products [22].

number of fishing vessels in service in 2021.

3.4. Fish stock assessment

3.4.1 Demersal fish stocks

A total of 860 distinct taxonomic groups (species, genus, family, or higher taxa) have been identified from bottom trawl surveys conducted as part of the FRAP project from 2009-2015. These groups include nearly as many small pelagic taxa and over 150 invertebrate taxa. There are still about 500 taxa that are demersal fish. Because demersal species have a high level of biodiversity, they are typically grouped together into families for assessment purposes (Table 2). One or two multiple species have been chosen for identification each group/ family. Catch statistics are rarely assigned to the species level because of the extremely low species resolution in the fisheries statistical data (catch and effort). Thus, trends in catch rate, or catch per unit effort, or CPUE, must be applied to large populations. In general, the most trustworthy indication for assessing stock status is an abundance index, such as CPUE or surveys.

The identical stratification design, identical gears, and comparable sample procedures have been employed in six surveys conducted since 1977. The location was chosen based on perceived changes in the acoustic data, with the exception of survey 1984401, that was random. The sample selection process is anticipated to induce a positive bias into the swept-area methods used for biomass estimation, as tows are only done when fish are seen on the fish finder.

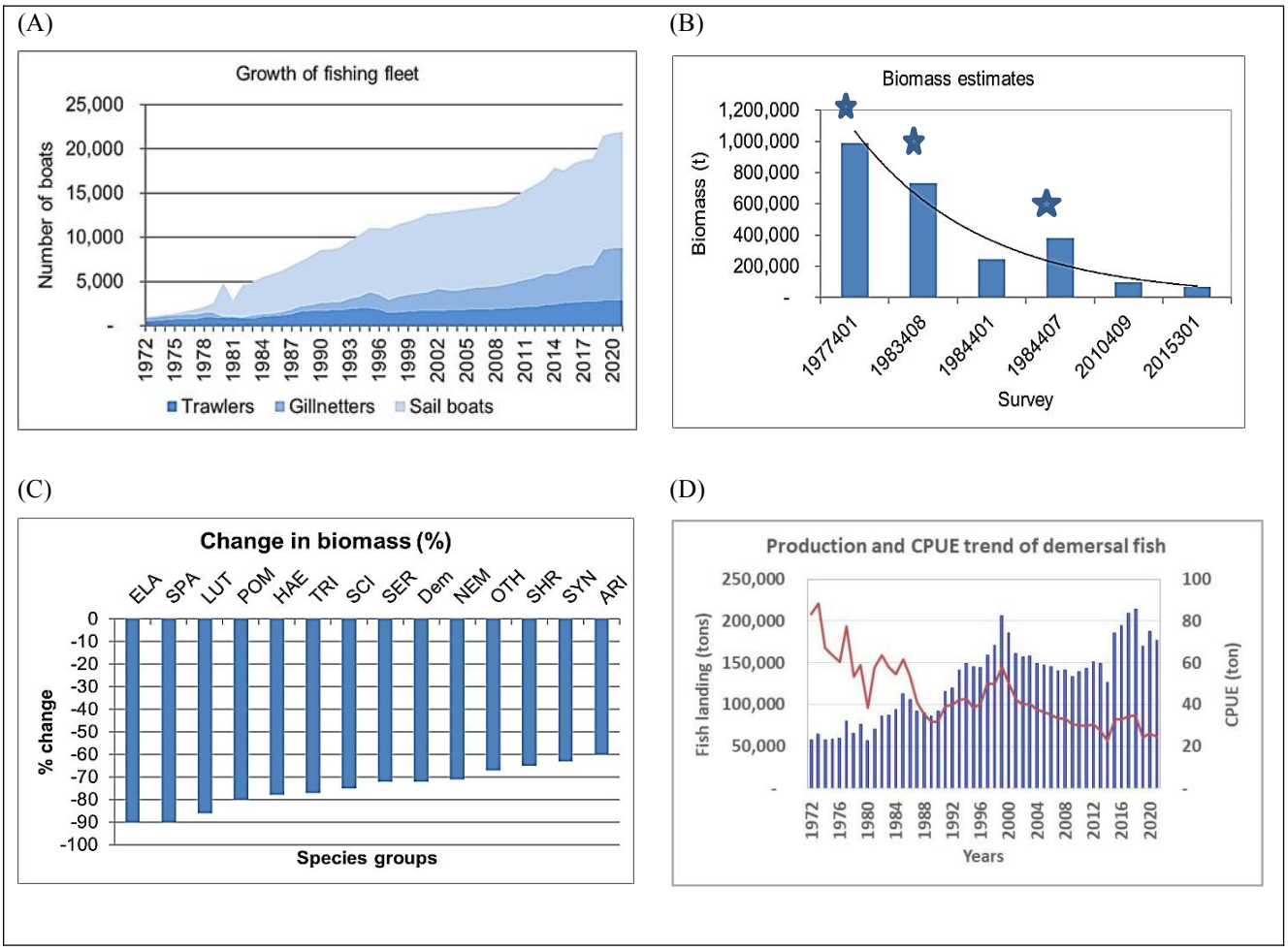

Figure 2. (A) Growth of the fishing fleet [25]; (B) Biomass estimates based on demersal trawls by the RV *Dr Fridtjof Nansen* (1977-2010) and the RV *Ferdows-I* (2015), Asterisk indicates acoustic surveys during which bottom trawls were aimed at fish concentrations, Source: [5]; C) Variation (%) in the biomass of primary demersal families or groups in demersal surveys under taken by RV *Dr Fridtjof Nansen* during Voyage 1984401 with 2015301in Pakistan waters: ELA: Demersal elasmobranchs; SPA: Seabream; LUT: Snappers; POM: Pomfrets; HAE: Grunters; TRI: Ribbonfish; SCI: Croakers; SER: Groupers; DEM: all demersal; NEM: Threadfin; OTH: others; SHR: Shrimp (various families); SYN: Lizardfish; ARI: Sea catfish. Source: modified after [5] and (D) Production and CPUE trend of demersal fish stocks, modified after [2].

The estimates of catch rate and biomass for the surveys (1984401, 2010409, and 2015301) that used random station selection are impartial and consistent. Figure 2B compares the demersal fish stock estimates from the fisheries resource assessments conducted in 1977, 1983, 1984, 2010, and 2015. Even with this potential source of bias, trends generally exhibit a high degree of constancy. Survey carried out in 2015, using the RV *Ferdows-I* with similar trawl net to that used in the RV *Dr. Fridtjof Nansen;* showed a further decline in catches from 2010 to 2015.

3.4.2 Reduction in index of abundance

The biomass estimates of demersal fish stock from 1977 to 2015 are displayed in Figure 2B, using two distinct approaches: swept area trawl and acoustic integration and methods. The biomass estimates using the acoustic approach are displayed in the bars with strike, which are greater than the biomass estimates using the swept area methods. The estimations show a downward trend and a notable drop in biomass among the swept area techniques surveys (i.e., 1984401, 2010409, and 2015301 surveys). Figure 2C shows how the catch rates from the surveys conducted in January 1984 and 2010 varied. The most significant commercial families or groups are included.

