# Marine fisheries catches for mainland India from 1950 - 2018

by

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**Abstract**

India's marine fisheries provide domestic food supply and livelihoods for millions of people. India has ongoing challenges with malnutrition resulting from nutrient and protein shortages, which can be partially addressed through marine fisheries. To ensure continued production from India's fisheries and guarantee supply into the future, these fisheries must be managed sustainably to reduce harmful impacts from fishing. There is little evidence of effective management, and unsustainable resource use occurs as a result of substantial overcapacity in marine fishing fleets. Catches from India's mainland Exclusive Economic Zone were reconstructed from 1950 to 2018 using comprehensive and standardised methods. Analysing available national and international data sources indicated that catches reported by the Food and Agriculture Organization (FAO) on behalf of India, from 1973 to 2013, likely suffer from accuracy issues. To rectify this, India should consider requesting a retroactive correction to their international fisheries catch baseline to ensure consistency in the global catch data. The result of reconstructing catches suggests that data reported to the FAO under-represent actual catches by at least 6.7% since 1950, primarily due to under-representation of small-scale fisheries and exclusion of discarded catches. Industrial catches increased substantially after 2005, driven by transitioning to multi-day trawl fishing. This increase in multi-day trawling has offset any effect of a declining discard rate on the total quantity of discards. Bycatch is increasingly marketed for fishmeal production, introducing incentives for trawlers to target traditionally discarded organisms, resulting in considerable pressure on marine resources and threatening domestic food supply.

## Contents

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## 1. INTRODUCTION

Marine fisheries provide food security and sustain the livelihoods of millions of people in India (Mini, 2008), and fishing has been an important activity for the Indian population for thousands of years (Bagchi and Jha, 2011). Excluding the Andaman and Nicobar Island territories, India's mainland Exclusive Economic Zone (EEZ), declared in 1977, extends over 1.63 million $km^2$ (www.seaaroundus.org/data/#eez/356), including the Lakshadweep Islands (Figure 1).

India's population is over 1.35 billion people, making it the second most populous country in the world (World Bank, 2018). This population struggles with acute shortages of animal protein and high rates of malnutrition (Radhakrishna and Ravi, 2004; Ritchie et al., 2018). Despite this, the rate of fish consumption in India is relatively low, currently around 5–9 kilograms per year, which is substantially lower than the worldwide average of 20 kg per year (Shyam, 2016; FAO, 2018b). This would suggest there is potential to improve domestic diets with marine fish, which can provide a valuable contribution to nutrition and food security through protein and micronutrient availability (Golden et al., 2016; Hicks et al., 2019). Although landings have increased over the last two decades, marine fish consumption in coastal villages may actually be declining (Ravikanth and Kumar, 2015). On the other hand, the export of fish from India has increased substantially in recent years, from approximately 500,000 tonnes in 2005 to 1 million tonnes by 2013 (Salim et al., 2015), which seems surprising, given the high rates of domestic food insecurity. India's marine fisheries provide livelihood and employment to almost four million people, of which approximately two million are fishers (Sathianandan, 2017). Small-scale fisheries in India employ approximately 70 – 80% of the fishing workforce (Jena and George, 2018).

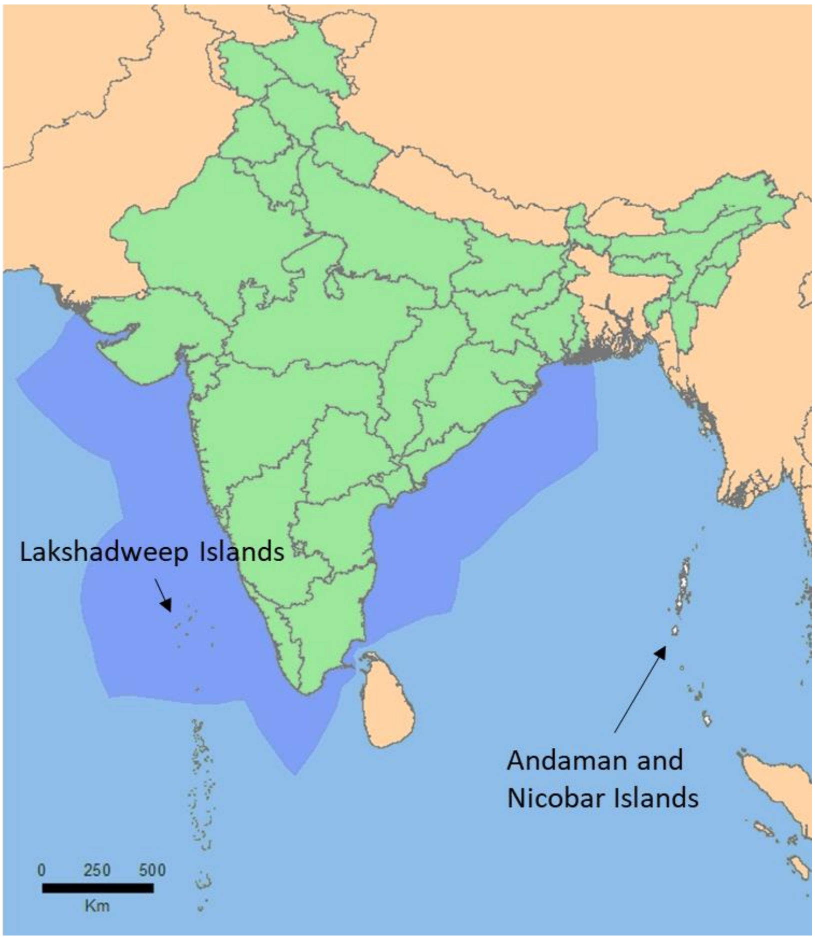


**Figure 1**. Mainland India (green) and the Indian mainland Exclusive Economic Zone (dark blue).

### 1.1. Marine fisheries

India's fisheries have traditionally been open access, characterised by limited to no regulation over the last 70 years, resulting in unsustainable development and growth (Devaraj and Vivekanandan, 1999; Satyanarayana et al., 2008; Bhathal, 2014). Despite numerous recommendations from India's primary fisheries research body, the Central Marine Fisheries Research Institute (CMFRI), that fishing capacity must be reduced to minimise overfishing, little has been done to regulate fishing effort in these fisheries (Rao, 2009). Although some regulations exist, there is little awareness and enforcement, creating major barriers to their effectiveness (Karnad et al., 2014).

In 1979 the Government of India introduced the Marine Fishing Regulation Act, allowing State Governments to demarcate fishing zones for artisanal (i.e., small-scale commercial) fishers in territorial waters (Gunakar et al., 2017). This policy also permitted gear and capacity restrictions in state-controlled waters up to 12 nautical miles, although regulations differ substantially between states (Bhathal, 2014). Beyond state waters, there is minimal regulation of domestic fleets within the EEZ (Rajesh, 2013), and the lack of effective management and regulation resulted in overfishing and overexploited fishery resources through the 1990s (Devaraj and Vivekanandan, 1999). In 2004 the Central Government implemented the Comprehensive Marine Fishery Policy, which emphasised sustainability and promoted recognition of small-scale fisheries (Bhathal, 2014). This policy also recognised the need to shift away from open-access fisheries to ensure continued, sustainable catches (Satyanarayana et al., 2008). Despite this, in 2011 27% of assessed Indian stocks, representing 18% of India's annual landings, were declining, depleted or collapsed (Sathianandan et al., 2011), although this may be as high as 68% of assessed stocks along the south-west coast (Mohamed et al., 2010). In subsequent years, the CMFRI has been developing policy advice for maritime states to assist transitioning from open-access to more regulated fisheries (Muktha et al., 2018; Sivadas et al., 2019).

India's marine fisheries have gone through several development phases since 1950 (Table 1). During the pre-development phase India's fisheries consisted almost exclusively of unpowered, artisanal vessels (Sathianandan, 2013). During this period, development focussed on improving the capabilities and efficiencies of the fleet (Gulbrandsen and Andersen, 1992). During the growth phase after 1970 the majority of growth in marine fisheries has been in the mechanised sector (i.e., industrial) (Bhathal, 2014), resulting in excessive increases to the number of mechanised vessels (Devaraj and Vivekanandan, 1999; Chandrapal, 2005). The substantial growth in the fishing fleet led to early signs of overfishing and considerable pressure on marine ecosystems. Overfishing has been identified in some Indian states since the 1970s with catch rates generally declining since this time (Kurien, 1991; Boopendranath, 2007). Regional fishing-induced changes in the trophic structure have been identified as early as 1967 (Bhathal and Pauly, 2008). During the full-capacity phase, growth in yields slowed as marine catches stabilised (see Figure 2) because fisheries were exceeding the maximum sustainable yields (Devaraj and Vivekanandan, 1999). During this time, India's fishing fleet continued to grow, doubling the effort expended and reaching approximately three times the optimum fleet size required to obtain maximum sustainable yields (Boopendranath, 2007; Teame, 2017). After 1999, technological improvements allowed trawlers to increase multi-day operations, expanding into deeper fishing grounds (Sathianandan, 2013). Subsequently, India's industrial fishing fleet has undergone a substantial transition to multi-day fishing operations, producing an increase in marine catches (Figure 2).

**Table 1.** Phases characterising changes and trends in India's marine fisheries. Source: (Satyanarayana et al., 2008)

| Phase | Period | Key characteristics of period |
|---|---|---|
| Pre-development | (1950 – 1968) | Predominantly non-mechanised crafts and gears. |
| Growth | (1968 – 1988) | Improvements in gears used, vessels, materials, increases in mechanisation, export and trade.<br>Development of industrial sector. |
| Full capacity | (1988 – 2005) | Stabilising catches.<br>Growth in motorisation of artisanal fleets (small-scale).<br>Intensification of mechanised fishing and multi-day fishing (industrial).<br>Implementation of seasonal closure for mechanised vessels (industrial).<br>Expansion of fishing grounds. |
| Management | (2005 – 2018+) | Range expansion and effort increases through multi-day fishing.<br>Recognition for need to regulate and manage fisheries to prevent declines. |

#### 1.1.1. *Current state*

According to FAO estimates, India currently has the sixth largest fisheries by catch in the world, increasing from approximately 530,000 tonnes in 1950 to almost 3.6 million tonnes in 2018 (FAO, 2018a). The marine fishing fleet of India is currently made up of around 72,500 mechanised vessels, of which approximately 35,000 are trawlers, 71,300 motorised and 50,690 unpowered vessels (Sathianandan, 2013). There are at least 30 common vessel-gear combinations catching approximately 2000 species from India's marine waters, of which approximately 286 are commercially important (Sathianandan, 2017). India's fisheries are complex due to the long coastline, large EEZ, large multi-gear fleet targeting multiple species, large fisher population and limited resources for monitoring (Moreno, 2012).

