## Article

# Length Based Stock Assessment of Five Fish Species from the Marine Water of Pakistan 

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#### Abstract

The marine fisheries resources of Pakistan have been drastically affected in the past few decades. Considering the limitations of previous studies and the data poor condition of the marine fisheries of Pakistan, this study employed the length-based Bayesian biomass (LBB) estimation method for analyzing the fisheries' representative length-frequency data of five exploited marine fish stocks (Nemipterus japonicus, Nemipterus randalli, Parascolopsis aspinosa, Saurida tumbil, and Lepturacanthus savala). The estimates of relative fishing mortality $(F / M)$ are higher than unity in four stocks except for $S$. tumbil, indicating overfishing. However, the current values relative to unexploited biomass $\left(B / B_{0}\right)$ are below 0.4 , which indicates that the stock biomass is deficient in delivering maximum sustainable yield. Overfishing and the mass exclusion of small and older fish from stocks threaten to deplete the biomass of all species. Therefore, this study recommended that increasing the mesh size in commercial fisheries would increase both the catch and biomass of these species. The existing number of boats should be reduced to reduce fishing mortality and bring it back to the ratio of relative fishing mortality (F/M) equal or less than unity, for a sustainable level.


Keywords: fish stock assessment; Pakistan; LBB method; length-frequency analysis; overfishing

## 1. Introduction

Due to the growing fishing pressure and overexploitation resulting from increased demand, the long term viability of marine capture fisheries has become a global concern, particularly in developing countries, where hunger is most prevalent and proper management tools and political will are lacking [1]. As a result, the resources of commercially important fish species have been steadily depleting. Therefore, effective management tools, including effort control, nets' mesh size regulations, and total allowable catch (TAC) limits, are essential to protect fish stock from further depletion and ensure sustainable usages of this sector [1,2]. Knowledge of stock status, particularly present exploitation levels and biomass status, must be examined first to develop these management tools [1].

The capture fisheries of Pakistan have a significant role in creating employment and earning foreign exchange, and the contribution of this sector is about $80 \%$ of the country's total fish production. The commercially important marine capture fisheries have 250 demersal fish species, 50 small pelagic fish species, 15 medium sized pelagic species, and 20 sizeable pelagic fish species. In addition, 15 shrimps, 12 cephalopods, and 5 lobsters were also reported from Pakistani marine waters [3-5]. The marine capture fisheries of Pakistan are mainly characterized by gillnet, trawl and "doonda" (fiberglass lifeboats made from scrapped ships), often targeting demersal fish. Gillnets are most commonly employed to catch demersal species, such as emperors, croakers (Sciaenidae), grunts, snappers and groupers [6].

The evaluation and exploration of marine fisheries resources are essential for the country's economy, but it requires significant investment and keen concentration [7]. Pakistan's
fisheries resources are open access. Moreover, the proportion of the country's exclusive economic zone (EEZ) fishery resources is still undetermined [8]. However, the findings of various fishing surveys conducted with the cooperation of foreign research vessels indicated the existence of untapped demersal fish stocks beyond the traditional fishing zones from 20 to 200 nautical miles (nm). In 2010, a Norwegian research vessel, Dr. Fridtjof Nansen, conducted a demersal fisheries resource surveys program. This survey discovered demersal species with 106,874 metric tons biomass capacity beyond the territorial limit [9].

The marine fisheries resources of Pakistan have been strongly affected in recent decades, mainly due to overfishing, unsustainable fishing practices and marine pollution. Overfishing and juvenile catches have been reported by studies that carried out the stock assessment of different fish species from the marine fisheries of Pakistan [10-14]. They reported both growth and recruitment overfishing [1]. More importantly, due to misreporting, incomplete and limited catch data, these studies used length-frequency data in FAO-ICLARM stock assessment tools (FiSAT) to explore the stocks' exploitation status.