For all of them, there have been significant shifts; in comparison to 1984, most families had declines 60-90% in 2010.

Figure 2D display the all demersal finfish landing statistics published in Handbook of Fisheries Statistics was consolidated into a single series (single bar) for the years 1972–2021 and trend of catch per unit effort (CPUE) (red line). The series has multiple peaks up until 2000, after which there has been a reduction in the total number of demersal fish landings since 2014. The trend is still decreasing, even if there was some recovery between 2015 and 2018. It appears that the CPUE decreased gradually between 1999 and 2014. After that, there was a little improvement, but the trend reverted to dropping, albeit more slowly than previously, as fishing efforts increased. These species are targeted by all kinds of fishing boats, but they have different capacities for fishing.

3.4.3. Stocks of small pelagic fish species

A broad group of species that are similar in size, behaviour, and habitat are together referred to as small pelagic. They may be effectively caught in large quantities due to their propensity to form vast schools.

Table 1. shows the distribution of operating fishing boats by province. Source: modified after [2].

	1986	2011	± in %	2021	± in %
Balochistan	2,133	4,568	114.16	11,118	143.39
Sindh	4,355	8,218	88.70	10,797	31.38
Total	6,488	12,786	97.07	21,915	71.40

Table 2. Species included in the demersal species groups for stock assessment analysis. Source: modified after [2].

Group	Family	Indicator species	No. of species
Groupers	Serranidae	*Epinephelus diacanthus*	13
Snappers	Lutjanidae	*Lutjanus argentimaculatus*	11
Small Croakers	Sciaenidae	*Otolithes cuvieri, Otolithes ruber*	25
Large Croakers	Sciaenidae	*Protonibea diacanthus*	08
Lizardfish and	Synodontidae	*Saurida tumbil*	7
Flatheads	Platycephalidae	*Platycephalus sp.*	10
Sea breams	Sparidae	*Argyrops spinifer*	11
	Lethrinidae	*Lethrinus nebulosus*	03
Threadfin breams	Nemipteridae	*Nemipterus japonicus*	11
Pomfrets	Stromateidae	*Pampus argenteus*	03
	Carangidae	*Parastromateus niger*	01
Hairtails (Ribbonfish)	Trichiuridae	*Trichiurus lepturus*	06
Grunters	Pomadasyidae	*Pomadasys maculatus, Pomadasys stridens*	20
Catfish	Ariidae	*Arius tenuispinis*	07
Others	Apogonidae	*Apogon sp.,*	11
	Mugilidae	*Liza sp.,*	06
	Polynemidae	*Polynemus sextarius,*	09
	Sphyraenidae	*Sphyraena obtusata,*	09

The primary gear for shallow-diving species worldwide is the purse seine, while pelagic trawls are used for deeper-diving species. The three most significant families in Pakistan are the Clupeidae (herrings and sardines), Engraulidae (anchovies), and Carangids (scads and jacks). Among the generally larger members of the Scombridae family is the significant small pelagic Indian mackerel (*Rastrelliger kanagurta*). The silvery colouring, glossy scales, and tapering bodies of these small schooling species are identical. Figure 3A illustrates the production and CPUE trends of small pelagic fish species from 1972 to 2021. It appears that in the mid-1980s, small pelagic fisheries experienced significant exploitation due to growing demand for fishmeal; however, since the 1990s, they have been steadily falling. There was a slight recovery between 2002 and 2009; however, the trend has now reverted to its previous negative direction. There have also been notable declines in the CPUE since the 1980s.

The Penaeidae family comprises the majority of the major shrimp stocks. The development of the trawl fishery in Pakistan was primarily focused on developing shrimp fisheries. The Penaeid prawn species prefers soft, muddy bottoms that are rather shallow. These conditions are perfect for trawling, particularly when mechanical winches are not employed. Figure 3B displays the production and CPUE trend along with number of trawlers for shrimp fishing from 1972 to 2021. It appears that shrimp production decreased from 23,867 tons in 1972 to 22,026 tons in 2021, with minimum of 14,800 metric tonnes in 2016 and a maximum of 34,900 metric tonnes in 1993.