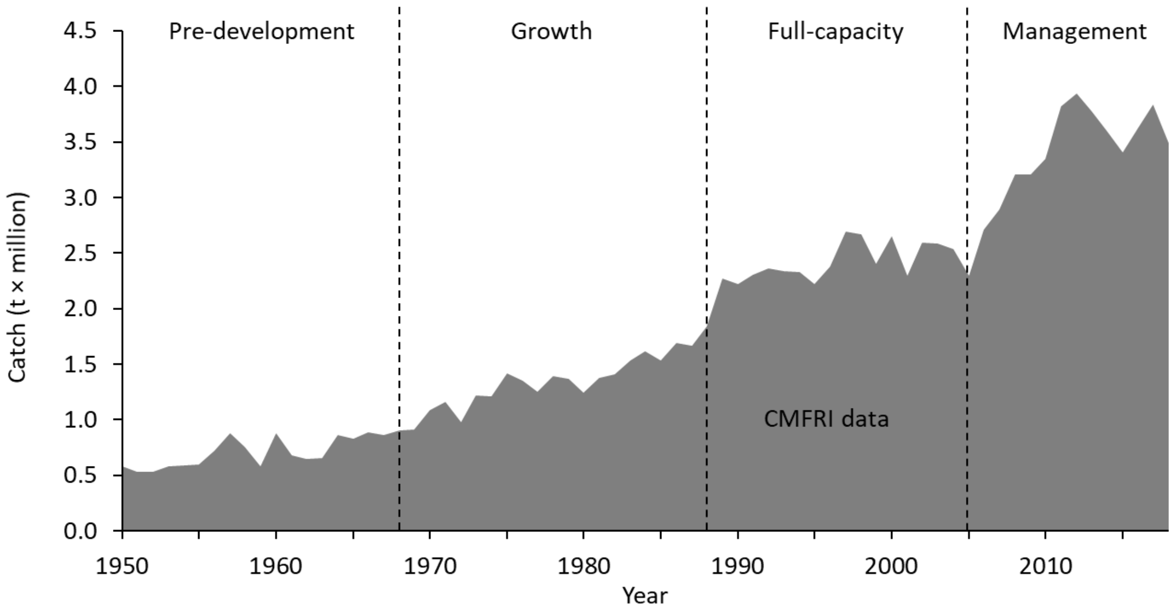


**Figure 2**. Reported catch baseline and development phases of India's marine fisheries from 1950 to 2018 based on CMFRI data.

Starting in 1985, foreign vessels were permitted to fish in the Indian EEZ under various charter and joint-venture schemes designed to facilitate technological and knowledge transfer to Indian fishers (Rao, 2009). In 1997, foreign fishing under these schemes ended due to protests from Indian fishers and a lack of demonstrable benefits (Rao, 2009). Performance of charter and joint-venture vessels was reported to be poor due to numerous operational challenges, although catches may have been underreported (Rao, 2009). In 2004, foreign vessels began operating again in the Indian EEZ under the Letter of Permission scheme (LoP) designed to assist developing India's large pelagic fishery. This program had operational and administrative difficulty, poor compliance and monitoring and the ability to transfer catches at sea (transhipment), likely resulting in underreported catches (Anonymous, 2019b). In 2017, this Letter of Permission scheme was rescinded due to being largely unsuccessful for the purpose of its design (Anonymous, 2019b).

There is evidence of Indian vessels fishing in Bangladesh waters (BOBLME, 2015); however, the magnitude of this activity is unknown. Furthermore, Indian trawlers have been reported to regularly fish in the Sri Lankan EEZ of the Palk Bay area (Scholtens et al., 2012). This activity has been increasing in magnitude since approximately 1976 (Hettiarachchi, 2007).

Estimates of the number of vessels crossing the border range from around 500 to 4,000 (Vivekanandan, 2004), although quantitative catch data are limited.

### 1.1.2. *Data collection systems*

There are several agencies that collect data on fisheries catches; essentially state and territory fishery departments and the Central Marine Fisheries Research Institute (CMFRI). Some data on vessels operating under charter, joint-venture or LoP schemes were collected by the Fishery Survey of India (FSI) using logbooks. These data are then combined with estimates made for domestic fisheries by the CMFRI or state fishery departments by the Department of Animal Husbandry, Dairying and Fisheries (DAHD&F), who then submit total catch estimates to the FAO (Anonymous, 2012). As of 2019, the Government of India has implemented a centralised Department of Fisheries, although it is unclear how this will affect fisheries data collection and reporting. The CMFRI and state fishery departments in India collect duplicate fishery statistics which show significant differences between taxonomic totals (Stobberup, 2012). As a result of growing concerns about the incomparability of datasets (Sridhar and Namboothri, 2012), in 2011, the state data collection process was standardised by officially adopting the methods developed by the CMFRI (Anonymous, 2012).

There is little published information available on the state fishery department estimation methods and final statistics prior to 2011. State departments are reported to be negatively impacted by poor staff strength (Sathiadhas et al., 2014), which may affect the accuracy of state fishery department estimates. Until 1985, State Governments were reported to be obtaining fishery statistics from the CMFRI (Anonymous, 2012). The changes that have occurred in India’s catch reporting structure and potential differences between duplicate datasets make it difficult to determine the accuracy of the data that have been submitted by the Government of India to the FAO over time.

In order to meet their mandated requirement of monitoring and assessment of exploited resources, the CMFRI developed a multistage, stratified sampling design at landing centres to obtain fishery statistics, which has been in operation since 1959 (Srinath et al., 2005). A less rigorous sampling design was used in early years (Anonymous, 2012), but the methods have been peer-reviewed to ensure their accuracy and validity (Kutty et al., 1973). The CMFRI have an extensive history estimating India’s marine fisheries catches and comprehensive documentation of data validation, training and integrity checks (Srinath, 2004; Srinath et al., 2005).

## 1.2. Catch reconstruction

Catch reconstructions complement officially reported statistics with best estimates of unreported catches (Zeller et al., 2016b). Subsequently, the total reconstructed catches are allocated to politically and ecologically relevant space (Zeller et al., 2016b). Reconstructions can be used as a foundation to inform countries and international bodies of potential issues with national and international datasets that may warrant further investigation. In this regard catch reconstructions complement official statistics by providing an indication of the underlying accuracy in national and international fisheries catch data.

In the absence of reported catch data for a sector or fishery known to exist, conservative estimates are preferable to attributing “no data” that translates into effective values of zero (Jacquet et al., 2010b). By reconstructing unreported catches using conservative estimates, the inherent downward bias in officially reported catch data can be reduced (Pauly and Zeller, 2016), thereby increasing the accuracy of catch data and any subsequent analysis.

The first reconstruction of India’s marine catches was performed by Bhathal (2005) from 1950 to 2000, and an update from 1950 to 2010 using a standardised method was undertaken by Hornby et al. (2015). Hornby et al. (2015) estimated substantial volumes of unreported subsistence (i.e., small-scale non-commercial) catches and discards. It has been pointed out by the Indian fisheries experts that Hornby et al. (2015) contained issues with the underlying data (A. Gopalakrishnan, CMFRI, pers. comm.), which led to overestimated subsistence catches and discards. The reconstruction presented here has been undertaken to revise, correct and update India’s comprehensive marine catch from 1950 to 2018, ensuring conservative methods and data sources, including collaboration with fisheries experts in India (Dr. Sathianandan, CMFRI), are used to minimise overestimation of catches. This will provide a more comprehensive time-series estimate of India’s marine catch and ultimately a more accurate understanding of these fisheries.

# 2. METHODS

This reconstruction for India's mainland fisheries catch followed the approach of Zeller et al. (2016b). This required utilising all publicly available primary and secondary data sources to identify data gaps and complement the officially reported baseline with time-series estimates for those gaps. Domestic catches from India's mainland EEZ were estimated by fishing sector; industrial, artisanal, subsistence and recreational (i.e. small-scale and non-commercial) (Zeller et al., 2016b).

This reconstruction does not address large pelagic tuna catches made by foreign vessels operating under the Letter of Permission scheme. Large pelagic tuna catches taken by foreign fleets fishing in the Indian EEZ were not included in the catch estimates presented here but have been addressed globally elsewhere (Coulter et al., 2020). Catches made by these vessels have likely been underreported, and further research is needed to comprehensively account for the landed and discarded catch of foreign vessels.

## 2.1. Baseline data

As a preliminary step, fisheries catch datasets collected by the CMFRI and State fishery departments were analysed to determine the accuracy of the underlying data. CMFRI data sourced from published estimates (http://www.cmfri.org.in/annual-data) and available literature was compared to data reported by the FAO on behalf of India (FAO, 2018a). The time-series and methods of each dataset were inspected to determine potential issues. Based on the result of this preliminary investigation, CMFRI data was utilised as the reported baseline for this reconstruction as it was deemed to be most reliable, accurate and consistent. Catch data by taxon from 1950 to 2018 were compared between CMFRI and FAO datasets and a coefficient of variation was obtained by dividing FAO totals by CMFRI totals for comparable taxa.

## 2.2. Fishery sectors

Marine catches were assigned to industrial or small-scale sectors based upon the type of propulsion and gear category used by the vessels. Although the boundaries between sectors may sometimes be blurred, for the purposes of this work the broad definitions of Bhathal (2005), supported by Jena and George (2018) were used. Vessels with inboard engines and/or mechanisation for operating fishing gears (e.g. winches) have been treated as industrial, while vessels using outboard engines and unpowered craft are considered artisanal. Catch proportions from the artisanal and industrial sector were determined based on estimates published by the CMFRI on sectoral contributions (Appendix Table 1). These proportions were applied to annual catch estimates published by the CMFRI from 1950 to 2018 to obtain annual contributions from the industrial and artisanal sectors. Here, subsistence catches were estimated based only on the catches taken home by artisanal fishers for their own and family consumption (Appendix Table 1). Thus, subsistence catches are clearly underestimated here, and current ongoing collaborative research may give better estimates in the future. Marine recreational fishing is minimal in the mainland India EEZ, with most recreational fishing focussing on inland rivers or the Andaman and Nicobar Islands (Gupta et al., 2015). Assuming them to be negligible, recreational catches were not estimated for the mainland EEZ.

### 2.2.1. *Industrial sector*

The industrial sector was broken down further into catches made by trawl or other gears, based on over 80 individual CMFRI reports of sectoral contributions for each state, e.g.,(Mini and Srinath, 2003; Mathew, 2015; CMFRI, 2018b). These were combined to generate country-wide estimates of industrial trawling and other industrial gears.

#### 2.2.1.1.<u>Charter scheme (1985 – 1997)</u>

Industrial catches operating under foreign fishing schemes are absent from the CMFRI database. These were sourced or reconstructed from available reports collected by the Fishery Survey of India (FSI) found in published literature. Compiled annual catch data from logbooks were available for these vessels from 1990 to 1997 (Appendix Table 1). In the absence of comprehensive logbook data that may provide a more accurate understanding of reporting quality by charter vessels, it was assumed that all catches were reported in compiled logbook data. Using annual catch estimates per vessel for years with available data, interpolations were performed back to 1985 based on the number of vessels operating at the time (Rao 2009).

#### 2.2.1.2. <u>Large trawlers</u>

Logbook data from 1982 to 1986 (Rao, 1988a), were used to calculate unreported catches from these vessels (Appendix Table 1). The unreported component of catches by these vessels was calculated by applying the average catches from vessels that submitted logbooks, to the number of vessels that did not submit, based on Rao (1988a). Data for this fishery component were included in CMFRI estimates after 1986 (Rao, 2009).

### 2.2.2. *Small-scale fisheries*

#### 2.2.2.1. Lakshadweep Islands

Catches from the Lakshadweep Islands (Figure 1), which are not included in CMFRI data, were estimated based on published landings data available from different periods (Appendix Table 1). Lakshadweep has a small pole and line fishery that has been in operation since at least the early 1960s. Although some mechanised vessels are used for pelagic species, catches in Lakshadweep are made by traditional, artisanal fishers (Sivadas, 2002). Since these data sources have only been in existence since 1959 (Varghese, 1987), the 1959 catch total was extended back to 1950 as fishing occurred well before 1950 (Koya et al., 1984).

