

# Bycatch in Indian trawl fisheries and some suggestions for trawl bycatch mitigation

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Globally, trawl is the major fishing gear used in marine fisheries and in India, it contributes to more than one-third of the marine fish production. Trawl fishing has been critically evaluated from a sustainability perspective, especially analysing its bycatch composition. Most of the bycatch from trawlers contains valuable edible species with high market demand. However, a portion of the bycatch which does not have such demand in the edible fish market, known as low-value bycatch (LVB), continues to be a matter of concern from an ecological and economic perspective. During 2017–19, 30–60% of trawl landing in India was constituted by LVB, which was mainly used for fishmeal preparation. To enhance the value and utility of LVB, this study explores the possibility of converting waste from LVB into edible resources using pufferfish and triggerfish. It also highlights the positive impact of efforts by different Government agencies for bycatch mitigation like the implementation of minimum legal size in reducing the juvenile component in bycatch, with a social survey-based account of fisher's perceptions and suggestions on successful bycatch mitigation.

**Keywords:** Ecological impacts, fishery economics, low-value bycatch, minimum legal size, trawl.

TRAWL is the most common gear contributing to a majority of the marine fish catch and trawl fisheries sector. It accounted for about 40% of the marine fish production (1.43 million tonnes) during 2017–19. It contributes more than 75% of the marine fisheries exported from India. Bycatch in marine fisheries has been a topic of interest, since non-selective gears have been widely adopted for commercial fishing. Trawling has been projected as the most detrimental fishing activity, responsible for a high percentage of bycatch and it has been critically evaluated from a sustainability perspective<sup>1–4</sup>. In India, the practice of bottom trawling was introduced for shrimp exploitation and the species caught

by trawlers other than shrimps were considered bycatch. According to this criterion, the percentage of bycatch in trawlers was more than 80 along the west<sup>5</sup> and east coast<sup>6</sup> of India. During the early years of trawling, facilities for fish preservation and transportation were limited and the entire portion of the catch other than the intended target was forced to be discarded. However, improved transportation and preservation facilities of fishes, finfishes, cephalopods and edible crabs, which were the bycatch in shrimp trawling, are in demand for consumption in the domestic and international markets. These developments led to a significant target shift in trawling and some of the trawlers shifted the main targets towards groups with the highest economic return in the market. Due to these developments, 'bycatch' from trawlers became a relative term when considering this shift in the target groups<sup>7</sup>. Even with good transportation and storage facilities, the problem of resource wastage from bycatch remained, as a considerable portion of the catch landed was not in demand in the edible fish market. This part of the bycatch was used for fish meal and fertilizer preparation. This has been a point of concern since most of the studies carried out in India indicated that this portion of the catch were dominated by juveniles of commercial fishes<sup>8–14</sup>. The present study focuses on this particular portion, which has been named as low-value bycatch (LVB)<sup>9</sup>. Generally, LVB in trawl fishery is constituted of two major components. The first part consists of non-commercial species with no edible value. The second and more important part is the bycatch consisting of juveniles of commercial fishes below marketing size, and non-commercial resources, with a majority formed by stomatopods, non-edible crabs, other crustaceans and molluscs<sup>9</sup>. Excessive exploitation of small-sized, non-commercial and commercial resources from the ecosystem will impact the production of many carnivorous fishes of high commercial value, which prey on small sized non-commercial resources<sup>15</sup>. The growth of overfishing or juveniles in bycatch is found to impact commercial species production directly. Behera *et al.*<sup>14</sup>

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and Dineshababu and Radhakrishnan<sup>16</sup> described the probable consequences of 'growth overfishing' in marine fisheries in economic and biomass terms. The present study analyses the quantity, diversity, and utilization of LVB from trawl landings at all the major maritime states of India, covering more than 64% of the multi-day trawl landings in the country.

## Methodology

There are an excessive number of terminologies used in bycatch research. For simplicity, the terminologies used in the present study will follow the classification provided by Costa *et al.*<sup>17</sup>, which was tailored to suit the Indian context. 'Commercial catch' refers to the fishes which are landed for human consumption; the fishes landed (intentionally or unintentionally) which are not suitable for direct human consumption constitute LVB. Apart from the landed catch, some are discarded back into the sea. This could be due to non-acceptance at the landing centre/legal prohibition to land/or lack of space in the vessel. This portion of the catch is known as discards.