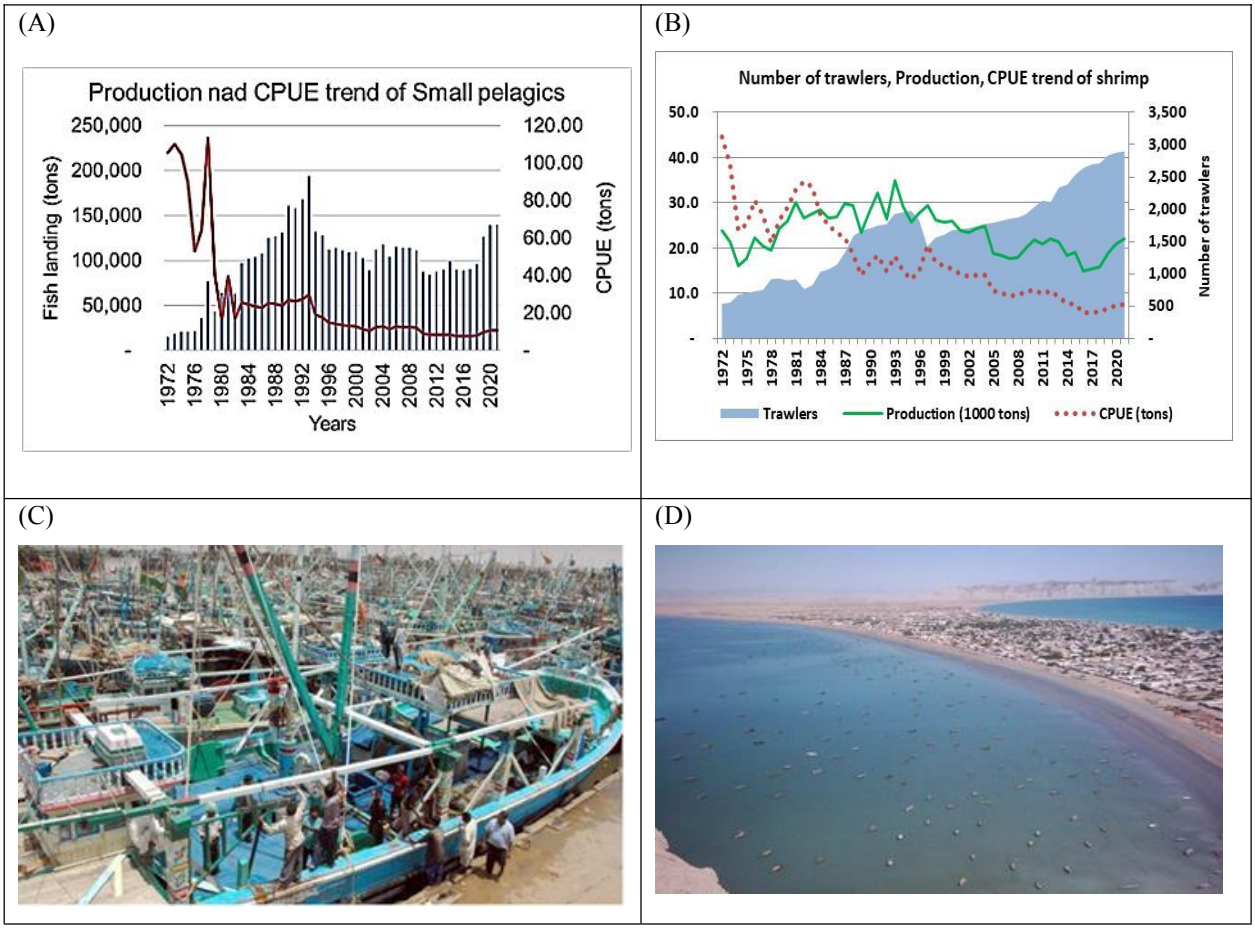

Figure 3. (A) Production of tiny pelagic fish species and CPUE trend, modified after [3]; (B) Production and CPUE trend of shrimp species, modified after [3]; (C) Crowded fishing boat berthing at KFH and (D) Arial image of the fishing boats in West Bay of Gwadar.

Whereas, the CPUE is decreasing continuously, contrary to this, the number of trawlers is increasing year after year.

3.4.5. Ecological changes

In the course of the FRAP project's fisheries resource surveys, the following ecological changes were noted:

- Recent surveys have revealed a decline in large-bodied, slowly growing, and highly valuable predatory species (e.g. sharks, rays, guitarfishes, groupers, snappers, grunters, croakers, emperors, jacks);
- increased numbers of short-lived, fast growing, small-sized species with low commercial value (e.g. threadfin breams, lizardfishes);
- A large and varied variety of cephalopods, primarily squids and cuttlefish (which are also an opportunistic, fast-growing group);
- Recent surveys have revealed an abundance of jellyfish, which further strongly supports a severely disrupted resource system.

3.5. Major issues in marine fisheries

3.5.1. Over-capacity of fishing fleet

Mechanised boats and non-mechanized boats (boats without inboard motors) are the two types of fishing boats. Under the former, there are further divisions for trawlers and gillnetters. Statistics from 1972 to 2021 are shown in Figure 2A and Table 1 (refer to section 3.3). Figure 3C shows fishing boats berthing at Karachi Fish Harbour (KFH), while an aerial view of the fishing boats in Gwadar's West Bay is presented in Figure 3D.

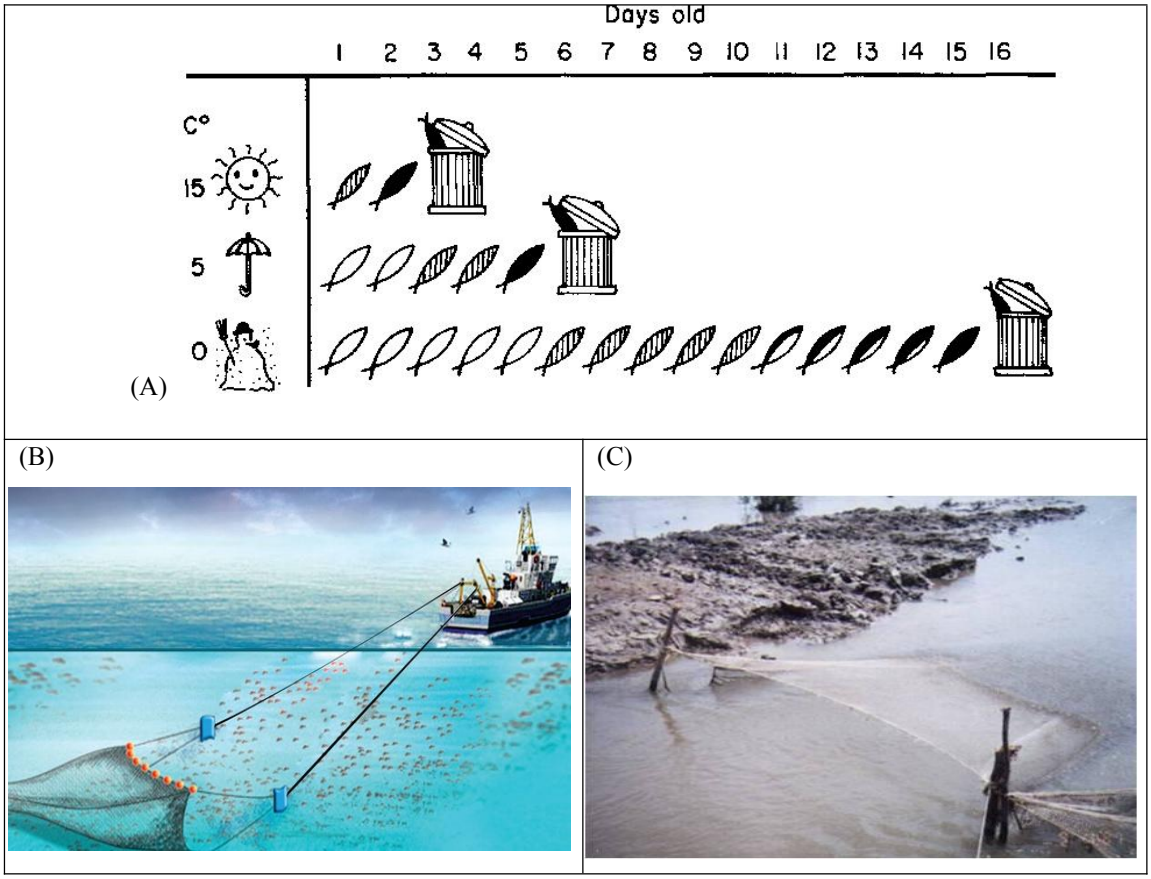

Figure 4 (A) Schematic drawing shows the shelf life of fish in ice storage [3]; (B) demonstrating how to trawl on the ocean floor; (C) ESBN fixed at the mouth of creek.

Figure 5. (A) A typical fishing boat’ s fish hold; (B) using channel water to de-ice fish and shrimps ; (C) fish on floor at the fish market hall (KFH) for auction; and (D) placing shrimp for sale in boxes without ice.

Table 2: A summary of the fish species found in shrimp trawlers' bycatch, or trash fish Source: [2]

S. No.	Group name	%
1	Bony fish	91.75
2	Crab	2.29
3	Cephalopod	2.67
4	Shrimp	1.88
5	Rays	0.99
6	Squilla	0.30
7	Coelenterate	0.02
8	Echinoderm	0.02

3.5.2. Use of harmful fishing equipment (such as trawling and ESBN)

According to the Sindh government, it is prohibited to utilise trawling methods (Figure 4B), trawl nets with less than 25 mm mesh size at cod-end, which are used by shrimp trawlers, and estuary set bag nets (ESBN) (Figure 4C), also called 'bulla nets'. However, local fishers are still using these nets without any limitation. Trash fish are young fish and shrimp species that are unintentionally collected as bycatch by shrimp trawlers. Marine Fisheries Department has conducted study on the species composition and size frequency distribution of fish species found in trash fish. Table 2 summarises the species of fish identified among the trash fish.