Due to a lack of data, traditional stock assessment methods are unable to estimate sustainable fishing levels for the majority of world fish stocks [15]. Complex stock assessment models require large data sets [16], including total removals over time, catch-at-length or age, relative or absolute abundance indices, fishing effort, and information on life-history parameters $[15,17]$. Such datasets are often unavailable for most small scale fisheries, especially in developing countries such as Pakistan. In data poor fisheries, two types of methodologies are commonly used, catch based methods and length based methods [18]. In comparison to statistical catch data, length-frequency data is conveniently available because it takes less time and effort. The length based approaches avoided depending on a complicated dataset and instead utilized size composition data acquired from various sources to establish species level evaluations [19], which certainly strengthens the management of fisheries in developing countries [20]. Furthermore, the authenticity of statistical catch data is critical to the efficiency of catch based approaches. However, data on marine fisheries captures were deformed due to discarded bycatch, illegal fishing, and neglected small scale fisheries [21,22]. Systematic deformations in catch patterns will affect the estimation results, which will preclude effective management. The length-based Bayesian biomass (LBB) modeling approach to integrate the results can support the production with more reliable estimates [23]. The LBB [24] estimation method was applied in this contribution to assess the fisheries representative length-frequency data of five exploited marine fish stocks (Nemipterus japonicus, Nemipterus randalli, Parascolopsis aspinosa, Saurida tumbil, and Lepturacanthus savala).

To ensure minimal data requirements, the LBB method relies on the ratios of natural mortality to somatic growth $(M / K)$ and fishing mortality to somatic growth $(F / K)$, rather than absolute rates of growth and mortality. After estimating the above ratios with fisheries' representative length-frequency data, the LBB method includes them to estimate the ratio of currently exploited biomass to unexploited biomass $\left(B / B_{0}\right)$ and biomass required to produce maximum sustainable yield (MSY) $\left(B / B_{M S Y}\right)$ [24]. Among the length based methods, LBB is capable of producing the most robust estimates for the species that grow throughout their lives, such as the most commercially important fish and invertebrates [23]. In this study, we used the LBB method for the first time to evaluate the stock status of five commercially important fish species (N. japonicus, N. randalli, P. aspinosa, S. tumbil, and L. savala) from the marine capture fisheries of Pakistan. The outputs of this study will be a guideline for the fisheries' managers to formulate effective management strategies for the sustainability of the marine fisheries of Pakistan.

## 2. Material and Method

2.1. Study Area

The coastline of Pakistan extends 1100 km from the northwest Iranian border (the Balochistan coast) to the southeast Indian border (the Sindh coast), with a $240,000 \mathrm{~km}^{2}$ exclusive economic zone (EEZ), wherein the country can explore and exploit its aquatic
resources (Figure 1). The entire maritime zone of Pakistan covers more than $30 \%$ of the country's geographical area and contains some very productive regions with abundant fisheries and mineral resources.


Figure 1. Map indicating study area in Pakistani coastline with the location of sampling sites.

### 2.2. Sample Collection

The length-frequency data from January to December 2019 were collected from the commercial fishing vessels sailing in Pakistan's exclusive economic zone (EEZ) landing at Karachi Fish Harbour. The fishing vessels made the trips around 60 stations to the nearshore waters of Karachi (Figure 1), utilizing a 10.8 m beam bottom trawl with a mesh size of 50 mm and a cod-end of 25 mm . A total of 25,895 individuals belonging to five species (Table 1) were collected from the landing site twice a week during the above period. Fishers gather their catch in different heaps at the landing center. Therefore, to ensure the representation of all length classes in our samples, we asked the fishers to mix the heap very well and collected $10-30 \%$ ( $10 \%$ during high landing and $30 \%$ during low landing) of each well mixed heap. The specimens were examined using a taxonomic identification sheet/field guide [25], the samples from each sampling were measured in the nearest millimeters (mm).

The LBB method requires priors to estimate parameters ( $\left.L_{\infty}, Z / K, M / K, F / K, L_{c}\right)$. According to Froese et al. (2018), priors for those parameters can be generated by pooling the relevant length-frequency data across years and fitting association equations to the completely selected part of the catch in numbers curve using the nonlinear least-squares estimator function nls() in R. (Froese et al., 2018) [24]. The estimated priors by LBB are given in Table 1.

