Doctoral Dissertation

博士論文

Vulnerability Assessment for Hilsa (*Tenualosa ilisha*) and its Data-limited Bycatch Stocks from Hilsa Gillnet Fishing of Bangladesh

(バングラデシュのヒルサ (*Tenualosa ilisha*)
資源とヒルサ刺網漁によるデータに乏しい混獲資源の脆弱性評価)

Presented to

Graduate School of Environment and Information Sciences
Yokohama National University
国立大学法人 横浜国立大学大学院
環境情報学府

By

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September 2021

2021 年 9 月

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Declaration

I hereby declare that the work presented in this dissertation titled "Vulnerability Assessment for Hilsa (*Tenualosa ilisha*) and its Data-limited Bycatch Stocks from Hilsa Gillnet Fishing of Bangladesh" for the Doctor of Philosophy is original and was carried out by me, Md. Hasan Faruque, under the active supervision of Dr. Hiroyuki Matsuda, Professor, Department of Natural Environment, Graduate School of Environment and Information Sciences, Yokohama National University, Japan. I have duly acknowledged others' works with references, and this work has not been submitted elsewhere for a degree.

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Acknowledgments

All praise and glory to Almighty ALLAH, who gave me full strength, courage, and patience to carry out this research. This doctoral thesis would not have been possible to complete without the kind support from many people and organizations.

First and foremost, I am deeply indebted to my respected supervisor, Dr. Hiroyuki Matsuda, Professor, Department of Natural Environment, Graduate School of Environment and Information Sciences, Yokohama National University (YNU), Japan, for accepting me as a doctoral student to pursue my studies and research in his laboratory. From the first day of my doctoral journal, his encouragement, scholastic guidance, insightful suggestions, and kind cooperation in every respect of my study and research helped me immensely to complete all challenging tasks. I am grateful that he allowed me to pursue my academic interests and integrate them in my way.

I would like to express my heartfelt gratitude to my honorable co-supervisors, Professor Dr. Fumito Koike and Dr. Akira Mori, Department of Natural Environment, Graduate School of Environment and Information Sciences, YNU, Japan, for their insightful comments on my research during the pre-defense session that helped me a lot to improve the quality of my research. I am also grateful to Professor Dr. Maiko Kagami and Dr. Shinji Shimode for serving as my doctoral research evaluation committee members.

I am grateful to the Japanese government for awarding me the most prestigious MEXT (Monbukagakusho) scholarship for my studies in Japan, and thankful to the Graduate School of Environment and Information Sciences, YNU, for sponsoring me through the Research Promotion Program (grant No 65A0515b) in carrying out my research survey in Bangladesh.

I would like to convey my heartfelt thanks to the University of Dhaka (DU) authorities for giving me study leave to pursue doctoral studies in Japan. I am highly grateful to all of my teachers and colleagues at the Department of Fisheries, DU, Bangladesh, for their motivation, valuable suggestions, and kind assistance during my research.

I am thankful to my respected teacher Dr. Muhammed Shafi (Honorary Professor), Dr. Dewan Ali Ahsan, Professor (former), Department of Fisheries, DU, and Dr. Md. Niamul Naser, Professor, Department of Zoology, DU, for their inspiration and motivations during my study. I am forever thankful to my beloved teacher and colleague, Dr. Anwar Hossain, for introducing me to my supervisor, Dr. Hiroyuki Matsuda, at the initial stage of my application to YNU. His encouragement, valuable suggestion, and motivation inspired me greatly to carry out my doctoral studies.

I would like to thank Dr. Rod Fujita and Dr. Kendra Karr of the Oceans Program at the Environmental Defense Fund, USA, for providing me the Excel version of the Productivity Susceptibility Analysis tool and associated guidance notes.

I am also grateful to all the local fishery authorities in our surveyed areas in Bangladesh for their support during the field survey. I am deeply indebted to all the Hilsa fishers for providing valuable information about the Hilsa fishery and its bycatch by taking part in face-to-face interviews and focus group discussions. I am also thankful to the editors of *Fisheries Research* and *Fishes* journals and anonymous reviewers for their insightful comments and suggestions that enhanced the quality of articles published from this research work.

I am greatly indebted to all the past and present members of Matsuken. In particular, Dr. Yusuke Yonekura, Mr. Haruki Natsukawa, Hiroki Namba, Yukie Shibata, Daiki Tanaka, Yuta Takemoto, Makoto Nishimoto who provided a community and support during this journey, including intelligent insights and sharing of skills. A very special thanks to Ms. Satoko Nakata for her kind cooperation and supports during my study in Japan.

I duly acknowledge all my friends and well-wishers who encouraged and supported me during my research. I am grateful to the Japanese people for their generosity and kind cooperation during my stay in Japan.