#### 2.2.2.2. Estuaries

Estuarine catches are made entirely by the artisanal and subsistence sector (Srivastava et al., 1985). These catches are not estimated by the CMFRI as they are not officially considered to be marine (A. Gopalakrishnan, CMFRI, pers. comm.). For consistency with all global catch data (Zeller et al., 2016b), catches from estuaries were treated as marine in the present study. Landings were linearly interpolated between years with available data (Appendix Table 1). Catches were only estimated for major estuaries for which there were available catch data. It is likely that there are estuarine fisheries beyond these reported estimates, however, due to the wide range of reported tonnages from estuaries, basic substitutions for estuaries without data were not performed. Catches of freshwater species from estuaries were excluded based on the reported taxa. From the available data, freshwater species accounted for less than 1% of the estuarine catch and catches reported from freshwater regions of the estuary accounted for just over 5% of total catches (Mitra et al., 1997). In the absence of sufficient data to differentiate freshwater species catch, 10% of reported volumes were removed to approximate freshwater taxa catches.

#### 2.2.2.3. Bivalves

A substantial coastal artisanal fishery exists for marine bivalves. Since 2013, the CMFRI has been estimating these catches (CMFRI, 2014a); however, prior to this estimates had only taken place occasionally (Appendix Table 1). Using available reported data from bivalve fisheries, linear interpolations were performed to calculate the unreported catches from this fishery between 1950 and 2013. Since the earliest anchor points were found in 1960, catches were calculated back to 1950 based on the calculated per-capita catch by the coastal rural population.

2.2.2.4. Subsistence

A conservative estimate of subsistence catches was made based on catches made by the artisanal sector and taken home for personal and family consumption. Numerous sources indicate approximately 5% of artisanal landings are taken home for consumption or barter (Norr, 1975; Kurien and Willmann, 1982; Srinivasu and Mohan, 2015). A conservative value of 5% of catches was relabelled from the reported artisanal sector to take-home subsistence, since the CMFRI baseline of reported data is generated before fishers remove their take-home catch (A. Gopalakrishnan, CMFRI, pers. comm.). A conservative value of 5% of estimated estuarine catch was attributed to the subsistence sector, based on the reported take-home catch of artisanal freshwater fishers (Devi et al., 2012). Unreported take-home subsistence was added to estuarine reconstructed estimates since reported catch estimates are made at the point of sale after fishers have removed their take-home catch (Mitra et al., 1997). A conservative value of 1% of artisanal bivalve catches was also attributed to the subsistence sector, since bivalves are not widely consumed and widely used for lime production or exported (Alagarswami and Meiyappan, 1987a).

## 2.3. **Discards**

To properly account for gear-specific discarding differences (Dineshbabu et al., 2014a), discards were estimated separately for industrial trawlers, other industrial gears and artisanal gears.

### 2.3.1. *Trawlers*

Published estimates of discarding by Indian trawlers are often at the regional or state level (Dineshbabu et al., 2014a). To account for regional variation in discarding, trawl catches were estimated for each state from 1950 to 2018 (see 2.2.1). Trawl catches were estimated by voyage type, multi-day versus single-day trawling, since each has substantially different discard rates (Dineshbabu et al., 2014a). Discard proportions of total landed catch were taken from published estimates for single- and multi-day trawlers in each state and linearly interpolated between years with no data (Appendix Table 1). If a discard proportion was not available for a given state, the value from the nearest state was used. Relevant discard proportions were applied to the calculated landed catch from single- and multi-day trawlers for each state from 1950 to 2018 (Appendix Table 1). State discard estimates were then combined to obtain a total discard estimate for the Indian mainland EEZ.

#### 2.3.2. *Other sectors and gears*

There is limited information on discarding by other gears, although several reports suggest the volume is minor (Koya et al., 2018). Despite this, there is some evidence of limited discarding from artisanal and industrial non-trawl gears (Srinath et al., 2008; Suuronen et al., 2017; Das and Edwin, 2018). Based on this general information, it was assumed that non-trawl industrial and artisanal gears have a 1% discard rate. Further research is required to refine and improve on this approximation.

### 2.4. **Taxonomic breakdown**

#### 2.4.1. *Sectors*

The taxonomic composition of the reported CMFRI data (Appendix Table 1) was applied to the estimated industrial and small-scale catches. The underlying assumption of this is that both industrial and small-scale sectors are catching taxa in approximately the same proportions. This may not be an accurate taxonomic separation of sectors; however, distinguishing taxon-specific landings between sectors proved difficult, as industrial and artisanal fishing vessels operate multiple, often similar, gears depending on the season or target taxa (Ramani et al., 2010).

#### 2.4.2. *Discards*

The taxonomic composition of low-value taxa from the reported CMFRI catch data (Appendix Table 1), was applied to the estimated industrial trawl, industrial non-trawl and small-scale discard totals. It was assumed that high value taxa would always be retained although this may underestimate discarded catches of juveniles from high-value species (Dineshbabu et al., 2014b). Some taxonomic information on discarding is available (Gordon, 1991; Dineshbabu et al., 2014a); however, these data are often at the regional level and may not be appropriate for raising to country-wide estimates. Publicly available and regular estimates of the taxonomic composition of discards is needed to improve these estimates.

#### 2.4.3. *Indian fishing in foreign EEZs and high seas waters*

Indian vessels have been reported fishing in the EEZs of Bangladesh, Sri Lanka and even Pakistan. This study estimated some catches taken in Bangladesh and Sri Lankan waters.

Catches from Pakistan waters have not been estimated but are thought to be minimal due to the political situation between these countries (Gupta and Sharma, 2004). A conservative estimate of 2.5% of the top four taxa in Bangladesh's data reported by the FAO, that are also reported from India's east coast, was assumed to have been caught in Bangladesh waters (*Tenualosa ilisha*, *Harpadon nehereus*, *Acetes* spp. and Engraulidae). These data were removed from the Indian east coast landings, and assigned to the Bangladesh EEZ. In the absence of comprehensive estimates of vessel numbers and tonnages, conservative estimates made by Kasim (2015) were used based upon information from 520 vessels crossing the border. Taxonomic proportions from landing centres where 50 – 90% of catch is from Sri Lankan waters were applied to tonnage estimates from Sri Lankan waters from 2005 to 2010. Tonnage estimates by taxon for the period 2005 to 2010 were converted to a proportion of the Indian east coast total for the same years. These proportions were interpolated from zero in 1973, based on first reports of trawlers operating in the Sri Lankan EEZ in 1974 (Hettiarachchi, 2007). The 2010 proportions were held constant until 2018 due to a lack of more recent quantitative data. Indian catches of industrially caught large pelagic species under the reported data of the Indian Ocean Tuna Commission (IOTC) were not accounted for here, as they are estimated separately by Coulter et al. (2020).

## 2.5. **Uncertainty**

The uncertainty around total reconstructed catches were estimated in the form of "data reliability" scores (see Appendix Table 2), adapted from Mastrandrea et al. (2010) based on the methods of Zeller et al. (2016a). Uncertainty ranges of the reconstructed dataset were based on confidence scores evaluating the underlying data and information sources reliability, including any assumptions made for each of four components (industrial landings, artisanal landings, subsistence landings, and discarded catches) across four time periods (1950 – 1969, 1970 – 1989, 1990 – 2009, 2010 – 2018) for reconstructed catches. For each time period and each reconstructed component (industrial, artisanal, subsistence and discards) a single score was created (Appendix Table 2). Scores for each time-period and component were raised to total reconstructed catches based on the catch-weighted averages.

# 3. RESULTS

Overall, the net difference between the data reported by FAO on behalf of India and the CMFRI reported baseline indicates that India may have misreported almost 5 million tonnes to the FAO since 1950. The data reported by FAO closely matches CMFRI data before 1972 and after 2013. However, between 1973 and 2013, reported FAO and CMFRI data show deviating catch statistics (Figure 3). During this time, data reported by FAO was on average 5% higher than CMFRI data and shows increasing deviation to the CMFRI estimates over time. Despite this, both datasets indicate generally similar trends of gradually increasing catches from 1973 to 2013. The peak in 2012 in the CMFRI data is not reflected in the data reported to the FAO by India in the mid-2010s database (Figure 3). Starting in 2014, the data reported to the FAO by India matches fully with the CMFRI data (Figure 3).

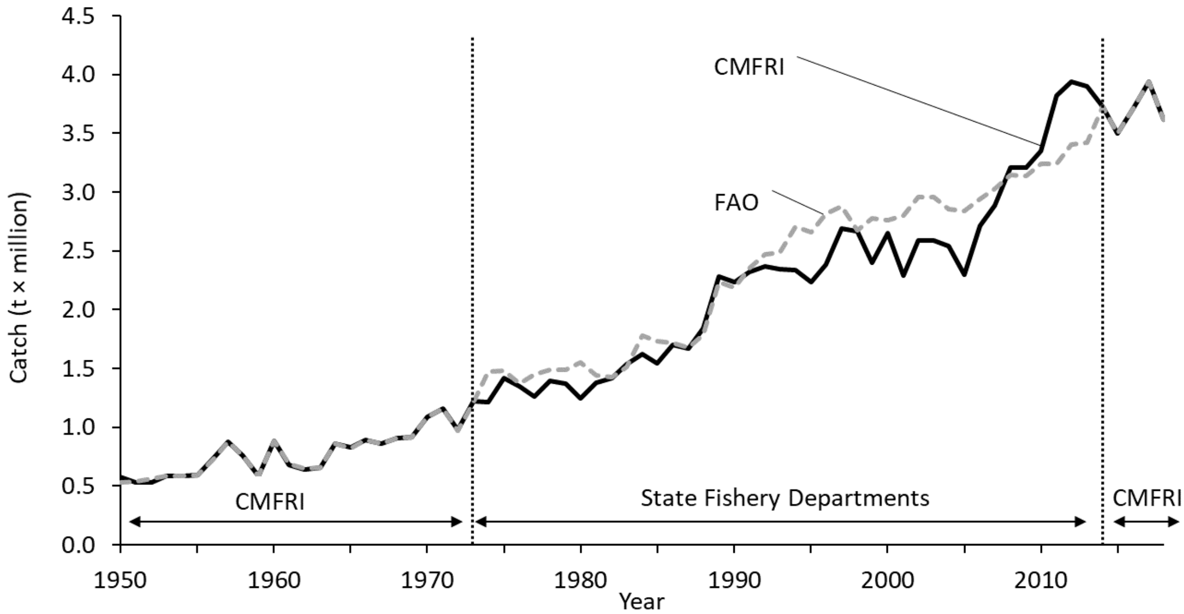


**Figure 3.** CMFRI data used as reported baseline in the present study (solid line) and data reported by FAO on behalf of India (dashed line) from 1950 to 2018. The relevant time periods and underlying datasets submitted to the FAO are marked at the bottom.

The data reported by the FAO shows substantial differences in taxonomic resolution compared to the CMFRI data (Appendix Table 3, Appendix Figure 1). The taxonomic comparison between data reported by the FAO and the CMFRI illustrates a clear pooling up of taxonomic detail into higher, less differentiated taxa in the data presented by the FAO on behalf of India (Figure 4). This results in poorer taxonomic resolution of the fishery data reported by India to the international community.