Table 1. Prior and basic information of the fish species in Pakistani coastal waters.

| Scientific Name | Common Name | $\begin{gathered} \text { Min } \\ (\mathrm{mm}) \end{gathered}$ | $\begin{aligned} & \text { Max } \\ & (\mathrm{mm}) \end{aligned}$ | Numbers | $\begin{gathered} L_{i n f} \\ \text { Prior }(\mathrm{cm}) \end{gathered}$ | $\begin{aligned} & Z / K \\ & \text { Prior } \end{aligned}$ | M/K <br> Prior | F/K <br> Prior | $\begin{gathered} L_{c} \\ \text { Prior } \end{gathered}$ | Alpha <br> Prior |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Nemipterus japonicus | Japanese threadfin bream | 40 | 330 | 7348 | 33 | 4.6 | 1.5 | 3.13 | 12.2 | 24.5 |
| Nemipterus randalli | Randall's threadfin bream | 30 | 240 | 15,253 | 26.7 | 4.1 | 1.5 | 2.56 | 10.2 | 25.4 |
| Parascolopsis aspinosa | Smooth dwarf monocle bream | 70 | 200 | 247 | 20.3 | 3.1 | 1.5 | 1.57 | 11.5 | 28.6 |
| Saurida tumbil | Greater lizardfish | 100 | 460 | 1909 | 55.2 | 2.4 | 1.5 | 0.852 | 19.9 | 18.7 |
| Lepturacanthus savala | Savalai hairtail | 130 | 1070 | 1138 | 109 | 4.8 | 1.5 | 3.28 | 30.6 | 16.6 |

Note: Min = minimum observed length; Max = maximum observed length; Numbers = total specimens; $L_{\text {inf }}=$ prior asymptotic length; $Z / K=$ prior total mortality relative to somatic growth; $M / K=$ prior natural mortality relative to somatic growth; $F / K=$ prior fishing mortality relative to somatic growth; $L_{c}=$ prior length at first capture.

### 2.3. Length-Based Bayesian Biomass Estimation Method (LBB)

The LBB estimation was carried out using the statistical software $R$ and the R-code (LBB_33a.R), downloaded online at http:/ / oceanrep.geomar.de/44832/, (accessed on 14 August 2020) [26]. This method can be used with any commercially important fish or invertebrate that grows throughout their lives [24].

The von Bertalanffy (1938) [27] growth function is below:

$$
\begin{equation*}
L_{t}=L_{\infty}\left[1-e^{-K\left(t-t_{0}\right)}\right] \tag{1}
\end{equation*}
$$

where $t$ is the age of fish, $L_{t}$ is the length at age $t, L_{\infty}$ is the asymptotic length, $K$ represents the growth coefficient (year ${ }^{-1}$ ), and $t_{0}$ is the theoretical age of fish when length is zero.

To predict growth, selectivity, and mortality parameters, LBB is based on the catch curve in numbers (Froese et al., 2018) [24]. Relative fishing mortality $(F / M)$ was calculated from $F / M=(F / K) /(M / K)$ in this study, using the estimated parameters by LBB. The optimum length $\left(L_{\text {opt }}\right)$ at which maximum yield can be possible and the optimum length at first capture ( $L_{c_{-} \text {opt }}$ ) was derived from Equations (2) and (3) (Holt, 1958; Froese et al., 2016) [28,29]:

$$
\begin{gather*}
L_{o p t}=L_{\infty}\left(\frac{3}{3+\frac{M}{K}}\right)  \tag{2}\\
L_{c_{-} \text {opt }}=\frac{L_{\infty}\left(2+\frac{3 F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)} \tag{3}
\end{gather*}
$$

An index of yield per recruit $\left(Y^{\prime} / R\right)$ (Beverton and Holt, 1966) [30] was from the following equation:

$$
\begin{equation*}
\frac{Y \prime}{R}=\frac{\left(\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)}\left(1-\frac{L_{c}}{L_{\infty}}\right)^{M / K}\left(1-\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)}{1+\left(\frac{1}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)^{2}}{1+\left(\frac{2}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{\left(1-\frac{L_{c}}{L_{\infty}}\right)^{3}}{1+\left(\frac{3}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}\right) \tag{4}
\end{equation*}
$$

An index of catch per unit effort per recruit (CPUE'/R) was derived from Equation (5) (Beverton and Holt, 1966) [30]:

$$
\begin{equation*}
\frac{\text { CPUE' }}{R}=\frac{\frac{\gamma^{\prime}}{R}}{\frac{F}{M}}=\left(\frac{1}{M}\right)\left(1-\frac{L c}{L_{\infty}}\right)^{M / K}\left(1-\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)}{1+\left(\frac{M}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)^{2}}{1+\left(\frac{2}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{\left(1-\frac{L_{c}}{L_{\infty}}\right)^{3}}{1+\left(\frac{3}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}\right) \tag{5}
\end{equation*}
$$