I owe my deepest gratitude to my beloved wife, Sharfunnesa, for her unconditional love, sacrifice, carrying, encouragement, patience, and support in every way that allowed me to study with ease.

Finally, I want to express my heartfelt appreciation to my mother and the rest of the family members for their unconditional trust, love, supports, endless patience, and prayers.

-Author

List of Abbreviations and Acronyms

AFM	Age at first maturity
AFMA	Australian Fisheries Management Authority
ASA	Alternative scoring approach
BAR	Barishal
BAU	Barguna
BHO	Bhola
BS	Breeding strategy
CHA	Chandpur
CHI	Chattogram
COX	Cox’s bazar
CR	Critically endangered
CSA	Conservative scoring approach
CT	Catch trend
DD	Data deficient
DoF	Department of Fisheries
DQ	Data quality
DQCP	Data quality categories for productivity attributes
DQCS	Data quality categories for susceptibility attributes
DQSP	Weighted average data quality scores for productivity attributes
DQSS	Weighted average data quality scores for susceptibility attributes
EN	Endangered
ERA	Ecological risk assessment
ERAEF	Ecological risk assessment for the effect of fishing
EXS	Exploitation status
FAO	Food and Agriculture Organization
FGD	Focus group discussion
H	High
ICCAT	The International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
IUCN	The International Union for Conservation of Nature
k	Von Bertalanffy growth coefficient
kg	Kilogram
L	Low

L_∞	Asymptotic maximum length
LC	Least concerned
L_{mat}	Length at maturity
L_{max}	Maximum size
M	Estimated natural mortality
M	Moderate
MF	Measured fecundity
MSC	Marine Stewardship Council
MTL	Mean trophic level
NE	Not evaluated
NMFS	National Marine Fisheries Service
NT	Near threatened
ODQC	Overall data quality categories for vulnerability
ODQS	Overall data quality scores
OF	Overfishing
P	Productivity attribute/score
PAT	Patuakhali
PSA	Productivity susceptibility analysis
RRA	Residual risk analysis
S	Susceptibility attribute/score
SFM	Size at first maturity
T	Temperature
t_{mat}	Age at maturity
t_{max}	Maximum age
UF	Underfishing
USD	US dollar
V	Vulnerability
VC	Vulnerability categories
VSER	Vulnerability scores excluded regulations
VU	Vulnerable
WCPFC	Western and Central Pacific Fisheries Commission

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General Abstract

The sustainable management of fisheries resources is a challenging issue for fisheries managers across the world. Fisheries manager requires the accurate stock status prior to set the harvest control rules or effective management measures to protect or conserve the stock and thus to ensure the long-term sustainable use of it. However, the actual stock status for the greater portions of global fish stocks is still unknown, and they remain unmanaged or managed with insufficient scientific guidance, leading to suboptimal catch rates and adverse social and economic consequences for those who depend on fishing. The stock status compared to different biological reference points (e.g., maximum sustainable yield) can be adequately made by conventional quantitative stock assessment method, particularly in data- and capacity-rich settings. However, the majority of small-scale fisheries, which account for half of the global fishery catches, are treated as data-limited fisheries. These data-limited fisheries lack the biological and catch data, resources, and expertise required to estimate stock status using conventional quantitative stock assessment techniques. Following the increased need to address fishing's impacts on the whole range of exploited stocks, including bycatch species, fishery scientists have sought to develop comprehensive methods to assess the potential risk of various fishing types (gillnet fishing, seine net fishing, longline fishing, etc.) in data- and capacity-constrained situations, where the fully quantitative assessment is not likely due to data scarcity. Productivity susceptibility analysis (PSA) is one such risk assessment tool that has been proven useful in fishery sciences. This semi-quantitative fisheries risk assessment tool assists the fisheries manager to evaluate the relative risk of both target and non-target fisheries stocks for a particular gear type in a data and capacity-constrained situation, thus prioritizing management and research among species. This tool typically compared the inherent recovery potential (i.e., productivity attributes) of species once depleted with their susceptibility to fishing activities in elucidating the overall species vulnerability.

We performed a PSA to evaluate the relative risk to bycatch stocks in gillnet fishing (gillnet shares > 95% of Hilsa catch in Bangladesh) along with target stock, Hilsa. The Hilsa (*Tenualosa ilisha*) is an iconic flagship species of Bangladesh, a south Asian country. Recent studies suggest that this geographical indication product of Bangladesh, owing to its high economic value and socio-cultural importance, is becoming increasingly threatened by excessive fishing pressure. Additionally, given the multi-species nature of Bangladeshi fisheries, it is nearly impossible to catch Hilsa selectively, with significant numbers of both riverine and marine species (Hilsa migrates both in sea and freshwater) being caught by Hilsa

fishing nets. Even though many other non-target (bycatch) species are caught using Hilsa gillnet fishing, no risk assessment has been carried out to identify the relative vulnerability of bycatch stocks of Hilsa gillnets, either by Bangladesh or any other Hilsa fishing nations (e.g., India, Myanmar, Iran, Pakistan, etc). This is mainly because of the lack of information on bycatch species.