3.5.3. Post-harvest procedures that cause large losses

Fishing boats are handcrafted from wood and do not have modern freezer or chiller storage (Figure 5A-D). In order to prevent bruises during storage, the shrimps and fish are not kept in fish boxes appropriately. Generally, fisheries products

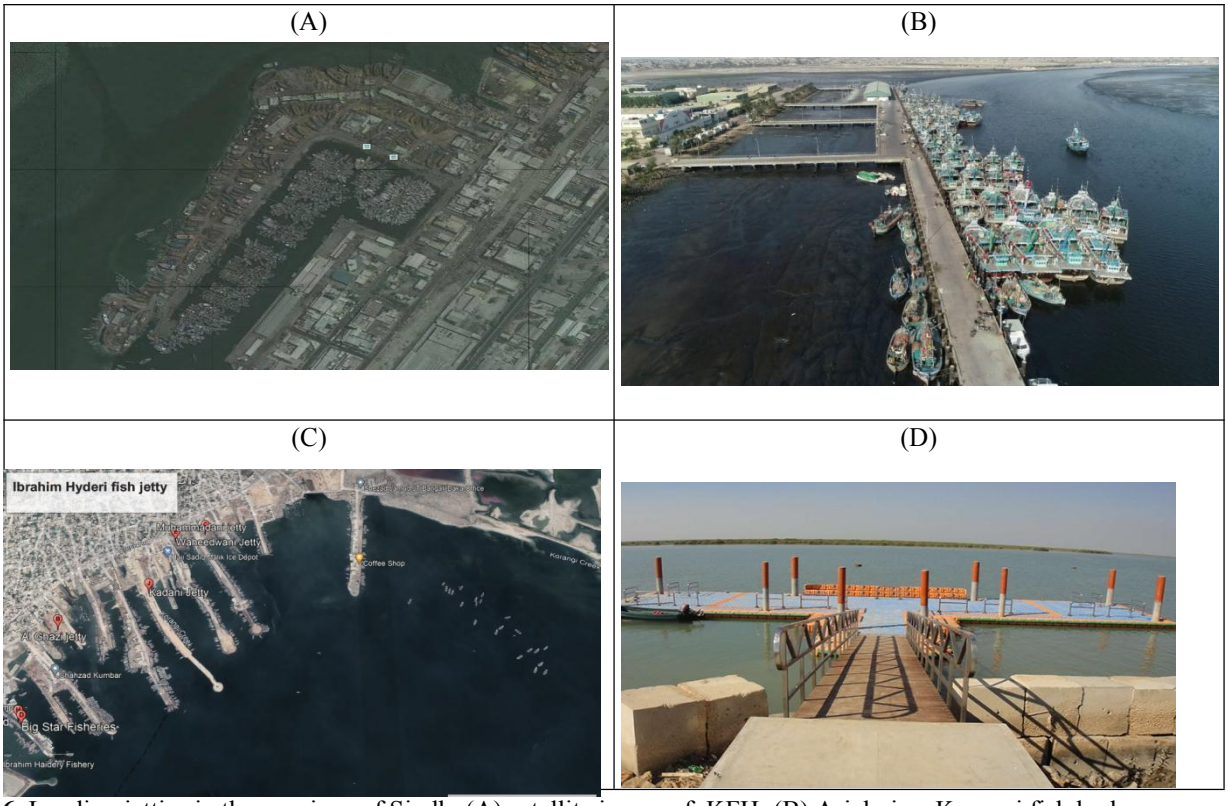

Figure 6. Landing jetties in the province of Sindh, (A) satellite image of KFH; (B) Arial view Korangi fish harbour; (C) satellite image of fish jetties at Ibrahim Hyderi; (D) A floating pier at Keti Bander.

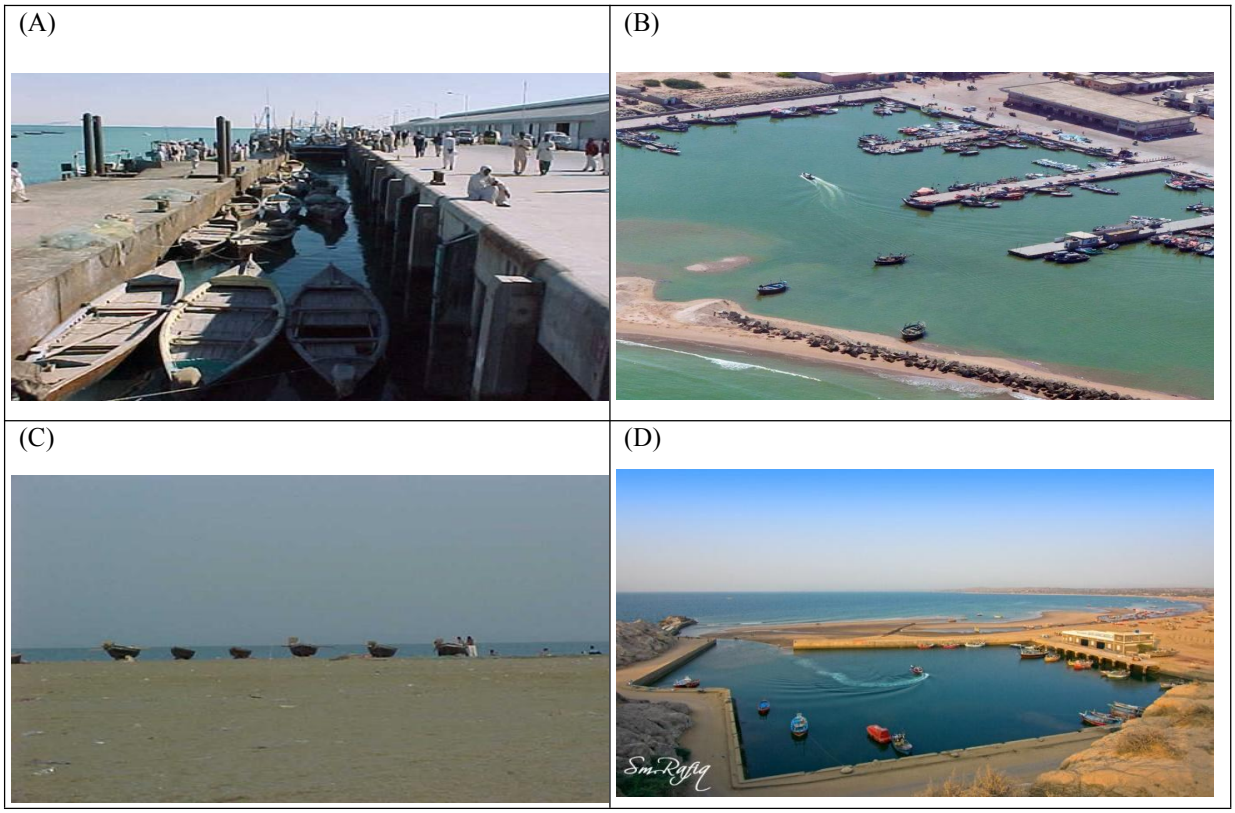

Figure 7. Landing sites in the province of Balochistan, (A) Gwadar fish harbour with floating pontoon; (B) Pasni fish harbour, an Arial view; (C) landing site at Ormara beach, and (D) An Arial view of Gaddani fish harbour.