Data on the catch and bycatch species composition of the trawlers operating multi-day cruises from major maritime states of India (Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal) were collected from selected trawl landing centres of the respective states. The data and samples were collected from the fisheries harbours with weekly sampling. The methodology described by Garces *et al.*<sup>18</sup> was followed for sampling and analysis of trawl catch and bycatch. Characterization of bycatch was done using the methods described by Mahesh *et al.*<sup>13</sup>. A combination of quantitative and qualitative methods was used to collect data for a study on the perceptions of stakeholders on trawl fisheries. Qualitative methods (e.g. structured questionnaires) provided information on the context and qualitative methods. For example, focused group discussions (FGDs) and key informant interviews provided detailed ground-truth data<sup>19</sup>. A customized questionnaire was prepared and distributed among fishermen of these trawl landing centres to estimate the discard percentage and also discern the social perspective of fishermen on bycatch and discard issues.

## Result and discussion

### Trawl fishery

Trawl was the dominant gear contributing to most fish catch during 2017–19. The average annual trawl fishery production during this period was 2,044,835 tonnes. Also, 80% of the trawl catch (1,608,174 tonnes) was contributed by multi-day trawl nets (MDTNs) operated by fishing trawlers overnight from 2 to 14 days in a single cruise.

Tables 1 and 2 provide details of MDTN catch of the major maritime states along the west and east coast of India respectively, as well as trawl landing centres, the percentage contribution of the centre to the respective state's MDTN catch, LVB landing LVB percentage, estimated discard percentage (using questionnaire data) and the fishmeal plant/fish oil plants<sup>20</sup>.

### Characterization of LVB from different maritime states

**Gujarat:** LVB and species composition of multi-day trawlers in Gujarat were estimated from the Veraval and Mangrol trawling centres. Two hundred and ninety-eight species were identified from these LVB landings, of which finfishes formed the major portion. *Decapterus* spp., *Thryssa* spp., *Platycephalus* spp., lesser sardines, *Lagocephalus* spp., *Mene maculata* and silverbellies were the major contributors to LVB throughout the study period. However, from 2018 onwards *Odonus niger* dominated the finfish portion of LVB. In 2007, the species was entirely used in the fish meal industry but during the latter part of the study, well-preserved large-sized triggerfishes found a place in the commercial fish market for surumi preparation. Non-penaeid shrimps, squilla and non-edible crabs also formed a part of LVB, and were used mainly in preparing fertilizer and poultry feeds. The juvenile commercial fishes other than the species listed above found in LVB were ribbon fishes and thread-fin breams.

There was a notable difference in the species composition of LVB compared to the last decade<sup>7</sup>. During the study conducted between 2007 and 2012, non-penaeid shrimps and *Lagocephalus inermis* were the dominant species in LVB. Presently, only small-sized pufferfishes are seen in LVB, while the large-sized *L. inermis* have found a commercial market, contributing to the edible fish market. From an economic perspective, LVB plays a significant role in Gujarat. There are five fish meal units with a capacity of 201 tonnes/day and one fish oil unit with a capacity of 2 tonnes/day, which are currently in operation<sup>20</sup>, utilizing LVB from the trawl landing centres of Gujarat.

**Maharashtra:** LVB and species composition of multi-day travels in Maharashtra were estimated from the New Ferry Warf trawl landing centre. *O. niger*, *Scomberoides* spp., *Platycephalus* spp., *Decapterus* spp., *Ilisha* sp., *Alepes* spp., *Cynoglossus* spp. and squilla were the major constituents of LVB from Mumbai. Juveniles of Bombay duck, *Coilia* spp. and ribbonfishes also formed a portion of LVB. An increase in the percentage of finfish species in LVB was noticed compared to the last decade where crustaceans, squilla, *Charybdis* crabs and non-penaeid prawns contributed to more than 25% of LVB<sup>7</sup>, which had reduced to 10% as observed in the present study. LVB is considered one of the major economic commodities in Maharashtra as well, as six fish meal units with a total capacity of 468 tonnes/day

## RESEARCH ARTICLES

**Table 1.** Multi-day trawl net (MDTN) catch, low-value bycatch (LVB) landing and LVB percentage, estimated discard percentage and details of fish meal/fish oil plants in States from the west coast of India

State	Average MDTN catch (tonne; 2017–19)	Coordinating centre	Trawl operating centre	MDTN catch at the centre (tonne)	Percentage of state MDTN catch	LVB landed (tonne)	Percentage of LVB	Percentage of discards*	Fish meal/ Fish oil plants**	
Gujarat	367,048	Veraval	Veraval	160,310	44	40,341	25–30	20	5/1	
			Mangrol	54,992	15	18,461	30–35	15		
Maharashtra	145,871	Mumbai	New ferry Warf	42,293	29	22,275	40–52	10	6/5	
Karnataka	329,180	Mangaluru	Mangaluru	145,398	44	48,398	30–35	10	20/21	
			Malpe	111,690	34	34,779	30–35	10		
Kerala	254,046	Calicut	Calicut	82,867	33	37,422	15–35	10–25	5/5	
			Kochi	Munambam	68,980	27	20,694	15–30	10–25	
			Quilon	67,819	27	20,346	15–40	10–25		

\*Questionnaire based information. \*\*Marine Products Export Development Authority (MPEDA) (ref. 20).