In chapter 3 of this dissertation, we have focused on the identification of the bycatch of Hilsa gillnet fishing for the first time from Bangladesh water areas, which were then subjected to a detailed relative risk assessment with PSA. By using taxonomic keys and questionnaire interview with 300 local professional Hilsa fishers across Hilsa habitats, 130 species included Hilsa as the target species were identified where 52 marine bycatch and the target stock Hilsa, and 22 inland bycatch were subjected to PSA depending on data availability and magnitude of capture. We validated our vulnerability (V) results by comparing them with two other empirically derived assessment outcomes, the IUCN Red List and the exploitation rate (E). We also compared PSA scores with the catch trend of stocks from fishers' subjective recognition. Hilsa was found to be moderately vulnerable to gillnet fishing. The majority of the bycatch were found to be highly susceptible to fishing, with 17 bycatch species found to be in the high-risk category. Five species classified as high-risk group were known to be threatened species listed in the national IUCN Red List. Our finding revealed 82% accordance level between the exploitation rate and PSA-derived vulnerability scores. It implies that the E associated with overfishing corresponds to the V scores. Moreover, with few exceptions, we found that species with V score over 1.8 showed decreasing catch trend. Our result also revealed that around 55% of inland bycatch and 42% of marine bycatch is associated with overfishing ($V > 1.8$). Data quality analysis indicated that the majority of bycatch species received low data quality scores. It emphasizes the need for the improved data collection on species-specific life-history traits.

Despite different approaches used to assign the risk scores for missing information in PSA for the selected attributes of a given species, no formal comparison has been made between scoring approaches in terms of how well they can predict species vulnerability. In chapter 4, we have evaluated the PSA findings of 21 bycatch stocks of the Hilsa gillnet fishery of Bangladesh using two different scoring approaches. Two scoring approaches we used in our PSA analysis were designated as "conservative scoring approach (CSA; assign highest risk score for missing information)" and "alternative scoring approach (ASA; inclusion of experts opinion and/or usage of the empirical relationship equation to derive missing data if the value of correlated life-history parameters is known). We assumed that the higher consistency between the pairs of outcomes (*V* score and *E*; *V* score and catch trends) under two different scoring approaches for PSA would be a useful method in determining the reliable scoring approach for PSA that could be able to minimize the overestimation of species vulnerability. Our analysis revealed that the *V* scores increased by 0.0–0.20 with a mean value of 0.09 for 21 selected bycatches when CSA was applied. The inconsistency between the *V*-score-suggested fishing status ($V \leq 1.8$ = underfishing, $V > 1.8$ = overfishing) and the fishing status defined by exploitation rate ($E > 0.5$ = overfishing, $E < 0.5$ = underfishing) were 38.1% and 19.0% under CSA and ASA, respectively. As we presumed that species with decreasing catch trend are undergoing overfishing problem, a consistency between *V*-score-suggested fishing status and fishers' perceived catch trends was found to be higher when using ASA than when using CSA. Our analysis suggests that CSA could overestimate species vulnerability. Therefore, ASA is more reliable than CSA in PSA, which may increase the confidence of fisheries stakeholders in PSA.

The baseline information of our PSA-derived outcomes for the Hilsa gillnet fishery of Bangladesh assists the fisheries manager in setting management measures to protect the vulnerable stocks from being collapse unless more data are available for further assessment with a quantitative risk assessment approach. Furthermore, for the treatment of the missing information for the attribute, our findings could be useful guidance for fishery managers for selecting the reliable scoring approach in their PSA, which could minimize the false estimates in specie's vulnerability.

Chapter 1

General Introduction

1. General introduction

1.1 Background

Capture fisheries make a significant contribution toward food security and livelihood for millions of people across the world. Global food fish intake grew at an average yearly rate of 3.1 percent over the period 1961–2017 (FAO, 2020). In response to the increasing need for animal protein as a consequence of the growing global population, the fishing pressure on wild fisheries stocks or populations has increased several-fold. Excessive fishing pressure may result in overexploitation of fisheries stocks, which has emerged as a major threat declining stock abundance worldwide (Ding et al., 2017; Dulvy et al., 2003). More recently, stocks that had been overfished have begun rebuilding by controlling their fishing rates, while others continue to be overfished with similar frequency (Worm et al., 2009). Along with fishing activities, other co-occurring factors such as adverse climatic events, pollution, habitat degradation, and anthropogenic activities other than fishing have also accelerated stock depletion (FAO, 2020). The proportion of fisheries stocks being overexploited increased from 10% to 34.2% (Figure 1.1) between 1974 and 2017. However, Food and Agriculture Organization's (FAO) assessment on exploitation level does not reflect the actual status for whole fisheries stocks worldwide since their assessment covers only 25% of the global fisheries stock (FAO, 2020). Hence, the stock status for the more significant portion of the fisheries stocks still remains unknown (Jennings et al., 1999).