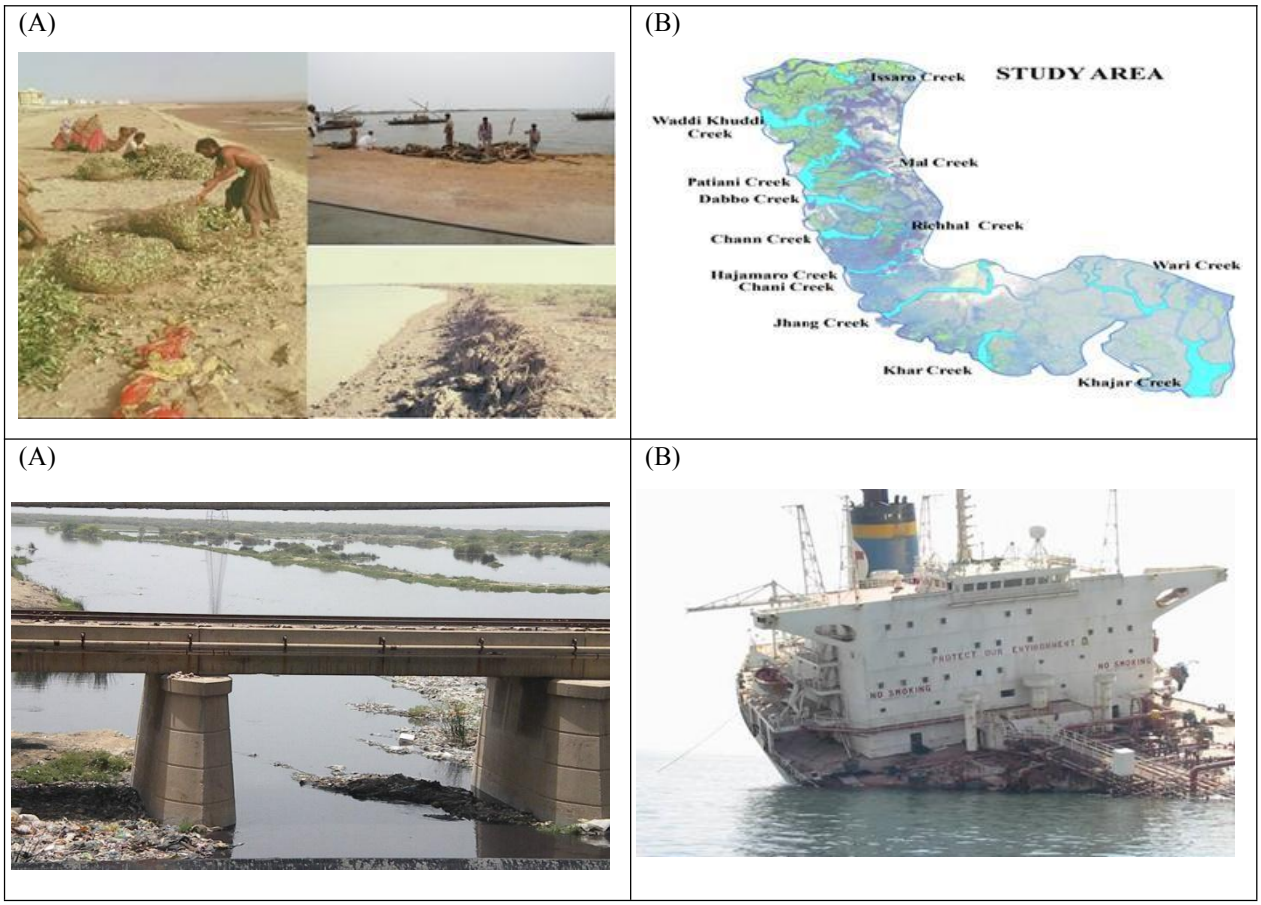

Figure 8. (A) chopping down mangroves, camels grazing, and evidence of erosion; (B) The FRAP project's 2014 creek survey area [27]; (C) Sewage-related marine contamination at Layri river; (D) Tasman Spirit oil leak in July 2003.

are not stored at a temperature that melts ice (i.e. 0°C), however improper proportioning of icing results in improper cooling during storage. There is a disregard for hygiene and no provision for drainage of melting ice water from the fish hold.

3.5.4. at landing sites, inadequate infrastructural facilities

The primary landing area in the country, Karachi Fish Harbour, is already overcrowded. The harbour has all the amenities that are required, such as a net-mending shed, a chill room, and a flake ice factory. Its turning basin is quite large. Ironically, despite the high level of pollution in the fish harbour, the seawater is nonetheless utilised to clean the harbour floor. The public and traffic flow are uncontrolled, which makes Karachi's operations chaotic. The discharge and loading of decaying "trash" fish renders Karachi Fish Harbour among the dirtiest harbours in Pakistan. Although a proposal to expand the harbour's facilities is being executed, there is a general concern that it won't improve the harbour's functionality or the unsanitary conditions that now exist. Local fishing boats do not use the Korangi fish harbour because it was designed for fishing vessels with a draft of more than five meters. Similarly, Gwadar Port was found to be unfit for the local fishing boats. The flood of 2022 destroyed most of the constructed floating jetties in the province of Sindh. No landing site in the country has a cool chain maintenance system in the country. Figure 6 and 7, respectively, shown the fish jetties or landing places in the provinces of Sindh and Balochistan.

3.5.5. Mangrove destruction

Mangroves are crucial for thousands of species, stabilizing shorelines, preventing erosion, and providing food for indigenous communities worldwide. In coastal places, mangrove cutting is prevalent. Camels also fed on it. There are signs of coastal erosion as a result of the removal of mangroves

(Figure 8A). Creek survey A study in 2014 (reference) conducted under FRAPP indicates that there is an increase in the expanse of forest acreage in the Indus Delta (Figure 8B).

3.5.6. Marine pollution

The main source of contamination in the ocean is untreated sewage discharge. The region surrounding Karachi's coast is the one affected by the marine pollution (Figure 8C). Plastic trash is another form of pollution that has an impact on marine life. The Tasman Spirit Oil Spill impacted 40 square km, including the shoreline close to the incident (Figure 8D).

4. Discussion

General information on all aspects of the fishing industry, with special reference to the years 1957–1961, along with studying both zonal and national levels [28]. Over the last five years, they assess how fish output, distribution, export revenue, processing facility installation, and fleet growth has changed. The marine fishing sector around Karachi's coast was evaluated in 1972, a number of topics including fishermen, boats, gear, industry structure, production, distribution, usage, processing, marketing, and exports. These studies offer insightful analyses of the fishing industry [29].