Equation (6) calculated the relative biomass per recruit in the exploited phase of the population, excluding the fishing activity (Froese et al., 2018) [24]:

$$
\begin{equation*}
\frac{B \prime_{0}>L c}{R}=\left(1-\frac{L_{c}}{L_{\infty}}\right)^{M / K}\left(1-\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)}{1+\left(\frac{1}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{3\left(1-\frac{L_{c}}{L_{\infty}}\right)^{2}}{1+\left(\frac{2}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}+\frac{\left(1-\frac{L_{c}}{L_{\infty}}\right)^{3}}{1+\left(\frac{3}{\left(\frac{M}{k}+\frac{F}{k}\right)}\right)}\right) \tag{6}
\end{equation*}
$$

where $\left(B^{\prime}{ }_{0}>L_{c} / R\right)$ refers to the exploitable proportion $\left(>L_{c}\right)$ of the unfished biomass $\left(B_{0}\right)$.
Finally, relative biomass depletion $\left(B / B_{0}\right)$ was derived from the following, Equation (7), for the exploited population (Beverton and Holt, 1966) [30]:

$$
\begin{equation*}
\frac{B}{B_{0}}=\frac{\frac{C P U E \prime}{R}}{\frac{B \prime_{0}}{R}} \tag{7}
\end{equation*}
$$

A surrogate for the relative biomass that is capable of producing MSY (Bmsy/B0, which is assumed to be 0.5) was calculated from re-running Equations (4)-(7) (Froese et al., 2018) [24]:

$$
\begin{equation*}
\frac{B}{B m s y}=\frac{\frac{B}{B_{0}}}{\frac{B m s y}{B_{0}}} \tag{8}
\end{equation*}
$$

Depending on the outputs, this study categorized the examined fish species into three groups, i.e., Grossly overfished ( $B / B_{m s y}<0.5$ ), Overfished ( $0.5<B / B_{m s y}<1$ ), and Healthy ( $B / B_{m s y}>1$ ).

## 3. Results

We assessed five fish stocks from Pakistan's marine water using the LBB method with length-frequency data. The results of these assessments are summarized in Table 2 and illustrated in Figure 2. Furthermore, these results are presented on the per species basis, as below.

Nemipterus japonicus (Bloch, 1791), Japanese threadfin bream
The estimated fishing mortality $(F / M=2.7)$ was almost three times higher than the fishing mortality required to produce MSY, thereby indicating the stock's overfishing status. On the other hand, the estimated biomass of the stock $\left(B / B_{0}=0.12\right)$ suggests that the stock of this stock is about to collapse and is thereby classified as grossly overfished. The estimated values of $L_{\text {mean }} / L_{\text {opt }}$ and $L_{c} / L_{c_{\text {_opt }}}$ ( 0.82 and 0.75 , respectively) also confirm that the existing selectivity of this fishery is responsible for the mass exclusion of immature fish from the population, which is a clear indication of the growth overfishing of the stock.

Nemipterus randalli (Russell, 1986), Randall's threadfin bream
The LBB outputs of the length data of $N$. randalli indicated that this species is suffering from heavy fishing pressure ( $F / M=1.6$ ) with a low standing stock biomass ( $B / B_{0}=0.2$ ) and is thereby classified as an overfished stock (Table 2). The estimated value of $L_{\mathcal{C}} / L_{\mathcal{C}_{-} \text {opt }}(0.76)$ confirms that small and juvenile fishing is the dominant feature of this fishery. Parascolopsis aspinosa (Rao \& Rao, 1981), Smooth dwarf monocle bream

This species' estimated exploitation and biomass status suggests that this stock is overfished, with $F / M=1.4, B / B_{M S Y}=0.81$, and $B / B_{0}=0.29$. The outputs of $L_{c 95} / L_{i n f}$ and $L_{\text {mean }} / L_{\text {opt }}$ ratio, on the other hand, are 0.95 and 1.0, respectively, indicating the exitance of mature and optimally sized fish in its stock. The selectivity of this fishery targets mainly the mature and optimally sized fish $\left(L_{c} / L_{c_{-} \text {opt }}=1.0\right)$. Saurida tumbil (Bloch, 1795), Greater lizardfish

The stock of this species is in good condition with low fishing mortality ( $F / M=0.95$ ). However, the estimated values of $B / B_{0}=0.31$, and $B / B_{M S Y}=0.86$ indicate that the biomass is insufficient to achieve maximum sustainable yield. Likewise, $L_{c} / L_{c_{-} \text {opt }}$ ratio is 0.72 , revealing a clear indication of fishing immature fish, which may cause detrimental consequences for the fishery.