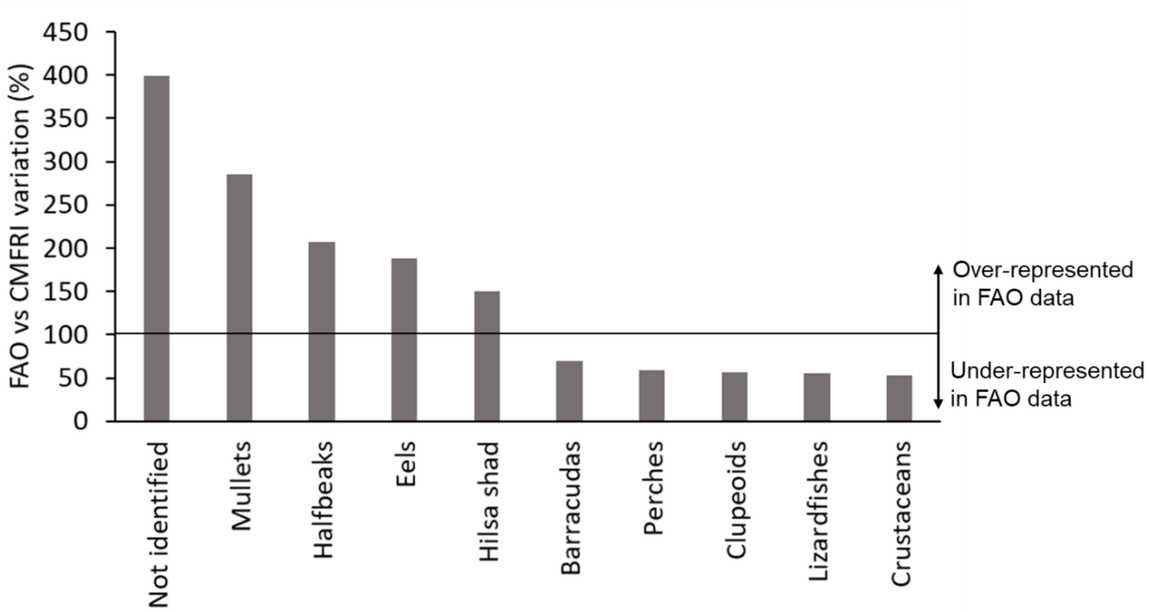


**Figure 4.** Taxonomic percentage variation between data reported by the FAO on behalf of India compared to the CMFRI data used as a baseline in the present study, from 1950 to 2018. Not including unidentified catches, the taxa here represents approximately 12% of India's reported landings in FAO data.

## 3.1. **Total reconstructed catches**

Total reconstructed marine catches were estimated for the Indian mainland EEZ waters at slightly over 140 million tonnes from 1950 to 2018, which is 6.7% higher than the 131 million tonnes reported to the FAO by India (Figure 5A). With reference to the CMFRI baseline data used here as the reported data foundation, slightly over 200,000 tonnes of catches have been unreported since 1950, 60% of which were landed catches with the remaining 40% being discarded catches (Figure 5B).

Data reliability estimates produced indicators of data uncertainty with uncertainty scores ranging from 2.7 (±23%) for the period 1950 – 1969, to 3.8 (±12%) for 2010 – 2018 (Appendix Table 4). High trust in the quality of the CMFRI data as the best estimates available for the reported baseline (Appendix Table 4), produced low overall uncertainty estimates for catch-weighted total reconstructed catches (Figure 5A, B).

## 3.2. Industrial sector

Just over 60% of total catches were taken by the industrial sector, which is responsible for the majority of growth in landings since 1970 (Figure 5A, Appendix Table 5). The per year growth in this sector slowed in the late 1990s and early 2000s to slightly over 60% of total catches, or 1.5 million tonnes per year. Starting in the mid-2000s, industrial catches increased again to over 3 million tonnes per year, or 75% of total marine catches in recent years (Figure 5A).

Industrial multi-day trawling began in 1967 (CMFRI, 1967), and did not provide a significant contribution to India's total catches until the mid-1980s, when the contribution increased to about 5% of India's total (Figure 5A). Since 1980, the contribution from multi-day trawling increased dramatically to contribute almost 20% of India's catches by mid-1990. After 2005, the contribution from multi-day trawling has continued to increase to approximately 37.5% of India's total marine landings.

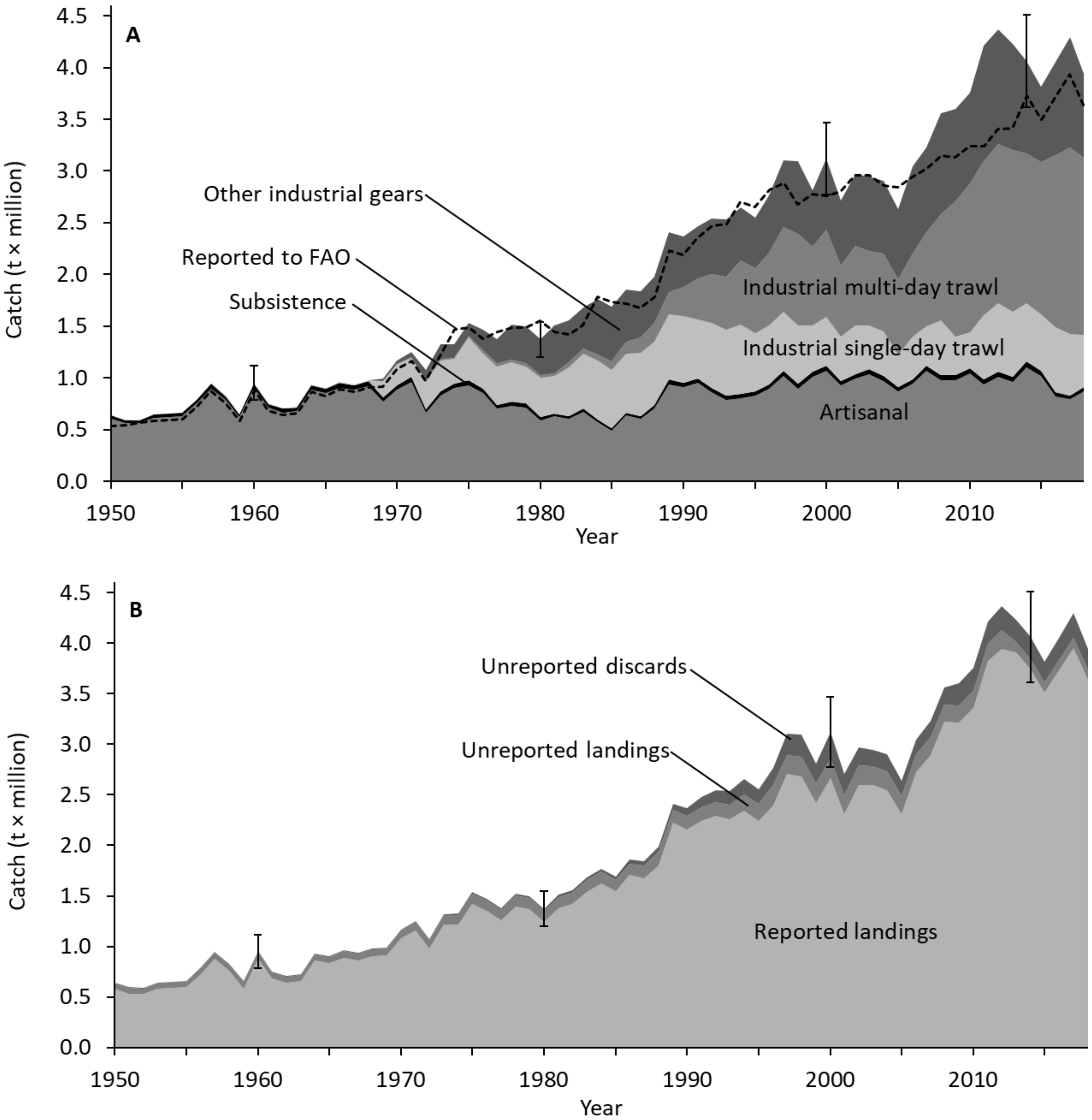


**Figure 5**. Reconstructed marine fisheries catches (with uncertainty ranges indicated) for the Indian mainland EEZ waters (excluding Andaman and Nicobar Islands) by (**A**) fishing sector with data reported to the FAO by India overlayed as a dashed line; and (**B**) reporting status, with unreported discards presented separately.

### 3.3. **Small-scale sectors**

The small-scale sectors have maintained relatively consistent catches since 1950, with an average catch of around 730,000 tonnes per year (Figure 6). Small-scale catches ranged from a minimum of just over 500,000 tonnes in 1985 to maximum of 1.1 million tonnes in 2007 (Figure 6). On average, this sector contributes around 23% of India's total mainland EEZ catch in recent years, decreasing from almost 100% of landings in 1950 (Figure 5A). Over 95% of small-scale catches come from the artisanal sector, with the remaining catch contributed by subsistence fisheries. Small-scale catches have been underreported by approximately 17% since 1950 (Appendix Table 5). Due to the proportion of catches taken home by artisanal fishers for self and family consumption, the subsistence sector follows the same trends as the artisanal sector.

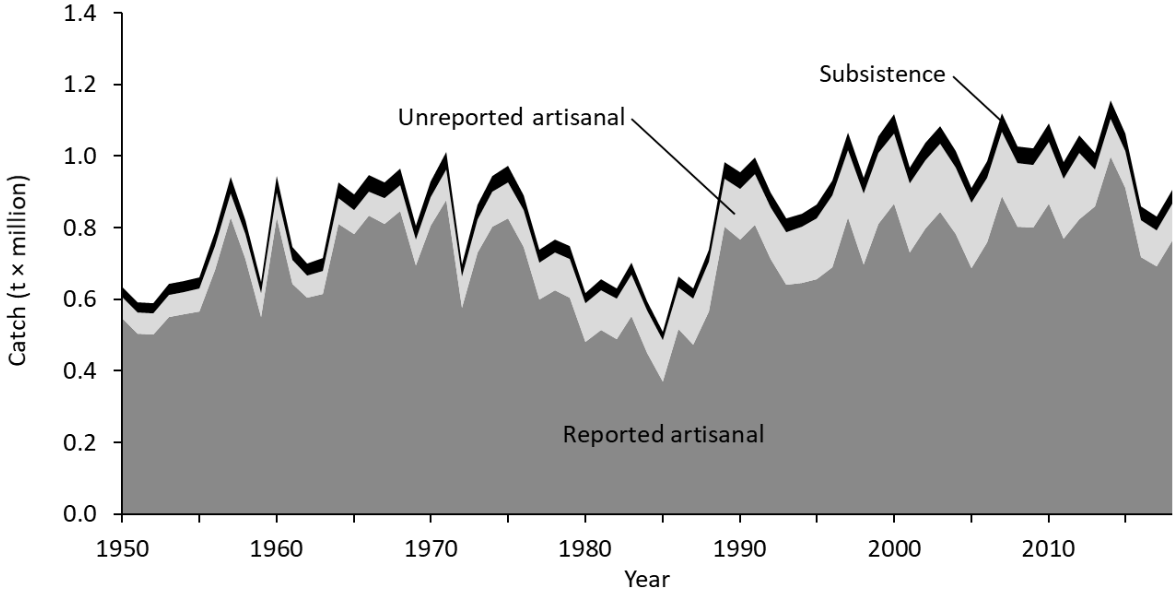


**Figure 6**. Indian small-scale marine fisheries sector catches from 1950 to 2018. Subsistence catches are likely underestimated and should be considered as extremely conservative, minimal estimates.

### 3.4. **Discards**

In the late 1980s the estimated volume of discards by Indian fleet fishing in mainland waters began increasing dramatically to a peak of 250,000 tonnes in 2000, before declining temporarily in the mid-2000s, after which discards increased again to levels slightly below the peak volume by 2010 (Figure 7A). Other industrial and artisanal gears contributed minor amounts of discards, on average 6000 tonnes each per year (Figure 7A). The discarded proportion of catches from multi-day trawlers increased steadily after 1980, from approximately 1% of trawler catches to a peak of 18% in 2000 (Figure 7B). After this, the proportion declined until 2007, where it has remained at about 10% of multi-day trawl catches.