**Table 2.** MDTN catch, LVB landing and LVB percentage, estimated discard percentage and details of fish meal/fish oil plants in states from the east coast of India

State	Average MDTN catch (tonne; 2017–19)	Coordinating centre	Trawl operating centre	MDTN catch at centre (tonne)	Percentage of state MDTN catch	LVB landed (tonne)	Percentage of LVB	Percentage of discards*	Fish meal/ fish oil plants**
Tamil Nadu	132,139	Chennai	Kasimedu	32,408	25	5833	18–20	20	10/11
			Mandapam	Nagapattinam	22,407	17	57,968	15–18	30
Andhra Pradesh	95,131	Visakhapatnam	Visakhapatnam	31,653	33	0	0	30	
			Kakinada	42,208	44	3377	8–10	25	
Odisha	58,885	Puri	Balasore	18,588	32	7063	33–40	10	
			Paradeep	20,588	35	6794	35–40	10	
West Bengal	134,208	Digha	Digha, Mohana	68,536	51	26,044	35–45	10	2/0

\*Questionnaire based information. \*\*Marine Products Export Development Authority (ref. 20).

and 11 fish oil units with a capacity of 196 tonnes/day are being operated in the state<sup>20</sup> directly depending on LVB from the trawl landing centres of Maharashtra and Gujarat.

**Karnataka:** A total of 242 species were identified from LVB landings of Karnataka, of which fishes formed the majority. *O. niger*, *Sardinella gibbosa*, *Megalaspis cordyla*, *L. inermis*, *Therapon* spp. and juveniles of *Trichiurus lepturus* and *Nemipterus randalli* were the major constituents of LVB. During the last decade, *L. inermis* contributed to 12.80% of LVB landings forming the highest finfish component of LVB. This has reduced substantially, since large-sized *L. inermis* are now accepted in the edible market which can be considered an encouraging example, that resources which were considered low values in earlier years can be made to high value commodity by giving proper advisories for its handling and preservation. In the Karnataka fishery economy, LVB plays a significant role as the state is the major producer of fishmeal and fish oil India, and the major raw material for fishmeal and fish oil production is LVB from trawlers. Like the edible fish market, the LVB market is highly competitive in Karnataka and due to this, the fish-dominated LVB invariably fetches more than Rs 20/kg. There are 20 fish meal units with a capacity of 1842.5 tonnes/day and 21 fish oil plants with a production capacity of 587.5 tonnes/day (ref. 20) being operated in the state. The requirement of raw material for these plants was met by

LVB from Karnataka as well as that transported from landing centres along the Indian coast. There was also a need for raw materials to be imported for fish meal preparation to meet the demand in the state.

Juvenile dominance in LVB off the Karnataka and Goa coasts has been well documented. Dineshbabu *et al.*<sup>9</sup> reported that LBV in commercial trawlers along the Mangaluru coast was constituted by juveniles of 45 commercially important species, which contributed about 34% by weight and 63% by number to the total landing of these species. Mahesh *et al.*<sup>13</sup> reported that commercially important juveniles of finfish formed 47.5% by weight and 56.1% by LVB in trawl fisheries off the Karnataka coast.

**Kerala:** LVB and species composition of multi-day trawlers in Kerala were estimated from the trawling centres of Calicut (Beyepore and Puthiyappa landing centres), Kochi (Munambam), and Quilon (Sakthikulangara and Neendakara). The study period witnessed the impact of the introduction of minimum legal size (MLS) on the Kerala coast as a result of the study being conducted by the ICAR-Central Marine Fisheries Research Institute at Kochi<sup>21</sup>. In 2017, MLS was imposed on marine fishing in Kerala and strict imposition started from 2018 onwards. In 2017, at most of the centres in Kerala, multi-day trawlers were reporting about 30% of the landings as bycatch, which decreased to about 15% after 2018. A detailed analysis of the impact of MLS is provided

later in the text. As many as 254 species were recorded from the bycatch in Kerala, of which *O. niger*, *L. inermis*, *Thryssa* spp., *Decapterus* spp., *Platycephalus indicus*, *Saurida tumbil*, *Muraenesox* spp., *Uranoscopus* spp., *Fistularia petimba* and juveniles of *Epinephelus diacanthus*, *N. randalli*, *Priacanthus hamrur* and *T. lepturus* were the major constituents. The juvenile composition in LVB considerably reduced from 44% to 16% from 2017 to 2019. In Kerala, there exists a good marketing network. There are also ten fish meal production units with a capacity of 468.34 tonne/day and five fish oil plants with a production capacity of 29.7 tonnes/day (ref. 19) is being operated in the State depending on LVB from the trawlers as raw material for fishmeal production<sup>19</sup>. It has been found that the fish meal plants located in south Tamil Nadu mainly depend on LVB from the trawlers operated off the south Kerala coast. Juvenile composition of bycatch was a serious concern before MLS implementation. Madhu *et al.*<sup>11</sup> reported that juveniles of commercially important species constituted about 84% of the total bycatch landed by commercial trawlers along the coast of central Kerala.