Table 2. Estimated results of five fish species for year 2019 length-frequency (LF) data by length-based Bayesian biomass (LBB) method.

| Scientific Name | $L_{\text {mean }} / L_{\text {opt }}$ | $L_{c} / L_{\mathcal{C}_{-} \text {opt }}$ | $L_{95 t h} / L_{i n f}$ | $B / B_{0}$ | $B / B_{M S Y}$ | F/M | F/K | Z/K | Status |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Nemipterus japonicus | 0.82 | 0.75 | 0.84 | $\begin{gathered} 0.12 \\ (0.086-0.17) \end{gathered}$ | $\begin{gathered} 0.34 \\ (0.24-0.47) \end{gathered}$ | $\begin{gathered} 2.7 \\ (2.1-3.5) \end{gathered}$ | $\begin{gathered} 4.6 \\ (4.1-5.1) \end{gathered}$ | $\begin{gathered} 6.3 \\ (5.9-6.7) \end{gathered}$ | Grossly overfished |
| Nemipterus randalli | 0.83 | 0.76 | 0.87 | $\begin{gathered} 0.2 \\ (0.13-0.28) \end{gathered}$ | $\begin{gathered} 0.55 \\ (0.37-0.78) \end{gathered}$ | $\begin{gathered} 1.6 \\ (1.2-2.2) \end{gathered}$ | $\begin{gathered} 2.9 \\ (2.5-3.4) \end{gathered}$ | $\begin{gathered} 4.7 \\ (4.4-5) \end{gathered}$ | Overfished |
| Parascolopsis aspinosa | 1.0 | 1.0 | 0.95 | $\begin{gathered} 0.29 \\ (0.18-0.45) \end{gathered}$ | $\begin{gathered} 0.81 \\ (0.5-1.2) \end{gathered}$ | $\begin{gathered} 1.4 \\ (0.98-2) \end{gathered}$ | $\begin{gathered} \hline 2.3 \\ (1.8-2.8) \\ \hline \end{gathered}$ | $\begin{gathered} 3.9 \\ (3.6-4.3) \end{gathered}$ | Overfished |
| Saurida tumbil | 0.77 | 0.72 | 0.83 | $\begin{gathered} 0.31 \\ (0.17-0.5) \end{gathered}$ | $\begin{gathered} 0.86 \\ (0.47-1.4) \end{gathered}$ | $\begin{gathered} 0.95 \\ (0.63-1.4) \end{gathered}$ | $\begin{gathered} 1.5 \\ (1.1-1.9) \end{gathered}$ | $\begin{gathered} 3.1 \\ (2.8-3.3) \end{gathered}$ | Healthy |
| Lepturacanthus savala | 0.76 | 0.67 | 0.94 | $\begin{gathered} \hline 0.13 \\ (0.09-0.18) \\ \hline \end{gathered}$ | $\begin{gathered} 0.37 \\ (0.25-0.5) \end{gathered}$ | $\begin{gathered} 2.1 \\ (1.6-2.8) \end{gathered}$ | $\begin{gathered} 4 \\ (3.5-4.5) \end{gathered}$ | $\begin{gathered} 5.9 \\ (5.5-6.3) \end{gathered}$ | Grossly overfished |

Note: $L_{\text {mean }} / L_{o p t}=$ mean length in exploited populations over length at maximum sustainable yield; $L_{c} / L_{\text {c_opt }}=$ length at first capture over optimum length selectivity; $L_{95 t h} / L_{\text {inf }}=$ length at 95 th percentile confidence intervals over asymptotic length; $B / B_{0}=$ current biomass over unfished biomass; $B / B_{M S Y}=$ biomass over biomass giving maximum sustainable yield; $F / M=$ fishing mortality over natural mortality; $F / K=$ fishing mortality over somatic growth rate; $Z / K=$ total mortality over somatic growth rate (the values within brackets signify 95th percentile confidence intervals).