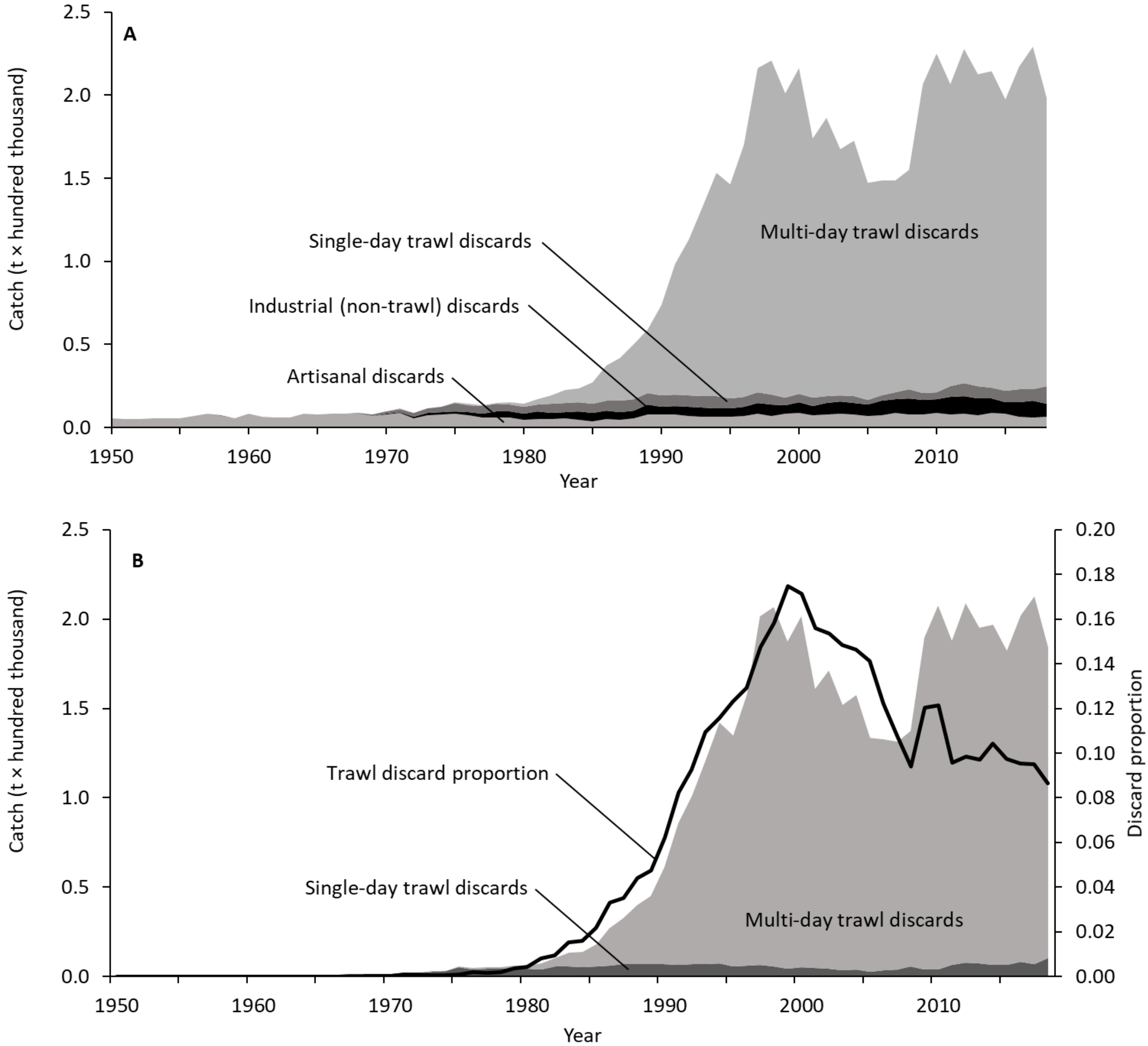


**Figure 7.** (**A**) Total discards by sectors for India, 1950 to 2018. (**B**) Discard total and proportion of catch from multi-day trawlers in India, 1950 to 2018.

## 4. DISCUSSION

The reconstructed catch totals for the Indian mainland EEZ waters were estimated to be nearly 7% higher than the data reported by the FAO on behalf of India from 1950 to 2018. Although there are apparent inaccuracies in state-collected data, catch totals reported by India to the FAO are generally consistent with reconstructed catches. This indicates that India has been reporting total marine catches reasonably accurately to the FAO. Despite this, the variation between the different national datasets, particularly state versus CMFRI data, submitted to the FAO at different times introduces unnecessary inconsistency and taxonomic inaccuracies since 1950. The substantial taxonomic pooling in the data reported by the FAO on behalf of India may mask important patterns and trends in India's marine fisheries over the last six to seven decades (Bhathal, 2005; Bhathal and Pauly, 2008), and makes international comparisons challenging (Pauly and Zeller, 2016).

The observed differences between CMFRI and FAO reported catch data suggests there may be accuracy and consistency issues in the international catch database for India. It is suspected that deviating statistics after 1972 are the result of state fishery department estimates being submitted to the FAO by DAHD&F, as state fishery departments have been estimating marine fish landings since 1972 (Kulkarni and Srivastava, 1985). State-collected data have continued to deviate from CMFRI estimates (Figure 3), despite training from the CMFRI on estimating catches since 1982, and standardised methods after 2011. The transition by India to CMFRI data from state-collected data after 2013 results in a peak in internationally reported catches during 2014; however, this is an artefact from utilising different data sources, as CMFRI data suggests catches declined substantially during these years (Figure 3). This transition between datasets without time-series corrections introduces inconsistency into the international catch data for India.

Potential accuracy issues may be present in the data presented by DAHD&F on behalf of state fishery departments (Anonymous, 2014; 2019a). Some state- and species-level estimates appear to be inconsistent over time in state-collected data, containing noticeable gaps in the time-series, or including freshwater landings in marine estimates, such as frogs (*Rana* spp.) (Anonymous, 2014). Furthermore, state-collected data submitted to the FAO before 2006 (and possibly after) may have erroneously included some aquaculture production in marine capture estimates (Morgan, 2006). In 2013, the Indian Ocean Tuna Commission (IOTC) revised catch estimates previously reported by the DAHD&F to those estimated by the CMFRI (Geehan et al., 2013). These issues highlight potential underlying inaccuracies in the state-collected marine fisheries estimates.

There is considerable evidence to suggest catch estimates made by the CMFRI are more accurate than estimates provided by state fishery departments. Although there are clear differences between taxa, some differences may be less obvious and lead to incorrect taxon-specific catch trends. Despite highly similar catch totals between the CMFRI and FAO datasets for Indian oil sardines (Appendix Table 3), the large increase in landings since 2005 captured by the CMFRI (Appendix Figure 1) baseline is not evident in the data presented by the FAO before 2014 (FAO, 2018a). This is concerning, as Indian oil sardine has formed one of India's most important fisheries in recent years (Rohit et al., 2018). Thus, inaccurate catch data can potentially lead to fundamental inaccuracies when analysing catch data reported by the FAO on behalf of India. Additionally, taxonomically unidentified catches (i.e., pooled taxonomic groups) are almost 400% larger in the data reported by FAO, suggesting large amounts of catch are not accurately identified. If data collected by the CMFRI are more taxonomically accurate, as they appear to be, taxon-specific catch data submitted to the FAO are unreliable.

Based on this information, it is suspected that the CMFRI data provide a more accurate representation of India's marine fisheries. While these potential inaccuracies do not affect national fisheries research conducted by the CMFRI who utilise their own data, it may lead to inaccuracies in studies utilising FAO or DAHD&F data, e.g., (Srinivasa Gopal & Edwin 2013, Farejiya & Dixit 2017). Although the current research provides evidence to changes in India's reporting structure, this still needs to be confirmed with the Indian Government. India's international catch reporting framework highlights the need for transparency in underlying data sources for both national and international fisheries datasets. A viable solution to correct this would be for the Government of India to request retroactive data corrections from the FAO, to be conducted in collaboration with and using the data of the CMFRI, dating back to 1950. Such retroactive data corrections are not unusual and accepted as part of the FAO's data mandate (Garibaldi, 2012). The Government of India should seriously consider providing the FAO with a formal retroactive data correction request. This should replace the 1972 – 2013 FAO data for India based on state sources with the corresponding CMFRI data for this period and utilise species-level catch data available in the CMFRI catch database (A. Gopalakrishnan, CMFRI, pers. comm.), for all years. This correction would standardise and improve the quality of India's global marine fisheries data representation.

The period after the mid-2000s was marked by substantial increases in fishing effort, efficiency, fishing ground and hours spend fishing (Meenakumari B, 2014; FAO, 2017). This suggests that the considerable increase in India's marine catch since the 2000s may be the result of substantially increasing effort rather than optimising sustainable exploitation, and may potentially lead to reduced catches over time. Range and depth extensions in combination with effort increases to maintain catches in the face of declining catch rates (Morato et al., 2006), which may be aggravating overfishing in India. To minimise the impact India's fishing fleet has on marine stocks, there is an urgent need to regulate, monitor and enforce fisheries capacity reductions. While the CMFRI provide excellent statistics and analyses, there is an urgent need to translate best scientific knowledge directly into active and enforced policy. This may be problematic, as the need for effort reductions and regulation have been highlighted by the CMFRI since at least 1988 (Rao, 1988a; CMFRI, 1998). Although sustainability is a core policy of the Comprehensive Marine Fishing Policy implemented in 2004, real action and movement towards sustainability has been lacking until recently, when a committee for trawl capacity reductions was established (Hemalatha, 2019).

### 4.1. **Industrial sector discards**

Discarded catches were a major component of unreported catches, mainly due to discarding by the large trawl sector. Reducing waste from discarding in marine fisheries through increasing the utilisation of bycatch has been a major objective for global fisheries (Alverson et al., 1994). This reconstruction shows the current volume of discards in India's fisheries is relatively high at 6 - 8% of industrial catches, and efforts to reduce discards have been offset by increasing transitions to multi-day trawling (Figure 7B). India's trawl fleet traditionally undertook single-day trawling, which discarded very little due to the ability to store and utilise almost all catches made in a single day (Gordon, 1991). Multi-day trawlers discard substantial quantities of bycatch until the last few days of fishing due to the limited hold space and preservation capabilities (Dineshbabu et al., 2014a). Due to the higher discarded proportion of catch from multi-day trawlers and the increasing multi-day fishing effort, the volume of discards has continued to increase in recent years. Alongside other changes in India's fisheries that have increased the marketability of bycatch (Lobo et al., 2010), the increasing uptake of multi-day trawling will increase overfishing without improving domestic food supply, threatening livelihoods and food security for millions of people.

Despite an increasing contribution from multi-day trawling since 2000 (Figure 5A), the discarded tonnages were greatest in 2000 due to higher proportions of catch discarded. While the discarded proportion of catch has subsequently decreased, the benefits of this on total discarded tonnages have been offset by the increasing catches from multi-day trawlers. The decline in discard proportions in multi-day trawling is attributed to increased retention of low-value bycatch, resulting from declining target species availability (as a result of unsustainable exploitation levels) and increasing market value for low-value bycatch (Dineshbabu et al., 2014a). The value of low-value bycatch increased by three to six times from 2000 to 2011 (Aswathy et al., 2012), and catches increased from 14% of trawl landings in 2008 to 25% in 2011 (Dineshbabu et al., 2014a).

Although trawl landings increased between 2008 and 2011, this has not increased the quantity of fish sold for human consumption, rather, this increase corresponds to increases in catch sold as low-value bycatch (Dineshbabu et al., 2014a). Fish intended for human consumption must be iced, which reduces profit margins, whereas low-value bycatch can be landed in various states of decomposition. Despite this, reported taxa of low-value bycatch indicate that these catches contain considerable quantities of degraded edible and commercially important species (Dineshbabu et al., 2014a). Additionally, a large component of these species are made up of juveniles that if left to grow, would provide considerably larger catches (Menon, 1996; Mahesh et al., 2019) . The opportunity to sell any catch as low-value bycatch encourages trawlers to land potentially edible fish in an inedible state, reducing domestic food supply.