**Tamil Nadu:** LVB and species composition of multi-day trawlers in Tamil Nadu were observed from Mandapam (Nagapattinam FH) and Chennai (Kasimedu FH) during 2017–19. A total of 181 species were identified from the LVB landings. Major groups identified were *O. niger*, *Upeneus* spp., *Alepes kleinii*, *Thryssa* spp., *Terapon* spp., *Grammoplites scaber*, *S. gibbosa*, balistids, stomatopods, non-edible crabs, gastropods and juveniles of silverbellies, *Nemipterus* spp., *Saurida* spp. and flatfishes. There are ten fish meal units with a capacity of 468 tonnes/day and 11 fish oil plants with a production capacity of 47.5 tonnes/day (ref. 20) registered in the state. These plants are being run on LVB from Tamil Nadu and Kerala. Juvenile incidence in trawl bycatch was a major issue in Tamil Nadu also, Kizhakudan *et al.*<sup>8</sup> reported that approximately 70% of the total LVB was juveniles landed by commercial bottom trawlers from Chennai.

**Andhra Pradesh:** LVB and species composition of multi-day trawlers in Andhra Pradesh was estimated from the Visakhapatnam trawl landing centre during 2017–19. The bycatch landing in Visakhapatnam fisheries harbour was banned before the study period and the trawlers were not allowed to land bycatch in the fisheries harbour. One hundred and seventy-seven species from the discarded part of bycatch from Visakhapatnam coast were identified from the participatory and experimental trawling conducted. The trawl catch/bycatch data collected from Kakinada fishing harbour were also included in the study for reference (Table 2). Lesser sardines, flatfishes, sciaenids, *Thryssa* spp., *Terapon* spp., *Upeneus* sp., squilla and pufferfish, non-edible crabs, juveniles of silverbellies, *Nemipterus* spp. and *Saurida* spp. were identified from the bycatch of Visakhapatnam. Juveniles in the trawl bycatch of Andhra Pradesh have been well documented. Muktha *et al.*<sup>12</sup> reported that the juveniles of different

species caught in trawl nets contributed 63.6% to the total trawl catch along the coast of Andhra Pradesh. There are no registered fishmeal plants in Andhra Pradesh<sup>20</sup> and LVB from this state is being transported across its borders.

**Odisha:** LVB and species composition of multi-day trawlers in Odisha were estimated from trawl centres of Paradeep and Balasore district during 2017–19. Fifty-eight species were identified from the bycatch of which *M. cordyla*, *Cynoglossus arel*, *Stolephorus commersonii*, *T. lepturus*, *Opisthopetrus tardoore*, *Thryssa* spp. and *Coilia dussumieri* were the major ones. Off the Odisha coast also, juveniles in the bycatch are of great concern. A study conducted off the Andhra Pradesh and Odisha coasts by Behera *et al.*<sup>14</sup> revealed that on an average, 15.57% of the bycatch of trawlers operated along the coast was contributed by juveniles of commercially important species of finfishes and cephalopods; in terms of number, they contributed 18.75%. There are no registered fishmeal plants in Odisha<sup>20</sup>, and LVB from the state is transported across its borders.

**West Bengal:** LVB estimation and species composition of multi-day trawlers in West Bengal were estimated from the Digha trawl landing centre during 2017–19. Fifty-eight species of finfish and shellfish were identified from the trawl bycatch. Smaller clupeids, anchovies, *Coilia* sp., horse mackerel, Bombay duck, *Thryssa* sp., *Setipinna* sp., Leather-jacket fishes and goat fishes formed the majority of LVB. There are two fish meal production units with a capacity of 28 tonnes/day in West Bengal<sup>20</sup>, for which the major raw material is bycatch from the trawlers operating on the northwest coast of India.

#### *Decadal changes in the diversity of LVB along the Indian coast*

When compared with the species diversity in LVB from multi-day trawlers reported during the last decade<sup>7</sup>, the present study showed a notable reduction of crustacean composition in LVB. This reduction was particularly noticeable in Gujarat, Maharashtra and Karnataka. It was observed that crustaceans generally dominated bycatch discarded in most states due to their low preference for fishmeal plants. During the last decade, installing of high-speed engines on the multi-day operating trawlers facilitated profitable semi-pelagic/pelagic trawling<sup>21</sup>, replacing the comparatively slower bottom trawling. The high market demand for finfishes and cephalopods export market and the high demand for finfish-dominated LVB in fish meal plants have been ascribed to these changes in trawling operations<sup>22</sup>.