The Pakistani government permitted foreign flag deep-sea trawlers to fish demersal fish resource beyond 35 nautical miles in EEZ of the country; which were considered as surplus [16; 30]. These trawlers were permitted to fish from 1982 to 2005; the number of vessels allowed varied from 3 in 1987 to 20 in 2000 [31]. There haven't been any foreign trawlers working in Pakistan since November 2005 [31]. The foreign flag tuna long liner fishery industry began the longline tuna fishery in 1991, and by 1993, the fleet had grown to fifty vessels [9, 31]. Nine vessels were in use for offshore longline fishing as of May 2009 [31]. The Government of Pakistan continues to periodically accept applications from bottom trawlers, tuna purse seiners, and tuna long liners in accordance with the Deep-Sea Fishing Policy 1995; however, since 2009, no feasible plans have been submitted [31].

A new Deep Sea Fishing Licencing Policy was introduced in 2018. It prohibits local and foreign fishing vessels from trawling, and it rationalises the number of vessels according to the maximum sustainable yield of the fish stock. Only longline fishing for tuna, squid jigging, and mesopelagic fishing was allowed under joint ventures with foreign collaborators [32]. Under that policy, Zone-3 (area between 20 nautical miles to 200 nautical miles) would be subject to federal regulation, would be available for fishing licence acquisition to all provinces and the number of licences issued would be rationalised. Unfortunately, the hostility of the local fisherman led to the policy's shelving [33] and eventual repeal in 2021 [34].

The analysis of the overall fish production indicates that there are several peaks; the peak in production during 1980s (Fig.1B) was due to the beginning of deep sea fishing foreign flag fishing vessels (stern trawlers) in the country's EEZ beyond 35 nautical miles through a joint venture agreement with foreign companies, which increase growth rate between 1981-1990 [10, 23]. The growth rate remained high between 1991 and 2000 due to the introduction of tuna longline fishing by foreign flag vessels on the pretext of stock assessment of tuna and related species in the EEZ of the country, [31]. As part of the new deep sea fishing strategy, fishing licences for foreign-flagged vessels were issued throughout this time period; however, relatively few of these vessels were operational during this period, which accounts for the slow growth rate between 2001 and 2010 [23, 31]. The reason for the modest growth rate between 2011 and 2020 was due to extensive fishing by artisanal local fishing boats outfitted with mechanical trawl winches similar to that of deep sea fishing trawler with fine mesh size trawl net; resulting high rate of bycatch or catching juveniles of commercial species that used for fishmeal production [2, 23]. Aquaculture production increased between 2020 and 2021, which contributed to the high growth rate in total production of fish in that years [35].

The similar trajectory in fish production from marine sector and fish production from Sindh province (Fig.1C) are due to same reason as explain above because foreign fishing trawlers or tuna longline vessels sold their bycatch to Sindh based local fishing boats, as the area of operation of these foreign vessels was available only in the Sindh coastal Zone [3; 10; 31]. The

fish production from Balochistan province showed steadily growth rate from 1973 to 2021. Fishing for small pelagic fish species, especially sardine and Indian mackerel, since 2018 is the reason for the high growth rate observed in 2020 and 2021 [3; 23]. The fish production from EEZ was restricted to certain years; however, deep sea fishing brought the frozen fishery market; which caused a paradigm change in the fishery from frozen prawns to frozen finfish [23].

The fish exports, its value and average unit price per kilogram since 2000–01 (July–June) until 2022-23 (Fig. 1D) indicates that the Pakistan exports only 25% of the total fish production. Exports climbed from 82,045 metric tonnes in 2000–01 to 214,367 metric tonnes in 2022–2023 [22; 23]. In contrast to the global average price of 5.0 US dollars per kilogramme, the average unit price (green line in the graph) of exported fishery goods ranges from 2 to 2.5 US dollars per kilogramme [23; 36].

The growth of fishing fleet (Fig. 2A) shows that shrimp trawlers increased from 332 in 1970 to 2,896 in 2021 [3]. It was reported that these trawler were concentrated in shallow coastal water up to 20 meters depth [37; 38], however, after the installation of trawl winches these trawler are capable of fishing much deeper waters up to 100 meters [9]. Previously, these boats would solely trawl for shrimp [16], but since 2002, a high-opening bottom trawl net for fish and a prawn trawl net (particularly in August and September) have been used by almost all of these trawlers [9]. Apart from the reduction of shrimp stocks, operating such a sizable trawl fleet has had a number of detrimental effects on the ecosystem, that might significantly affect the fishing grounds' productivity and biodiversity [2]. Important fishing gear types that are used to catch big demersal species in coastal and offshore seas include longlines and handlines. Seabreams, groupers, eels, croakers, sharks, and rays are some of these species. Furthermore, beach seines and cast nets are significant pieces of equipment that are utilised in creeks, intertidal areas, and coastal waters [9].

Resources related to fishing are essential to a country's economic development and the well-being of its people. It is well recognised that fish populations may be impacted by overfishing and environmental degradation [1]. From the beginning, the Marine Fisheries Department has taken part in the fish stock assessment. The stock assessment was done as part of an international cooperation programme, primarily initiated under the International Indian Ocean Expedition (IIOE) between 1960 and 1970, or with the FAO/NORAD sponsored "*Dr. Fridtjof Nansen*" programme between the middle of the 1970s and the beginning of the 1980s, or with the research vessels of the organisation. Development plans related to fisheries was developed using the data produced by these research [2; 3]. The Marine Fisheries Department and the FAO collaborated to conduct surveys between 1983 and 1986 and 1990, using the department's research vessels, *Machhera* and *Tehkik*. For the first time, an attempt has been made to evaluate stocks using a statistically sound technique [3]. It is necessary to do regular resource evaluations, ideally once a year [1]. Unfortunately, the lack of a survey vessel has prevented any new assessment surveys from being conducted in Pakistan since 1990 [2, 3]. A number of important resources, including sharks, crabs, lobsters, prawns, and so on, are thought to have been badly overfished and appear to have already surpassed the limits of sustainable exploitation [2; 37]. It was obvious that Pakistan's fisheries management and management support data require updating and strengthening [1; 39].

For the FRAP investigation, all previous surveys using the same fishing gear and techniques were assessed; however, the data was first standardized [2]. When demersal fish stock estimates from resource surveys conducted in 1977, 1983, 1984, 2010, and 2015 are compared (Figure 2B), demonstrates that the declines in demersal fish populations between 1980 and 2015 ranged from 60 to 91% [2]. Catch rates declined even more between 2010 and 2015, according to a 2015 survey carried out using the RV *Ferdows-I* with comparable trawl net as used by the RV *Dr. Fridtjof Nansen* [2]. Over 500 different demersal species have been found in Pakistan between 2010 and 2015, demonstrating the country's rich diversity [2; 9]. As a result, information was shown at a higher taxonomic level (families or higher groupings). The following families and

groups, which are representative of the Indo-Pacific area, are important economically in Pakistan: hairtails or ribbon fish (Trichiuridae), seabreams (Sparidae), grunts (Haemulidae), catfish (Ariidae), lizardfish (Synodontidae), threadfin breams (Nemipteridae), and others. Furthermore, sharks and rays (a few families under the higher taxon Chondrichthyies) are important commercially in addition to being important components of Pakistan's fish assemblages [2; 3].