The landings of low-value bycatch are largely sold for fishmeal production (Chandrapal, 2005; Dineshbabu et al., 2014a). Fishmeal production requires on average four times the produced weight in raw material (Aswathy and Narayanakumar, 2013), the product of which is often used to feed farmed fish to be exported to food-secure countries (Cashion et al., 2017). Depending on demand, the price of fish for the production of fishmeal and fish oil may exceed the sale price of fish sold fresh for human consumption (Dineshbabu et al., 2014b), diverting fish away from domestic food supply. This is a serious issue for India, where marine fish represent an avenue through which nutrition and food security could be improved and provide substantial health benefits for millions (Golden et al., 2016; Hicks et al., 2019; Pauly, 2019).

Indiscriminate trawling in India has led to substantial changes in the benthic environment resulting in the disappearance of traditionally-caught species (Rao, 1988b). Subsidising declining catches of edible species intended for human consumption with bycatch for fishmeal production is leading to further damage to the marine environment, and will reduce future catches. Additionally, the landings of juveniles represents a concerning level of recruitment overfishing that may reduce the capabilities of populations to replenish (Pauly, 1994), risking future declines. The scale of overfishing and lack of effectively enforced regulation in combination with indiscriminate trawling results in considerable economic losses from suboptimal exploitation (Najmudeen and Sathiadhas, 2008). Many understudied species are capable of providing substantial contributions to recommended nutrient intake which is a vital component for human health (Bogard et al., 2015). The contribution to India's national nutrition from marine fisheries may decline under the effects of climate change (Golden et al., 2016), representing substantial challenges for this country already struggling with malnutrition. To minimise losses from domestic food supply and the risk of future losses resulting from damage to the marine ecosystem, India needs to drastically reduce the heavy reliance on industrial trawling. The CMFRI has been advising capacity restrictions for marine fisheries since 1988 (Rao, 1988a). There are reports that the Indian Government is beginning to investigate regulating fishing capacity of the trawl fleet; however, this will require strong political will for strict enforcement due to the scale of industrial overcapacity (Hemalatha, 2019).

## 4.2. **Small-scale fisheries**

The majority of unreported landings were contributed by the small-scale sector which was underreported by at least 17%. Although reconstructed catches suggest small-scale fisheries contribute to about a quarter of the Indian mainland catches in recent years, only take-home catches of artisanal fishers have been estimated as subsistence in this reconstruction due to a lack of available information on other forms of subsistence. Given the large population of India, it is likely the minimal estimates presented here under-value the importance of marine subsistence fishing in India. This is likely a highly conservative estimate of subsistence catches in India.

From 1950 to 2013, a substantial component of unreported landings were due to coastal bivalves which have been reported annually by the CMFRI since 2013 (CMFRI, 2014a). Prior to 2013, estimates were made periodically but were not interpolated between years. This is a clear example of improvements being made to national data collection systems over time, resulting in an apparent increase in reported landings despite this fishery existing long before, providing a clear example of a taxon-specific "presentist" bias (Zeller and Pauly, 2018). The inclusion of this fishery after 2013 introduces a clear example. The present catch reconstruction addresses this gap. The remaining unreported small-scale landings are predominantly due to estuarine landings which are not estimated by the CMFRI. In India, estuarine catches fall under the jurisdiction of inland fisheries management (Jha, 2008). Thus, these catches may still be reported internationally in FAO freshwater fisheries data, although freshwater catch data are known to have serious accuracy issues in India (Anonymous, 2012). Under-representation of small-scale fisheries in national data collection systems is a common issue in many countries around the world, particularly in developing countries (Jacquet et al., 2010a; Zeller et al., 2015; Teh and Pauly, 2018). At a local scale, these catches may be proportionally low; however, their contribution may be substantial when combined to country-wide estimates. Failing to adequately account for the full contribution of small-scale fishers can lead to under-representing the socioeconomic importance of small-scale fisheries, often the most marginalised group of fishers (Pauly, 2006). The increased contribution in this reconstruction demonstrates the importance of this sector for the livelihoods and food security of many fishers, given that 70 – 80% of commercial fishers in India are employed in small-scale fisheries (Jena and George, 2018). To ensure continued livelihoods and food security from these fisheries, increased monitoring and research is needed to understand the true scale of small-scale fisheries in India. There is the need for comprehensive and accurate data on all forms of fishing in India, such as the true scale of non-commercial subsistence fishing, to inform management in order to reduce the risk and harm from overfishing that has been so prevalent in the coastal fisheries.

### 4.3. **Previous reconstruction**

This reconstruction is an independently revised estimate of the Indian mainland marine fisheries catches intending to reduce the likelihood of overestimating reconstructed catches. The results presented here show substantial differences to previously reconstructed catches for the Indian mainland (Hornby et al., 2015). Internal concerns were raised within *Sea Around Us* regarding the assumptions and logic applied by Hornby et al. (2015), which was confirmed by concerns raised by in-country experts (A. Gopalakrishnan, CMFRI, pers. comm.). Hornby et al. (2015) did not fully account for the national and international reporting structure of India's marine fisheries, resulting in incorrect assumptions regarding India's marine catch reporting framework. The subsistence estimates of Hornby et al. (2015) were based on the work of Ganapathiraju (2012). The work and estimates of Ganapathiraju (2012) lacked verifiable information and documentation, which raised concerns regarding the accuracy of these data. Other work published by this author has raised concerns regarding the validity of the methods used and results presented (Ganapathiraju et al., 2017; Hilborn et al., 2019). Therefore, the work of Ganapathiraju (2012) was not utilised for this reconstruction, and methods were completely revised from Hornby et al. (2015), resulting in considerable differences from previous estimates. Due to a current lack of reliable information, the true scale of subsistence fishing in the marine sector remains poorly understood and is likely underestimated here. It is recognised that the importance of subsistence fishing is under-represented in many countries and requires concerted efforts to address (Zeller et al., 2015; Teh and Pauly, 2018). To address this for India, on-going collaboration with the Dakshin foundation in India will be undertaken over the next few years to better understand Indian subsistence catches.

## 5. **CONCLUSION**

Concerns about the sustainable trajectory of Indian marine fisheries have been growing since the 1960s; however, the recent concerning trends identified in this research highlight the need for urgent government action to reduce the damaging reliance on trawling. Furthermore, the increased and uncontrolled utilisation of bycatch and traditionally unmarketable organisms for fishmeal production greatly increases the levels of overfishing by creating commercial value for all organisms, regardless of size or level of decomposition. Recent policy changes are beginning to lay some foundation for ensuring sustainability for marine fisheries, but implementing changes will be difficult and require strong political will and enforcement due to the enormous reliance on industrial trawling in India’s fisheries.

Inconsistency in the international time-series and inaccuracies in the national fisheries data supplied to the FAO in the past introduces inaccuracies in the international baseline. This is particularly problematic due to India’s considerable contribution to regional and global catches. Depending on which data are used different results may be found, particularly at the taxonomic level. This may waste resources or lead to inaccurate advice for policy- and decision-makers. The most accurate data should be provided to the FAO, including for retroactive corrections, to guarantee the most accurate data are available to the international community.

The FAO are able to provide recommendations and guidance in fisheries management and development (FAO, 2006; 2016); however, accurate data over time are required to provide informed and effective policy and management advice. The inaccuracies identified in state-collected data submitted to the FAO between 1973 and 2013 and the changing data sources submitted to the FAO creates inconsistencies in India's international fisheries data baseline. To improve the quality of the international data, it is suggested that India request and provide FAO with retroactive data corrections back to 1950 in partnership with the CMFRI, in order to establish a consistent international catch baseline. This must also account for any fisheries that are not included in CMFRI estimates, such as Island Territories.

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## Appendix

**Appendix Table 1.** Primary anchorpoints used for reconstructing India's marine fisheries from 1950 – 2018. Anchorpoints used to calculate state sectors used for discard estimates are not included.

| Source | Data | Comments |
|---|---|---|
| (Nair and Banerji, 1965) | Sectors (artisanal and industrial) | 1950 - 1962 |
| (CMFRI, 1969) | Sectors (artisanal and industrial) | 1967 - 1968 |
| (James, 1987) | Sectors (artisanal and industrial) | 1969 - 1986 |
| (Sathiadhas, 1998) | Sectors (artisanal and industrial) | 1991 - 1996 |
| (CMFRI, 1998; 1999; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014a; 2015; 2016; 2017; 2018a) | Sectors (artisanal and industrial) | 1997 - 2018 |
| (Norr, 1975; Kurien and Willmann, 1982; Srinivasu and Mohan, 2015) | Take-home subsistence | 5% of artisanal catches |
| (Nair and Banerji, 1965) | Baseline/East-West | 1950 - 1962 |
| (CMFRI, 1969) | Baseline/East-West | 1967 - 1968 |
| (CMFRI, 1979) | Baseline/East-West | 1969 - 1978 |
| (CMFRI, 1980) | Baseline/East-West | 1979 |
| (CMFRI, 1981b) | Baseline/East-West | 1980 |
| (CMFRI, 1982) | Baseline/East-West | 1981 |
| (CMFRI, 1983) | Baseline/East-West | 1982 |
| (CMFRI, 1985) | Baseline/East-West | 1983 - 1984 |
| (Srinath et al., 2006) | Baseline/East-West | 1985 - 2004 |
| Available from: http://www.cmfri.org.in/data-publications-# | Baseline/East-West | 2005 - 2018 |
| (Jha, 2008) | Estuary totals | 1992 all estuary totals |
| (Sinha, 1997) | Estuary totals | 1998 all estuary totals |
| (Jhingran and Gopalakrishnan, 1973) | Estuaries, totals and taxonomy | Mahanadi 1960 - 1963, Chilika lake 1957 - 1960 average, Pulicat 1967 - 1969, Tamil Nadu peninsula estuaries 1967, Vembanad estuary 1965 |
| (Acharya et al., 2019) | Estuary total and taxonomy | Godavari estuary 1963-1964, Mahanadi estuary 2019 |
| (Srivastava et al., 1985) | Estuary total and taxonomy | Pulicat lagoon 1965 – 1980, Vembanad lake 1981, Narmada estuary 1981 |
| (Madhusoodana Kurup et al., 1992) | Estuary totals | Vembanad estuary 1988 |
| (Dutta et al., 1973) | Estuary total and taxonomy | Hooghly-Matlah estuary 1961 - 1971 |