Figure 2. Graphical results of LBB method for five commercially captured marine species from marine water of Pakistan. $L_{c}$ signifies the length at first capture, $L_{\text {inf }}$ indicates the species' limit of body length, and $L_{o p t}$ represents the maximum sustainable catch length.

## Lepturacanthus savala (Cuvier, 1829) Savalai hairtail

The outputs of LBB for this species are $F / M=2.1$ and $B / B_{0}=0.13$, indicating that this species' standing biomass has already been depleted due to overfishing. The estimation of $L_{\text {mean }} / L_{\text {opt }}$ (0.76) suggests that the absence of larger and older fish in the stock indicates recruitment overfishing. On the other hand, the estimated value of $L_{c} / L_{c_{-} o p t}$, which is
0.67, also shows the abundance of juvenile fish in the catch as an indication of growth overfishing (Figure 2). Since the biomass of this species is about to collapse, this stock is thereby categorized as grossly overfished.

## 4. Discussion

The data limited marine fisheries of Pakistan are historically characterized by misreporting, incomplete and limited catch data availability, and, hence, the application of traditional stock assessment methods, such as virtual population analysis (VPA), simple stock synthesis (SSS), or surplus production models (SPM), etc., are not able to produce the MSY for fisheries management [31-33]. Since many matrices have been developed, fishing mortality and exploitation rate are widely used to assess the exploited fish stocks in data poor conditions using fisheries representative length-frequency data. However, fishing is a complex economic activity, affected not just by overfishing but also by other factors such as climate change, globalization and environmental degradation, and it is often difficult to take necessary steps to protect the stocks depending solely on these reference points [34,35]. As a result, this study focused not only on exploitation but also on biomass status evaluation using the LBB method, which provides all required information that will help the policymakers to adopt adequate management measures for the sustainable management of the fishery [1].

### 4.1. Biological Overview of the Assessed Species

Nemipterus japonicus, a member of the Nemipteridae family, is a benthic species and is the most extensively dispersed fish in the Indo-Pacific region, ranging from South Japan to East Africa and the Red Sea (it is an immigrant to the Mediterranean). They are generally found in schools in sandy or muddy coastal areas and are captured at all yearly seasons from the coast of Pakistan [36]. Nemipterus randalli is an economically important demersal marine fish widely distributed from the Indian to the Red Seas [37] and mainly feeds on cephalopods, mollusks, crustaceans, and larvae of other fish species [38]. Parascolopsis aspinosa is a benthic species found in offshore waters on sandy or muddy bottoms. This species is distributed along the coast of the Persian Gulf, Gulf of Oman, Gulf of Aden, Arabian Sea, and the Bay of Bengal. From the Indian Ocean, this species has also been reported in Andhra Pradesh [39] and the Gujurat coast [40]. Saurida tumbil is a commercial species captured by trawling in demersal fisheries. It is the largest and most common Lizardfish species in the Synodontidae family, with a wide range of distribution in the region of Indo-West Pacific from the Red Sea to Southeast Asia and Australia [41,42]. Lepturacanthus savala is an economically valuable marine fish of Trichiuridae family. It is an amphidromous and benthopelagic fish distributed in tropical waters around the Indo-West Pacific and Indian Ocean coasts [4,43].

### 4.2. Comparative Overview of the Current Study with Previous Studies

The overexploitation of the capture fisheries is a global concern under the ever increasing pattern of population growth, especially in South Asia, where the uncontrolled and unregulated expansion of fishing activities due to the increased demand is a common phenomenon of the capture fisheries. In this study, data from Pakistani water revealed the depletion of fishing stock due to overfishing, where four out of five stocks are suffering from extreme overexploitation, which is two to three times higher than the sustainable level ( $F / M=1$ ).

The finding of $S$. tumbil shows that this species is harvested sustainably and shows similarities with previous studies in this area (Table 3). On the other hand, this study is the first attempt to evaluate the stock status of $P$. aspinosa in the marine water of Pakistan. The findings of the remaining three stocks ( $N$. japonicus, $N$. randalli, L. savala) showed a disparity between present and previous studies (Table 3). This may be due to the usages of different methodologies and data. Previous estimates were derived from FiSAT II analysis, while this study used a more updated and robust method, the LBB [44].