In the most important commercial families or groups of fish species, the catch rates from the surveys carried out in January 1984 and October 2010 differ significantly (Figure 2C). They have all seen significant changes; in comparison to 1984, most families had declines of 60–90 percent in 2010 [2; 5]. It appears that trends in Pakistan's overall demersal catches (from all fisheries) peaked in 2000, then declined, and stayed at about 150,000 metric tonnes (Figure 2D). However, catch rates, or the amount and availability of demersal fish species, have declined sharply, according to CPUE trends [2, 3].

Several species are categorised as small pelagic, primarily belonging to the families Clupeidae, Engraulidae, Carangidae, and Scombridae. 35 species or more make up the majority of small pelagic catches [2]. The trends in CPUE and the production of small pelagic fish species (Figure 3A) demonstrate that small pelagic fisheries saw a major boost in the mid-1980s because of the growing demand for fishmeal, but that there was a significant decline in CPUE in 1980. Since then, they have been gradually declining. For most small pelagic species, the main use is in the manufacturing of fish meal [2, 3].

Numerous studies have looked at the prawn fishery because of its commercial significance [2; 3; 37; 40; 41; 42; 43; 44; 45]. The production of shrimps exhibited a zigzag pattern, declining from 23,867 tonnes in 1972 to 22,026 tonnes in 2021 (Figure 3B). Meanwhile, the number of trawlers continued to rise, despite the constant decline in the CPUE [2; 3]. The FRAPP project study determined that the maximum sustainable yield (MSY) of shrimp stock is 19,600 tons. However, because to a steady growth in the size of the fleet (the number of prawn trawlers), as of 2013, the current level of exploitation was 22,294 tonnes, which is over the MSY. Despite the fact that the amount of fishing effort was rising and the catch per unit effort (CPUE) was steadily falling, nothing was being done [2, 3]. Furthermore, just 13,000 tonnes of replacement output are anticipated in the future, suggesting that the prawn supplies might collapse very soon. The study also projected a 20-year future scenario [2]. The stock appears to be much below the MSY standard and needs to be rebuilt immediately. Furthermore, it was estimated that the maximum number of trawlers that could be utilised to capture prawn resources was 1000. If effort is effectively reduced in the short term, better assessment of the costs and benefits of a given number of boats should be feasible through stock rebuilding and re-assessment [2]. This will need a steady, long-term decline in catch until the stock attains its peak production levels [3].

The subsequent ecological alterations have also been confirmed by these surveys: a) Large-bodied, slowly growing predatory species such as jacks, rays, guitarfishes, groupers, snappers, grunters, croakers, and emperors have become less common; b) the proliferation of small, quickly proliferating, transient species with low commercial value (e.g., threadfin breams and lizardfish); c) a broad variety of cephalopod species, primarily the opportunistic and fast growing group of squids and cuttlefish; d) Recent studies have revealed a large abundance of jellyfish, further confirming a critically disrupted resource system [2; 46].

The following facts are most likely the result of excessive fishing pressure and environmental deterioration, while natural factors like changes in the ecosystem or ecology may also have non-fishery consequences. In a productive cycle, bigger species that may be of interest to fishermen devour lower-level and grazer species in the marine environment, which in turn consumes primary producers. The ecosystem frequently flattens and the lower levels experience a boom in reaction to the removal of their predators when huge predators, or high trophic levels, are lowered by fishing [5]. "Fishing down marine food webs" refers to the methodical transition in landings and captures from long-lived, high trophic level piscivorous

demersal fish to short-lived, low trophic level planktivorous pelagic fish and invertebrates and is a result of excessive fishing [47]. Along with changes in species composition, big piscivorous fishes have generally shifted to smaller individuals. This is particularly true for snappers, one of the high-value species in the Lutjanidae family, whose maximum sizes range from 50 to well over 100 cm. In the most recent surveys, smaller species such as *Lutjanus argentimaculatus, L. bengalensis*, and *L. kasmira*, seldom measured longer than 25 cm. [5], even yet, little to no biomass has been added to the catch by some of the biggest and most expensive snapper species, such as *L. sebae, L. malabaricus*, and *L. argentimaculatus* [5]. Comparable trends have been seen in the grunts (Haemulidae), where the elimination of any fish longer than 25 cm implies that almost no spawning biomass is present in most species [2]. Merely 10% of the energy is transferred to the subsequent rung at every level of the food chain, with the remaining 90% being lost as heat. Global experience has shown that overfished stocks may often recover provided that fishing effort is successfully decreased (for Pakistan's demersal species group, estimated at 50%) and the size of the captured fish is sufficient to support appropriate spawning [2]. This would allow for the rebuilding of fisheries that are almost constant, incredibly successful, sustainable, and reduces fishing mortality for the majority of species groups [5].

Marine fisheries face a number of major issues, including an overcapacity fishing fleet, the use of destructive fishing methods or equipment, inadequate storage on fishing vessels, no cool chain maintenance system on fishing vessels and landing sites, improper infrastructure at landing sites, destruction of mangroves, and marine pollution. Furthermore, Figure 2A illustrates how the number of fishing vessels of all kinds increased gradually between 1972 and 2021 [26]. Data on the actual quantity of fishing effort was gathered in 2010 and 2011 through a Marine Fishing Vessel Census of fishing vessels and landing sites. Overall, it was discovered that the fishing fleet had grown by 97.1% (Table 1). Balochistan province saw a higher increase (114.2%) than Sindh province (88.7%) [2]. Another analysis claims that the fishing fleet increased to 21,915 in 2021, a 71.4% increase from 2011. Balochistan saw a 143.4% increase in provincial growth, compared to Sindh's 31.5% [45]. Figure 9A depicts a packed picture of the fish harbour in Karachi, whereas Figure 9B displays an aerial image of the overcrowded West Bay of Gwadar with fishing vessels. Information on fishing trip duration is also provided by the FRAP report, which reveals that average trip duration rose from 25.8 days in 2009 to 28.2 days in 2015 [2]. As shown in Figure 4A, fish kept on ice should not be consumed by humans after 15 days [3]. Furthermore, it was calculated that around 700 new boats are entering the fishery each year, and that approximately 600 boats cease to be used once they reach the age of thirty, which is the maximum age at which a wooden boat may remain in the sea water [2].