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| Source | Data | Comments |
|---|---|---|
| (Mitra et al., 1997) | Estuary total and taxonomy | Hooghly-Matlah estuary 1984 - 1993 |
| (Mitra, 2001) | Estuary totals | Hooghly Matlah estuary 1994 - 2000 |
| (Raman and Das, 2019) | Estuary totals | Chilika lake 2001 - 2015 average |
| (Shrivastava et al., 2009) | Estuary total and taxonomy | Krishna estuary 2004 - 2005 |
| (Asha et al., 2014) | Estuary total and taxonomy | Vembanad estuary 2012 |
| (Nair and Banerji, 1965) | Lakshadweep totals and taxonomy | 1959 - 1962 |
| (CMFRI, 1979) | Lakshadweep totals and taxonomy | 1969 - 1977 |
| (CMFRI, 1982) | Lakshadweep taxonomy | 1980 - 1981 |
| (Varghese, 1991) | Lakshadweep totals and taxonomy | 1972 - 1986 |
| (Pillai et al., 2006) | Lakshadweep tuna totals and taxonomy | 1995 – 1997, 1980 - 2001 |
| Available from: https://fisheries.utl.gov.in/FisheriesPortal/Developments | Lakshadweep totals and taxonomy | 1997 - 2001 |
| (Dhaneesh and Thipramalai, 2011) | Lakshadweep totals and taxonomy | 2002, 2003 |
| (Anonymous, 2015) | Lakshadweep totals and taxonomy | 2004 - 2013 |
| (Rao, 2009) | Large private trawlers | 1982 - 1986 |
| (Rao, 2009) | Charter vessels | 1990 - 1997 |
| (Narasimham, 1973) | Bivalves totals and taxonomy | Andhra Pradesh 1968 |
| (Alagarswami and Meiyappan, 1987a) | Bivalve totals and taxonomy | Major fisheries in all states 1985 |
| (Kripa and Appukuttan, 2003) | Bivalve totals and taxonomy | All major estuaries, 1996 - 2000 average and 1990 (pre-1995 average) |
| (Laxmilatha, 2015) | Bivalve totals | Kakinada bay windowpane oysters 2011 |
| (CMFRI, 2012; 2014a) | Bivalve totals | Kerala clam total 2011 - 2012 |
| (CMFRI, 2014a; 2015) | Bivalve totals and taxonomy | All major estuaries 2013 - 2014 |
| (CMFRI, 2016; 2017; 2018a; 2019) | Bivalve totals | Combined totals from major estuaries 2016 - 2019 |
| (CMFRI, 1981a) | Discard proportion (single-day trawl) | India 1979 |
| (Gibinkumar et al., 2012) | Discard proportion (multi-day trawl) | Andhra Pradesh, Gujarat, Kerala 1979 |
| (Rao, 2009) | Discard proportion (multi-day trawl) | Andhra Pradesh 1989, 1998 |
| (Kurup and Premlal, 2003) | Discard proportion (multi-day trawl) | Kerala 2000 - 2001 |
| (CMFRI, 2006) | Discard proportion (multi-day trawl) | Andhra Pradesh 2005 |
| (Dineshbabu et al., 2010) | Discard proportion (multi-day trawl) | Karnataka 2007 |
| (Dineshbabu et al., 2014a) | Discard proportion (multi-day trawl) | All States 2008, 2011 |
| (CMFRI, 2014b) | Discard proportion (multi-day trawl) | Maharashtra 2009 |
| (CMFRI, 2010; 2011) | Discard proportion (multi-day trawl) | Andhra Pradesh 2009 - 2010, Kerala 2010, Karnataka 2009 |

**Appendix Table 1.** Primary anchorpoints used for reconstructing India's marine fisheries from 1950 – 2018. Anchorpoints used to calculate state sectors used for discard estimates are not included.

| Source | Data | Comments |
|---|---|---|
| (CMFRI, 2013) | Discard proportion (multi-day trawl) | Maharashtra 2012 |
| (CMFRI, 2015) | Discard proportion (multi-day trawl) | Gujarat 2014 |
| (Alagarswami and Meiyappan, 1987b) | Cuttlefish retained after 1973 | India |
| (Sathiadhas, 2006) | High/low value taxa | India 1973, 1984, 1989, 1993, 2003 |
| (Kumar et al., 2005) | High/low value taxa | India 2002 |
| (Aswathy et al., 2012) | High/low value taxa | India 2000 – 2008 average |
| (Shyam et al., 2018) | High profit taxa | India 2017 |

**Appendix Table 2.** Scoring system for deriving uncertainty ranges for the quality of time series data of reconstructed catches presented in Zeller et al. (2016a). Reprinted from Zeller et al. (2016a)

| Score | | +/-%[a] | Corresponding IPCC criteria[b] |
|---|---|---|---|
| 4 | Very high | 10 | High agreement & robust evidence |
| 3 | High | 20 | High agreement & medium evidence **or** medium agreement & robust evidence |
| 2 | Low | 30 | High agreement & limited evidence **or** medium agreement & medium evidence **or** low agreement & robust evidence. |
| 1 | Very low | 50 | Less than high agreement & less than robust evidence |

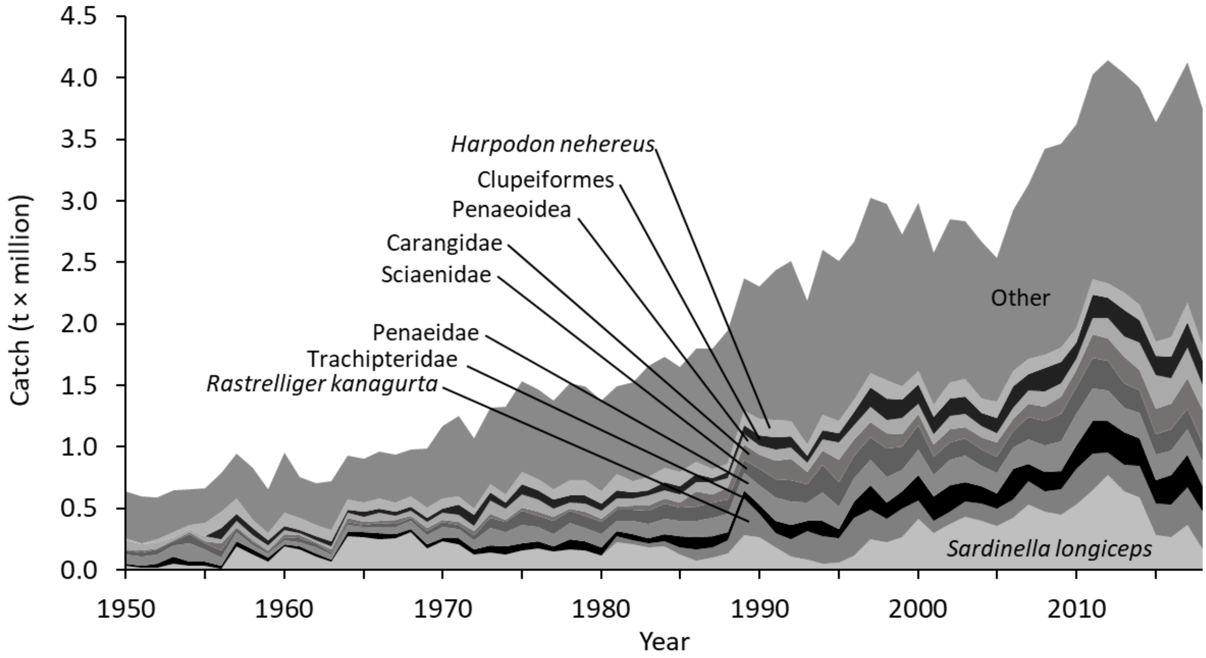
[a] Percentage uncertainty derived from Monte-Carlo simulations (Ainsworth and Pitcher, 2005; Tesfamichael and Pitcher, 2010).

[b] "Confidence increases" (and hence percentage ranges are reduced) "when there are multiple, consistent independent lines of high-quality evidence" (Mastrandrea et al., 2010).

**Appendix Table 3.** Variation in catches by different taxonomic groups between the data reported to the FAO by India and the CMFRI baseline data from 1950 – 2018.

| **Taxon** | **Variation (FAO/CMFRI)** | **Taxon** | **Variation (FAO/CMFRI)** |
|---|---|---|---|
| Miscellaneous | 3.99 | Pomfrets | 0.99 |
| Mullets | 2.85 | Prawns | 0.98 |
| Halfbeaks | 2.07 | Indian oil sardine | 0.98 |
| Eels | 1.88 | Silverbellies | 0.90 |
| Hilsa shad | 1.51 | Molluscs | 0.88 |
| Unicorn cod | 1.46 | Mackerels | 0.82 |
| Croakers | 1.41 | Ribbonfishes | 0.81 |
| Threadfins | 1.36 | False trevally | 0.80 |
| Tunas | 1.31 | Cephalopods | 0.79 |
| Bombay-duck | 1.28 | Anchovies | 0.78 |
| Wolf-herrings | 1.28 | Carangids | 0.78 |
| Goatfishes | 1.25 | Flatfishes | 0.71 |
| Catfishes | 1.23 | Barracudas | 0.69 |
| Billfishes | 1.15 | Perches | 0.59 |
| Sharks, rays & skates | 1.11 | Clupeoids | 0.57 |
| Seerfishes | 1.03 | Lizardfishes | 0.56 |
| Flyingfishes | 1.00 | Crustaceans | 0.54 |

**Some taxonomic groups have been pooled to ensure comparability between datasets. Source: (FAO, 2018a), CMFRI*




**Appendix Figure 1.** Taxonomical composition of marine catches from India's mainland EEZ by the 10 most common taxa. The "Other" category accounts for 74 additional taxonomic groups. The full dataset, including all taxa and all other data parameters, will be freely at www.seaaroundus.io/data/#/EEZ/356 by late 2020 or 2021.

**Appendix Table 4**. Catch weighted reliability scores for each fishing sector and total reconstructed catches from 1950 – 2018. Reliability scores are based on catch weighted scores for sector sub-components across four time periods, following the approach of Zeller et al. (2016a).

| **Time period** | **Industrial** | | **Artisanal** | | **Subsistence** | | **Discards** | | **Total reconstructed catch** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Score | ± % | Score | ± % | Score | ± % | Score | ± % | Catch-weighted average score | ± % |
| 1950 - 1969 | 3 | 20 | 3 | 20 | 1 | 50 | 1 | 50 | 2.9 | 21 |
| 1970 - 1989 | 4 | 10 | 4 | 10 | 1 | 50 | 1 | 50 | 3.9 | 11 |
| 1990 - 2009 | 4 | 10 | 4 | 10 | 1 | 50 | 1 | 50 | 3.8 | 12 |
| 2010 - 2018 | 4 | 10 | 4 | 10 | 1 | 50 | 2 | 30 | 3.9 | 11 |

**Appendix Table 5**. Reconstructed totals (in tonnes) separated by sector, reporting status (reported, unreported), catch type (landed, discarded) and from 1950 – 2018.