Due to the changes in trawling operations, the trawlers are equipped with various trawl nets suited for each target, according to the species availability. However, such offshore operational changes are not reflected in the literature regarding trawling in India, and most bycatch studies are discussed based on bottom trawling. Under the present operational

changes in trawling, bycatch from Indian trawling is no longer comparable with global bycatch. Globally, disturbances and destruction of benthic biota caused by sweeping the sea bottom continue to be projected as the most undesirable impacts of the trawling operation<sup>1-4</sup>. After the introduction of semi-pelagic trawling in commercial fishery studies in India, in recent years there seems to be a significant reduction in the destruction of the benthic ecosystem from trawling operations<sup>10-13</sup>. These changes in trawling operations have led to increased juvenile composition of commercial fishes, including pelagic fishes in LVB. Behera *et al.*<sup>14</sup> reported that LVB from multi-day trawlers operated off the Andhra Pradesh and Odisha coasts were constituted by juveniles of 20 commercial species weighing 12,757 tonnes (286.86 million in number) per year, and their contribution to the total landings of these species in the trawl bycatch was 55.30% by weight and 57.03% by number.

#### *Impact of LVB in fishery economics*

LVB marketing is as efficient as edible fish marketing in India, especially along the west coast. LVB is being marketed across the states with competitive prices. Along the west coast of India, the lowest price for LVB recorded was Rs 10/kg (average) in Gujarat, whereas in the southern states fish-dominated bycatch fetched more than Rs 25/kg. Aswathy and Narayanakumar<sup>21</sup> estimated that a multi-day operation over 10 days per cruise costs more than Rs 450,000 (US\$ 6605). Recently, some trawl operators are finding it difficult to meet the operational cost of commercial fish landing alone. Since LVB is an assured source of income, trawl operators prefer to keep it on-board or in the fish hold as far as possible so that the marketing of LVB covers a part of the operational cost. In the present study, the annual estimate of LVB from trawl landing centres observed along the Indian coast was around 350,000 tonnes. Expecting the value realization at a minimum price of Rs 10/kg, the LVB is worth Rs 3500 million annually, which is considered one of the major sources of income for trawl operators to keep the trawling operation economically feasible and profitable. According to the Marine Products Export Development Authority (MPEDA) of India<sup>20</sup>, 49 fish meal and 44 fish oil production units have been registered, estimated to produce 3224.50 tonnes fish meal and 877.68 tonnes fish oil daily. These industrial units are operate on raw materials from LVB and other low-priced fish. Even though exact annual production values from these plants are not available, the MPEDA record shows that more than 80,000–90,000 tonnes of dry fishmeal and fish oil were exported from India during 2017–19, contributing an average of Rs 7050 million to the export revenue<sup>20</sup>. According to the export information of fishmeal, it can be assumed that the annual estimate of LVB from the present study could have been an underestimation. Many consignments of LVB are transported directly from the trawlers to fishmeal plants, which has denied the opportunity to determine its actual valuation at the landing

centres. Fish-dominated LVB has a high demand for fish-meal and oil plants, and recently, fish oil plants have started importing low-value, oil-rich fishes from other countries to meet their raw material demand.