Many fishing methods and gear are prohibited by both international and national legislation because they are considered harmful for biodiversity and environment:

i) Although the trawling method (Figure 4B) and trawl nets with a mesh size of smaller than 25 mm in cod-end are forbidden by the Sindh government [48], local fishermen nevertheless use them to catch prawns [9]. Significant quantities of trash-fish, which are by-catch from trawl fishing are among the daily landings at KFH [2]. Since they are small sized and have low demand from customers, they are known as "trash fish". Trawling is the main technique for obtaining trash fish, which is then processed to produce fishmeal for use in poultry feed [2; 3; 9; 37; 42]. As part of the FRAP project, MFD has conducted studies to look at the size frequency distribution and species composition of trash fish. Preliminary results for the different categories show that bony fish (different families) make for about 92% of trash fish (Table 2). When given the right safeguards against overexploitation, around 35% of the fish species found in trash fish have considerable market potential [2]. Additionally, using trawl nets or the trawling method in Balochistan territorial waters is prohibited under Balochistan Sea Fisheries Ordinance [13].

ii) Small pelagic fish species such as sardines, anchovies, and

scads are captured in Pakistan using seine gear, which is locally known as "Katra" net. These boats are thought to number 600, of which 100 are based in Damb (Balochistan) and 500 are based in Sindh [9]. The Sindh Government forbids its use [48], however, it is still in use [9]. By capturing young fish and shrimp that are significant to the commercial industry, this type of gear depletes fish supplies and disturbs the ecosystem in creeks and extremely shallow coastal waters [9; 49]. Local fishers are openly utilising this net in both provinces [9], even though it is prohibited by both provincial governments.

iii) The estuary set bag net (ESBN), commonly referred to as "Bulla" or "Bullo," has been used in the creek area of Sindh since the late 1970s (Figure 4C). Fish and shellfish that migrate with the tides are harvested with this equipment in the streams of the Indus Delta. In order to capture a large number of juveniles and even larvae of fish and shrimp species that are important to the economy, it often utilises a very small mesh size and sets totally through smaller channels. Despite the fact that Sindh government ban its usage, about 8,000 ESBNs are still being in used in nearly all of the larger and minor creeks in the Indus Delta system [9]. Furthermore, the government of Balochistan also prohibit the use of this fishing method within its territorial waters [9, 13].

iv) The pelagic gillnet, also known as a drift net, is the main type of fishing gear used in of Balochistan province. Its length exceeds 2.5 km [31]. However, Resolutions 70/75 of the United Nations General Assembly of 2015 [50] and the Indian Ocean Tuna Commission resolution 17/07 of 2017 prohibits the use of nets greater than 2.5 km [51].

b) Post-harvest losses: Fish is a highly perishing food, as soon as it is caught, it starts to go deteriorate. The pace of degradation is significantly influenced by temperature. Similarly, the rate and pace of deterioration are determined by temperature and length of storage. Fish that has been caught and left on deck without being properly stored may thus deteriorate in a matter of hours [36]. Fish and shrimp are not kept in the fish hold in an acceptable way [1]. The fish holds are not well insulated, and there is no automated cooling system. A variety of factors, including poor fish storage on the fishing vessel, poor storage design, poor cool chain maintenance on the fishing vessel, poor transportation and auction hall, and insufficient infrastructure at the landing site, are considered to be responsible for between 60% and 70% of post-harvest losses [1; 2; 6]. Figures 6 and Figure 7 depict the landing sites in the provinces of Sindh and Balochistan, respectively. Crushed block ice is used for chilling; it is not enough to maintain fishery goods at the necessary 0°C temperature. From the fishing boat to the point of final processing, contamination and spoilage must be controlled [1]. Sorting fish and shrimp on tables was advised, and it was also suggested that fish boxes be utilised at landing sites and auction halls to improve to reduce post-harvest losses [1; 6]. However, these protocols are not being precisely followed. Furthermore, it was recommended that fishing trip should not exceed ten days and that fish and shrimp be properly kept and handled from the point of capture to the point of disposal [1; 6].

c) Mangrove destruction: Numerous resources, both biological and non-living, are closely related to the Sindh creeks [14]. One of the largest deltas in the world, these deltaic streams cover 600,000 hectares along Pakistan's coast, having been produced by the Indus River [52; 53]. The mangrove forests found in these creeks are thought to be the sixth biggest in the world [14]. Many marine fish and shellfish species' larvae and juveniles thrive in the mangrove ecosystem [54]. Mangrove cutting is prevalent in coastal areas and the Indus creek system, where local camels feed on the mangroves (Figure 8A). Mangrove deterioration appears to be contributing to coastal erosion [45]. In the survey regions, the mangrove forest land area has grown (Figure 8B), according to a 2014 research conducted as part of the FRAP project [27].

d) Marine pollution: Pakistan enjoys unrestricted access to marine resources, which has led to the unregulated use of these resources and the overexploitation of certain fish species [1; 2]. The degradation of the ecosystem in coastal regions has resulted in reduction nursery grounds of many fish and shrimp species [14]. The volume of sewage effluent and industrial trash that is discharged into Pakistan's aquatic environment is

rapidly increasing (Figure 8C). The organic load of sewage steadily lowers the oxygen level of water and decreases the variety of plant and animal life [55]. Most companies discharge into the ocean untreated their waste water effluents and high amounts of hazardous heavy metals [56]. It is estimated that Karachi would need 650 MGD of water, which will result in 472 MGD of sewage being produced per day. There is now only 50 MGD of the 150 MGD total treatment capacity being processed, and 422 MGD of raw sewage is discharged into the sea daily [57]. The impact of sewage contamination in the water is limited to Karachi coastal region [1]. Marine life may be impacted by the recent large increases in the use of pesticides and fertilisers in agriculture [58]. On July 27, 2003, the oil ship Tasman Spirit grounded in the Karachi port. The Tasman Spirit split in two on August 13, resulting in a catastrophic oil spill [59]. The first Tasman Spirit Oil Spill damaged an area estimated to be 40 square kilometres (Figure 8D). This affected the general pollution of the beach around the event. A 500–600 kg dead fish collection was done, including 20% sardines and 50% mullet [60]. The main consequences of pollution along the Karachi coast include habitat loss, eutrophication in some areas brought on by deteriorating water quality degradation, toxicity to marine organisms, especially to commercial species' larval stages, suffocation of intertidal marine vegetation and animal, sub-lethal effects on growth and reproduction, red tides, pathogen-contaminated fish and shellfish, as well as bioaccumulation of hazardous substances, particularly heavy metals, It ultimately causes the polluted nearshore ecosystem to lose its marine life resources. It was suggested that implementing an integrated coastal zone management plan in a specific coastal area would aid in the reduction and control of marine pollution [55]. The metal content steadily dropped as water sample locations got farther away from the sea's edge where the Lyari River empties into the ocean [61]. Except for waste and sewage from fish processing facilities in Gwadar East Bay [62] and plastic pollution in Genz, the Gwadar district, as a result of Cyclone Kyarr in November 2019 [63], there is no pollution along the Balochistan coast.

5. Conclusion

The marine fisheries resources are overfished; the overcapacity of fishing fleets, the use of harmful fishing gear, and post-harvest losses are the main factors contributing to the decline of fish stocks. The significant percentage of post-harvest losses can be attributed to poor landing site infrastructure, storage aboard fishing vessels, and inadequate cold chain maintenance during transit or transportation. Fish stocks are also being negatively impacted by the degradation of mangroves and marine pollution. Rebuilding fish stocks requires the implementation of the recommendation of the FRAPP report 2016 in letter and spirit, i.e. 50% reduction of fishing fleet on priority basis.

Data Availability statement

The data will be available upon justifiable request to the corresponding author.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Author Contributions

MWK: Investigation, Methodology, Writing - Original Draft; GA: Conceptualization, Supervision; Review and Editing.

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