| Year | Reported | | | Unreported | | | Discards | | Reconstructed total | FAO Reported |
|---|---|---|---|---|---|---|---|---|---|---|
| | Industrial | Artisanal | Subsistence | Industrial | Artisanal | Subsistence | Industrial | Artisanal | | |
| 1950 | 3,672 | 547,533 | 28,818 | 0 | 58,364 | 1,521 | 46 | 5,475 | 645,428 | 529,822 |
| 1951 | 4,109 | 503,317 | 26,490 | 0 | 59,013 | 1,556 | 51 | 5,033 | 599,570 | 539,909 |
| 1952 | 1,802 | 500,219 | 26,327 | 0 | 60,085 | 1,592 | 23 | 5,002 | 595,050 | 564,333 |
| 1953 | 1,534 | 550,933 | 28,996 | 0 | 61,645 | 1,626 | 19 | 5,509 | 650,263 | 582,100 |
| 1954 | 988 | 557,907 | 29,364 | 0 | 62,768 | 1,659 | 12 | 5,579 | 658,277 | 588,304 |
| 1955 | 337 | 565,619 | 29,769 | 0 | 63,898 | 1,693 | 4 | 5,656 | 666,976 | 596,729 |
| 1956 | 3,172 | 682,677 | 35,930 | 0 | 66,122 | 1,726 | 39 | 6,827 | 796,493 | 720,348 |
| 1957 | 4,334 | 827,623 | 43,559 | 0 | 68,624 | 1,760 | 53 | 8,276 | 954,229 | 875,503 |
| 1958 | 4,733 | 713,698 | 37,563 | 0 | 67,901 | 1,759 | 57 | 7,137 | 832,848 | 755,903 |
| 1959 | 4,757 | 550,838 | 28,991 | 0 | 67,181 | 1,785 | 57 | 5,508 | 659,119 | 584,603 |
| 1960 | 7,226 | 828,832 | 43,623 | 0 | 69,401 | 1,735 | 88 | 8,288 | 959,193 | 879,703 |
| 1961 | 7,207 | 641,648 | 33,771 | 0 | 68,461 | 1,762 | 87 | 6,416 | 759,353 | 683,603 |
| 1962 | 7,717 | 604,386 | 31,810 | 0 | 60,941 | 1,585 | 94 | 6,044 | 712,578 | 644,303 |
| 1963 | 7,425 | 614,945 | 32,366 | 0 | 64,897 | 1,766 | 105 | 6,149 | 727,653 | 655,403 |
| 1964 | 5,064 | 811,575 | 42,714 | 0 | 70,445 | 1,932 | 79 | 8,116 | 939,925 | 861,703 |
| 1965 | 9,203 | 781,735 | 41,144 | 0 | 67,548 | 1,773 | 142 | 7,817 | 909,362 | 824,203 |
| 1966 | 13,380 | 832,144 | 43,797 | 0 | 68,625 | 1,781 | 209 | 8,321 | 968,257 | 889,703 |
| 1967 | 10,387 | 809,589 | 42,610 | 0 | 71,337 | 1,914 | 160 | 8,096 | 944,093 | 863,603 |
| 1968 | 13,454 | 845,709 | 44,511 | 0 | 72,537 | 1,937 | 216 | 8,457 | 986,821 | 903,903 |
| 1969 | 182,405 | 693,139 | 36,481 | 0 | 73,736 | 2,018 | 1,242 | 6,931 | 995,952 | 911,803 |
| 1970 | 238,467 | 803,201 | 42,274 | 0 | 79,884 | 2,220 | 2,161 | 8,032 | 1,176,239 | 1,085,585 |
| 1971 | 237,724 | 875,811 | 46,095 | 0 | 85,242 | 2,401 | 3,215 | 8,758 | 1,259,247 | 1,161,355 |
| 1972 | 371,712 | 576,153 | 30,324 | 86 | 87,048 | 2,591 | 3,990 | 5,762 | 1,077,665 | 971,395 |

**Appendix Table 5**. Reconstructed totals (in tonnes) separated by sector, reporting status (reported, unreported), catch type (landed, discarded) and from 1950 – 2018.

| Year | Reported | | | Unreported | | | Discards | | Reconstructed total | FAO Reported |
|---|---|---|---|---|---|---|---|---|---|---|
| | Industrial | Artisanal | Subsistence | Industrial | Artisanal | Subsistence | Industrial | Artisanal | | |
| 1973 | 450,487 | 728,694 | 38,352 | 325 | 92,995 | 2,761 | 5,469 | 7,287 | 1,326,370 | 1,210,155 |
| 1974 | 373,017 | 799,546 | 42,081 | 565 | 98,213 | 2,935 | 5,454 | 7,995 | 1,329,807 | 1,471,573 |
| 1975 | 553,277 | 822,112 | 43,269 | 804 | 100,649 | 2,988 | 8,129 | 8,221 | 1,539,450 | 1,481,414 |
| 1976 | 566,559 | 743,271 | 39,120 | 1,044 | 102,538 | 3,066 | 8,107 | 7,433 | 1,471,137 | 1,373,328 |
| 1977 | 626,761 | 597,810 | 31,464 | 1,283 | 103,228 | 3,116 | 9,170 | 5,978 | 1,378,810 | 1,446,539 |
| 1978 | 738,688 | 622,309 | 32,753 | 1,462 | 105,873 | 3,179 | 11,021 | 6,223 | 1,521,509 | 1,487,169 |
| 1979 | 733,528 | 600,823 | 31,622 | 1,640 | 108,997 | 3,292 | 12,152 | 6,008 | 1,498,062 | 1,488,853 |
| 1980 | 740,757 | 477,018 | 25,106 | 1,818 | 109,753 | 3,334 | 11,934 | 4,770 | 1,374,491 | 1,550,800 |
| 1981 | 836,337 | 510,110 | 26,848 | 1,996 | 112,097 | 3,377 | 14,907 | 5,101 | 1,510,773 | 1,439,994 |
| 1982 | 902,692 | 484,473 | 25,499 | 2,175 | 113,924 | 3,424 | 17,237 | 4,845 | 1,554,268 | 1,421,559 |
| 1983 | 958,456 | 548,655 | 28,877 | 1,797 | 116,649 | 3,471 | 19,894 | 5,487 | 1,683,285 | 1,511,919 |
| 1984 | 1,147,434 | 445,237 | 23,434 | 1,032 | 117,699 | 3,517 | 22,163 | 4,452 | 1,764,968 | 1,779,285 |
| 1985 | 1,149,745 | 365,732 | 19,249 | 1,322 | 116,524 | 3,434 | 26,331 | 3,657 | 1,685,995 | 1,733,979 |
| 1986 | 1,154,654 | 511,787 | 26,936 | 1,556 | 116,654 | 3,354 | 34,717 | 5,118 | 1,854,776 | 1,715,949 |
| 1987 | 1,171,280 | 466,707 | 24,564 | 0 | 126,982 | 3,818 | 38,470 | 6,442 | 1,838,262 | 1,678,298 |
| 1988 | 1,209,429 | 564,454 | 29,708 | 0 | 139,334 | 4,309 | 44,341 | 9,294 | 2,000,869 | 1,786,315 |
| 1989 | 1,384,140 | 803,771 | 42,304 | 0 | 133,663 | 3,910 | 51,958 | 11,017 | 2,430,762 | 2,231,023 |
| 1990 | 1,354,254 | 767,615 | 40,401 | 0 | 141,277 | 4,329 | 66,377 | 10,476 | 2,384,729 | 2,190,069 |
| 1991 | 1,395,703 | 812,775 | 42,778 | 0 | 140,321 | 4,185 | 92,637 | 8,128 | 2,496,526 | 2,352,987 |
| 1992 | 1,555,442 | 716,880 | 37,731 | 0 | 144,075 | 4,217 | 108,747 | 7,169 | 2,574,259 | 2,470,601 |
| 1993 | 1,387,950 | 558,784 | 29,410 | 0 | 146,787 | 4,226 | 127,297 | 5,588 | 2,260,040 | 2,485,505 |
| 1994 | 1,683,330 | 642,386 | 33,810 | 0 | 156,792 | 4,491 | 148,396 | 6,424 | 2,675,628 | 2,704,636 |
| 1995 | 1,567,805 | 656,475 | 34,551 | 0 | 169,932 | 4,959 | 140,550 | 6,565 | 2,580,837 | 2,655,329 |

**Appendix Table 5**. Reconstructed totals (in tonnes) separated by sector, reporting status (reported, unreported), catch type (landed, discarded) and from 1950 – 2018.

| Year | Reported | | | Unreported | | | Discards | | Reconstructed total | FAO Reported |
|---|---|---|---|---|---|---|---|---|---|---|
| | Industrial | Artisanal | Subsistence | Industrial | Artisanal | Subsistence | Industrial | Artisanal | | |
| 1996 | 1,665,181 | 679,878 | 35,783 | 0 | 200,124 | 6,319 | 163,774 | 6,799 | 2,757,857 | 2,814,181 |
| 1997 | 1,830,838 | 818,492 | 43,079 | 0 | 188,990 | 5,714 | 208,993 | 7,162 | 3,103,268 | 2,881,316 |
| 1998 | 1,924,039 | 676,049 | 35,582 | 0 | 198,731 | 6,247 | 213,441 | 6,760 | 3,060,849 | 2,677,497 |
| 1999 | 1,561,109 | 798,567 | 42,030 | 0 | 196,841 | 6,083 | 192,610 | 7,986 | 2,805,226 | 2,772,480 |
| 2000 | 1,750,932 | 856,896 | 45,100 | 0 | 197,877 | 6,107 | 254,543 | 8,569 | 3,120,024 | 2,759,174 |
| 2001 | 1,536,111 | 718,762 | 37,830 | 0 | 192,918 | 6,051 | 205,296 | 7,188 | 2,704,155 | 2,801,522 |
| 2002 | 1,758,369 | 789,712 | 41,564 | 0 | 191,164 | 6,016 | 173,988 | 7,897 | 2,968,710 | 2,960,926 |
| 2003 | 1,707,483 | 835,632 | 43,981 | 0 | 188,923 | 5,968 | 155,135 | 8,356 | 2,945,478 | 2,954,770 |
| 2004 | 1,649,186 | 737,283 | 38,804 | 0 | 185,951 | 5,958 | 161,300 | 7,373 | 2,785,856 | 2,854,786 |
| 2005 | 1,583,888 | 676,022 | 35,580 | 0 | 182,638 | 5,911 | 139,046 | 6,760 | 2,629,846 | 2,839,137 |
| 2006 | 1,924,801 | 746,877 | 39,309 | 0 | 180,884 | 5,876 | 138,732 | 7,469 | 3,043,949 | 2,941,066 |
| 2007 | 1,962,491 | 877,349 | 46,176 | 0 | 179,726 | 5,841 | 147,315 | 8,773 | 3,227,671 | 3,026,789 |
| 2008 | 2,375,791 | 793,000 | 41,737 | 0 | 176,419 | 5,806 | 155,881 | 7,930 | 3,556,565 | 3,147,843 |
| 2009 | 2,371,364 | 791,523 | 41,659 | 0 | 173,941 | 5,771 | 207,527 | 7,915 | 3,599,701 | 3,135,089 |
| 2010 | 2,443,081 | 858,425 | 45,180 | 0 | 172,147 | 5,736 | 224,556 | 8,584 | 3,757,710 | 3,237,088 |
| 2011 | 3,017,964 | 762,131 | 40,112 | 0 | 168,721 | 5,701 | 209,399 | 7,621 | 4,211,651 | 3,242,237 |
| 2012 | 3,079,321 | 815,508 | 42,921 | 0 | 186,586 | 5,866 | 229,806 | 8,155 | 4,368,165 | 3,407,148 |
| 2013 | 3,006,582 | 736,518 | 38,764 | 0 | 102,915 | 5,029 | 214,615 | 7,365 | 4,111,789 | 3,417,035 |
| 2014 | 2,694,641 | 853,303 | 44,911 | 0 | 104,083 | 5,029 | 213,564 | 8,533 | 3,924,064 | 3,725,154 |
| 2015 | 2,553,578 | 808,633 | 42,560 | 0 | 103,636 | 5,029 | 196,057 | 8,086 | 3,717,578 | 3,495,571 |
| 2016 | 2,976,456 | 620,700 | 32,668 | 0 | 101,757 | 5,029 | 219,991 | 6,207 | 3,962,807 | 3,708,823 |
| 2017 | 3,228,711 | 575,570 | 30,293 | 0 | 101,306 | 5,029 | 237,927 | 5,756 | 4,184,591 | 3,938,203 |
| 2018 | 2,835,430 | 619,575 | 32,609 | 0 | 101,746 | 5,029 | 200,475 | 6,196 | 3,801,059 | 3,620,128 |

**Appendix Table 5**. Reconstructed totals (in tonnes) separated by sector, reporting status (reported, unreported), catch type (landed, discarded) and from 1950 – 2018.

| Year | Reported | | | Unreported | | | Discards | | Reconstructed total | FAO Reported |
|---|---|---|---|---|---|---|---|---|---|---|
| | Industrial | Artisanal | Subsistence | Industrial | Artisanal | Subsistence | Industrial | Artisanal | | |
| **Total** | 76,219,877 | 47,413,059 | 2,495,424 | 18,905 | 8,168,686 | 256,930 | 5,501,578 | 484,311 | 140,558,770 | 131,699,058 |