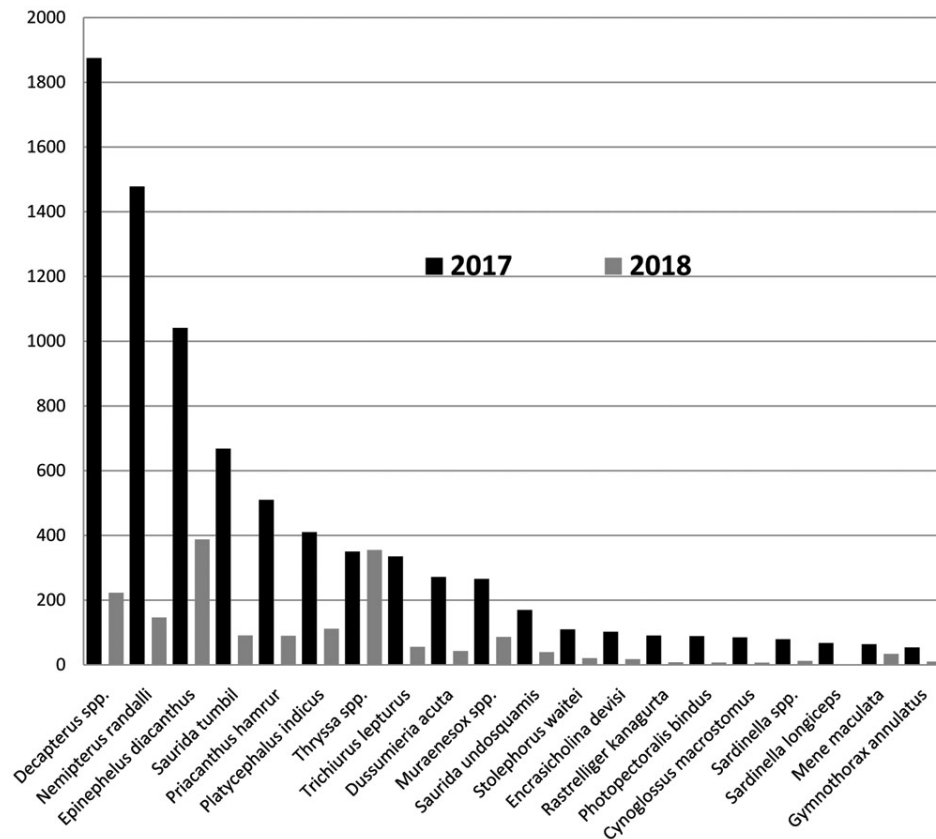
Competition from fishmeal plants for their raw material encouraged bringing as much bycatch as possible, and on some occasions, a high volume of LVB became an economic priority over a low volume of commercial fishes. This overemphasis on LVB catch and its subsequent storage is considered the cause of deterioration in the quality of commercial fishes caught with the LVB. It has been reported that high-value fishes which were landed with less preferred trigger fishes were rejected or procured at reduced prices by the buyers at the landing centres. Such instances are prevalent along the west coast of India during the last two years.

#### *Ecological impact of LVB landing on commercial fisheries*

The impact of LVB on the sustainability of marine fisheries has been widely discussed globally. From the Indian perspective<sup>1,4,9</sup>, ‘growth overfishing’, which resulted in lower production of commercial fishes in the Indian trawl bycatch has been highlighted by Behera *et al.*<sup>14</sup> as well as Dineshbabu and Radharkishnan<sup>16</sup>. The introduction of MLS to regulate landing size of fishes has decreased juveniles in the LVB landings from Kerala since 2018. The impact of the removal of non-commercial fishes at the LVB landings needs to be evaluated from an ecosystem perspective. Excessive exploitation of non-commercial components of the fishery, like stomatopods, non-edible crabs and non-edible fish varieties, may not impact the commercial fishery directly; however, irrational removal of these resources from the ecosystem will impact the production of many carnivorous fishes of high commercial value<sup>4</sup>. Internationally, it has been proved that better bycatch mitigation policies, with emphasis on prey–predator relationship analysis of the bycatch, can improve marine fisheries’ production of highly valued predator fishes<sup>15</sup>.

#### *Initiatives in bycatch mitigation in India*

Several studies have been carried out in the Indian waters on trawl gear selectivity regarding regulation of mesh size and shape to reduce bycatch<sup>23</sup>. However, the rapid changes during the last decade in increased boat size, use of high-speed engines, targeting juvenile pelagic shoals from surface and columnar water need multidimensional approaches to mitigate bycatch issues. Squires *et al.*<sup>24</sup> has reviewed the global fisheries bycatch mitigation and management. General bycatch conservation and management principles have been developed based on a multidisciplinary approach, along with a larger scale of people’s involvement and incentivization for bycatch mitigation. In India, mitigation of bycatch and sustainability of marine fisheries were carried out by



**Figure 1.** Changes in juvenile composition (tonne) in trawl fishing centres of Calicut during 2017 and 2018.

introducing the seasonal closure of fishery, MLS implementation, alterations to gear design like mesh size optimization, installation of bycatch reduction devices (BRDs), juveniles and trash fish excluder devices. These changes were implemented on a regional and national scale, with varying success rates in reducing LVB<sup>25</sup>. Seasonal closure of fishery was found to be highly successful in reducing fishing pressure, especially since in India this is mainly focussed on the spawning season of the fishes<sup>26</sup>. Along with seasonal closure, Dineshbabu *et al.*<sup>27</sup> suggested regional closure of fishing grounds (operational restrictions in trawling grounds) by identifying areas of high bycatch occurrences and juvenile assemblages. Avoiding such identified areas during prominent seasons can significantly reduce trawl fisheries. This will also help policymakers in identifying marine protected areas (MPA) and 'fishery refugia'; to resolve the issues in the long term. Implementing MLS in the southern states of the west coast of India has started revealing certain impacts. These impact studies are described later in this text and the perception of fishermen on the efficacy of ongoing regulations is also described.