Table 3. Comparative discussion of the present findings with other relevant research in the literature.

| Scientific Name | Region | Assessed Method | Assessed Result | Assessment Year | References |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Nemipterus japonicus | Pakistan | FiSAT II | Sustainable | 2009-2010 | $\begin{gathered} {[10]} \\ \text { Present study } \\ {[45]} \\ \hline \end{gathered}$ |
|  | Pakistan | LBB Method | Grossly Overfished | 2019 |  |
|  | Bangladesh | LBB Method | Healthy | 2016-2019 |  |
| Nemipterus randalli | Pakistan | FiSAT II | Sustainable | 2009-2010 | $\begin{gathered} {[12]} \\ \text { Present study } \\ {[45]} \end{gathered}$ |
|  | Pakistan | LBB Method | Overfished | 2019 |  |
|  | Bangladesh | LBB Method | Healthy | 2016-2019 |  |
| Parascolopsis aspinosa | Pakistan | LBB Method | Overfished | 2019 | Present study |
| Saurida tumbil | Pakistan | FiSAT II | Sustainable | 2009-2010 | [11] <br> Present study [45] |
|  | Pakistan | LBB Method | Healthy | 2019 |  |
|  | Bangladesh | LBB Method | Overfished | 2016-2019 |  |
| Lepturacanthus savala | Pakistan | FiSAT II | Sustainable | 2009-2010 | $\begin{gathered} {[13]} \\ \text { Present study } \\ {[45]} \end{gathered}$ |
|  | Pakistan | LBB Method | Grossly Overfished | 2019 |  |
|  | Bangladesh | LBB Method | Grossly Overfished | 2016-2019 |  |

Furthermore, sample size and temporal and spatial variation in sample collection significantly impact the size distribution of catch data and, therefore, the model outputs [1]. The sample size and the sampling area covered by this study are significantly broader than the previous studies, which are likely to result in disparities in the results. Figure 3 shows that, despite the fact that fishing efforts began to expand significantly in 2008, catches began to fall, which could be attributed to depleted stocks' biomass resulting from overfishing, providing strong support for the findings of the present study.

Time Series Catch and Effort Statistics (1991-2017)


Figure 3. Time series marine catch (tons) and effort (operational fishing boats) from 1991-2017 in Pakistan [46].

A comparison is drawn between the current findings of relevant stocks and the outputs of other recently developed research on length-frequency data analysis from the Bay of Bengal. The findings of $L$. savala are parallel with our study. However, comprehensive information is not available regarding the stock evaluation of $P$. aspinosa in the marine waters of Bangladesh. However, there is a discrepancy between current and regional research for the remaining three stocks (N. japonicus, N. randalli, and S. tumbil) (Table 3). These variations could be attributable to different sampling strategies, time periods, stock life cycles, and/or environmental and ecological variables [47].

The current state of each species should require the implementation of appropriate countermeasures, such as the use of larger sized mesh gears and a reduction in fishing intensity, to ensure the long term sustainability of fishing operations and the conservation
of fisheries. This will help avoid recruitment overfishing and minimize fishing pressure [1]. However, the abundance of juvenile fishes in the catch for every species was extremely high, except for P. aspinosa. The values of $L_{\text {mean }} / L_{o p t}$ indicate that very few larger fishes are present in those stocks included in this study. The high fertility rate of older and larger fishes is a key factor to avoid recruitment overfishing for a fishery [24]. From the evaluation of biomass status, it is obvious that the standing stock biomass of all stocks are below sustainable levels ( $B / B_{0}<0.4$ and $B / B_{M S Y}<1.0$ ) and on the verge of collapse due to overfishing and mass suspension of juveniles and older fish from the stocks. Thereby, the fishing mortality of these species should be reduced immediately to avoid further depletion of these stocks.

## 5. Conclusions

This study revealed that four out of the five stocks examined are overfished. Similarly, all species' estimated stock biomass are below sustainable limits. The structure of fisheries resources in the marine waters of Pakistan has been changed due to chronic overexploitation. Fishery managers should enforce species specific size limitations and specific mesh sizes for fishing nets, allowing all immature fish to escape and protecting adults from catches, particularly during the spawning season, to deliver better breeding benefits. However, enhancing the mesh size would be challenging to enforce [48]. Thus, we may propose that management measures, such as reducing fishing intensity, decreasing the number of fishing boats, and limiting fishing time, should be pursued for long term fisheries sustainability.

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