#### *Impact of MLS implementation on LVB*

During the study period, MLS at the landing centres has been strictly implemented in Kerala since 2017. This provided

an opportunity to analyse the impact of MLS implementation on LVB landings and its juvenile composition. Data from the Malabar region (Beyppore and Puthiyappa landing centres) were analysed. Before the implementation of MLS, LVB of MDTN from Calicut was about 35% of the landings, of which 43.7% was formed by juveniles of commercially important species (in terms of number, it was 53%). After the effective implementation of MLS and strict monitoring by the Marine Enforcement Squad of the Government of Kerala since 2018, LVB from MDTN reduced to 15% of the landings. More significantly, this was chiefly due to the reduction in juveniles in the LVB, which were found to have reduced to 16.3% of the LVB landings (20.8% by number) (Figure 1).

It can be concluded that after the introduction of MLS in marine fisheries, the LVB landings and juvenile percentage in the LVB have reduced significantly. Evaluating the MLS introduction results from different case studies, Graham *et al.*<sup>28</sup> concluded that MLS was a positive step towards reducing juveniles in the bycatch. However, it must be implemented in conjunction with mesh size regulation; otherwise it may lead to more discards from the trawlers. The LVB records from the Malabar region, Kerala, after the implementation of MLS also tend to show such supplementary measures, since from 2018 onwards the reported discard rate was higher.

*Social perceptions regarding initiatives on bycatch mitigation*

Globally, the inclusion of fisher's in the decision-making process is considered the fundamental criterion for developing successful approaches in mitigating bycatch<sup>24</sup>. In line with this, peoples' perceptions of such methods of bycatch mitigation in India have also been evaluated in the present study. Surveys on the social perceptions regarding LVB reduction were conducted among trawl fishermen from all the major maritime states using a custom-made questionnaire. The first topic of enquiry was mesh size regulation for trawl cod-end. According to studies<sup>23,29,30</sup>, a mesh size above 35 mm is necessary to avoid juveniles in the trawlers, and this finding has been debated. Trawl operators from almost all States, except Kerala, agree that a mesh size above 35 mm for the cod-end of trawls may not affect their commercial catches and must be strictly implemented. The second topic was regarding the practicability of its implementation. The fishermen from Odisha did not see any difficulty in its implementation. However, 10–20% of the respondents from Andhra Pradesh, Gujarat, Maharashtra, Tamil Nadu, Karnataka and West Bengal were doubtful about the practicality of its implementation. The respondents from Kerala responded differently to the implementation of mesh-size regulations. A majority of the respondents (66%) mentioned that mesh size regulations would reduce catch in prawns, and more than 50% of the respondents mentioned that uniform implementation of mesh size above 35 mm is not practical. They informed us that, except for the shrimp trawlers, most of the MDTNs were using larger mesh size for their trawlers at present. The fishermen of all the states agreed to use of a square mesh over a diamond mesh, as considering that this will help reduce juveniles. They mentioned that the drive to change mesh size has to be initiated from the net manufacturing factories and incentives have to be provided for the replacing existing nets. On a national basis, 80% of the trawl operators agreed to install BRDs if financial incentives and training were provided for their installation and operation. However, trawler operators from the west coast of India mentioned that since they carried more than one net in multi-day trawlers, installation of BRDs on all fishnets would be expensive and the operation for each target catch would require different designs. Regarding MLS implementation, queries were restricted to Kerala and Karnataka. Almost all trawl operators from these two states were aware of the implementation and considered that it would reduce juveniles in LVB. However, they were apprehensive that implementing MLS alone would improve the survival of juveniles of commercial fishes. At present, juveniles are not allowed to land in the harbors and trawlers would have to pay huge fines if the landed juvenile percentage is more than that allowed. So the juveniles caught are discarded back into the sea. During 2018 and 2019, even though juvenile percentage in LVB reduced considerably, the discard rate in Kerala increased substantially. Fishermen considered that the spatio-tempo-

ral juvenile assemblage of commercial fishes is supplementary information required for deriving desirable results of saving juveniles from MLS implementation. The perceptions in mitigation of bycatch in Indian fisheries were also found to be in line with the global perceptions that bycatch management principles should be formulated based on a multidisciplinary approach, the involvement of people and incentivizing bycatch mitigation approaches<sup>24</sup>.

*Promising case studies of bringing LVB into edible protein*

Many resources that were of high nutritional value were considered in low value bycatch and used only for fishmeal in earlier years, but by understanding their high nutritional value through research and awareness programmes, many such LVB resources are now being marketed as high value fishes. Such instances of species which were earlier used for fishmeal and fertilizers now contributing to human food and protein have been described by Haraksingh *et al.*<sup>31</sup>. In the Indian scenario, when the transportation and storage facilities were limited, most of the species caught in shrimp trawling were fetching only fertilizer value, but with the advent of marketing and storage facilities these bycatches because highly valued resources, which were distributed far and wide with high acceptability. There are examples from the recent past that pufferfishes, which were once considered a menace in the fisheries due to their highly predatory nature and lack of value when landed are now the major part of low-value bycatch in the southwest coast of India<sup>32</sup>. In recent years, fishermen have explored marketing possibilities of semi-processed meat of pufferfishes in domestic and export markets. They witnessed high demand in local markets and neighbouring States. As a result of market demand, pufferfish (*L. inermis*) was targeted by trawlers and preserved in hygienic conditions, and has become a commercial species. Similarly, triggerfish (*O. niger*), which was used only for fish meals until 2017, has found value as a part of surumi preparation, especially in Gujarat and Karnataka. So most of the large-sized triggerfishes have now become edible varieties, while small-sized and poorly preserved triggerfishes remain as LVB, especially when there is no proper marketing chain.

*Problems in data collection on LVB and discards*

Data collection on LVB landing and species composition was being done from the landed catch of trawlers and generally, LVB from MDTN landed in bad condition without preservation. In most cases, LVB estimation was done based on baskets/crates of unloaded LVB, and the species composition was estimated from samples often collected from decomposed heaps. Since it is not mandatory for trawl operators or marketing personnel to disclose LVB, sampling is a tedious process in some of the trawl landing centres. In Kerala, after the introduction of MLS, the trawl operators often declined

to provide information on LVB, fearing consequences from the Government. At present, its sampling is sparingly affected thanks to the goodwill and relationship between ICAR-CMFRI and the fishers. However, there should be a mechanism to make it mandatory to disclose the landing information and allow the collection of the samples for analysis to make the LVB research comprehensive. Ever since multi-day trawling started, the amount of bycatch discarded from the trawlers is known only to those who operate them. There is no mechanism so far available to know the exact discards from the trawlers. The results are based on information from sampling boats in participatory programmes<sup>7</sup>, experimental trawling<sup>14</sup> and selected trawler operators willing to share data<sup>33</sup> on a regional basis. After the introduction of MLS and other regulatory measures, fishermen are increasingly reluctant to share precise information on trawl catch. It is to be understood that LVB is the catch that is recorded in fishery assessment, whereas discards are a part of the catch unrecorded anywhere in the fishery estimation. More holistic efforts on bycatch mitigation will help develop measures to bring these unaccounted parts of the catch and boost the Indian fishery economy.

## Conclusion

The present study establishes that bycatch is a relative term in modern-day trawl fisheries, and most of the edible bycatch is complementary to fish production. However, high quantities of low-valued fishes, which do not have acceptance in the edible market, and non-commercial fishes, which do not have any established edible value, continue to be a matter of concern from an economic and ecological perspective. The present study mainly analysed the composition, and ecological and economic impact of these portions of the catch, i.e. LVB. It is to be kept in mind that fishmeal plants and fish oil companies play a significant part in the fishery economy, and these industries depend entirely on LVB. Trawl fishery is the backbone of the livelihood of millions of primary, secondary and tertiary stakeholders. A balanced approach considering the economy as well as ecology needs to be devised to benefit the country from a holistic perspective. Multiple attempts were made to analyse the composition of bycatch from all over India and all these studies have raised concerns over the high percentage of juveniles, especially those of commercial fishes in the LVB landings. A study focused on MLS introduction in Kerala showed that imposition of the MLS criterion in the landings substantially reduced LVB as well as juvenile percentage in LVB. However, the increased discards reported from trawlers during the MLS implementation have raised concerns about whether the MLS implementation alone can ensure achieving desirable results. There is a need for further research in this field to develop a bycatch management policy for India with a reduction of juveniles, finding value realization for LVB species and reducing ecological problems due to irrational removal

of prey species from the ecosystems. From the present study, it can be observed that the majority of the fishers across India are now willing to accept larger mesh size (above 35 mm) for trawl cod-end, which is a welcome change, and adopt the suggested fishing regulations, compared to the resistance that fishery administrators faced while advocating them during the past few decades. Such measures can be recommended as a viable mitigation option for bycatch reduction in light of better acceptability for adoption. The introduction of high-speed engines and the possible operational changes with a such facility, need to be considered as additional researchable issues while developing desired fisheries regulations in future. Since the present study was conducted across India (including all the coastal states of the country), the data generated through catch, bycatch sampling and sampling of socio-economic perspectives on trawl fisheries are exhaustive, revealing research gaps existing in bycatch mitigation. Considering the various multifaceted issues involved in trawl fisheries, it can be concluded that trawl bycatch mitigation measures need a multidisciplinary approach, considering the fast development of trawl fisheries. More involvement of fishers and incentivizing the best practices adopted for bycatch mitigation also need to be considered as viable options.

*Disclaimer:* The results presented in this study are solely the research findings of the scientists who have worked on developing guidelines for 'best practices in trawling' in India.

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