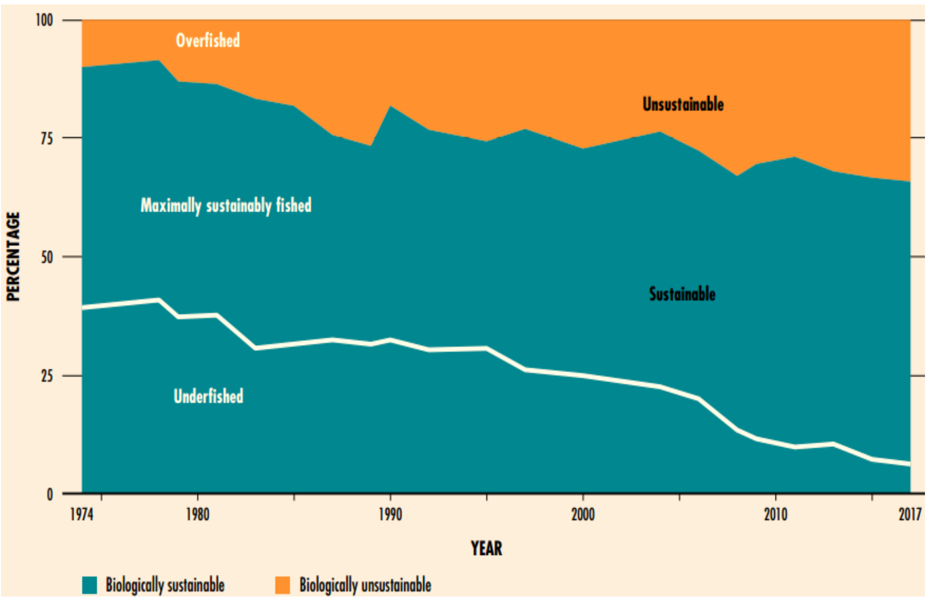

Figure 1.1 Global trends in the world's state of marine fish stocks between1974–2017 (FAO, 2020).

Fishing activity, by definition, has a direct effect on the abundance of targeted fish stocks or populations and may have a negative effect on the status of bycatch stocks (in this dissertation, the term bycatch is used to describe non-target species caught other than the target stock during fishing operations) (FAO, 2020). While bycatch's impact on the ecosystem is recognized as critical (Bellido et al., 2011), bycatch issues have been insufficiently assessed in single-species (target stock) oriented fisheries assessment and management over the past decades (Hobday et al., 2011). Consequently, the ecosystem approach to fisheries has emerged as a supplementary approach to single-species management for addressing the impact of fishing on the broader ranges of ecosystem units, including bycatch populations (Hobday et al., 2009; Link et al., 2002). Several nations globally mandate the adoption of an ecosystem approach to fisheries, and many organizations such as the FAO and the European Union (EU) have been promoting the policies supporting the ecosystem approach to fisheries (FAO, 2003; Jennings and Rice, 2011; Tromble, 2008). However, adopting the ecosystem approach to fisheries is challenging, especially for developing nations, where information on fisheries stocks' status is lacking (Pikitch et al., 2004). Numerous fisheries do not have statistics (e.g., catch, effort) on bycatch. The information accessible even for fisheries' target species varies significantly depending on their economic significance and regulatory status (Dowling et al., 2008; Shester and Micheli, 2011). Consequently, even simple proxies for stock abundance based on catch and effort statistics are unlike in most instances. Following the increased need to address the fishing impacts on the whole range of exploited stocks in data and capacity-limited settings, in order to support the ecosystem approach to fisheries, a good number of risk-based approaches have already been developed. One such method is the productivity susceptibility analysis (PSA), which has been used globally to assess the relative risk fisheries stocks confronted by fishing activities face (Hobday et al., 2011; Patrick et al., 2010; Stobutzki et al., 2001). This research intended to assess the vulnerability of Hilsa (*Tenualosa ilisha*) and its bycatch stocks for the first time from Hilsa gillnet fishing of Bangladesh using PSA to contribute toward the objectives of the ecosystem approach to Hilsa fisheries in Bangladesh.

1.2 Vulnerability assessment for fisheries stocks

It is now broadly acknowledged that fishing operations have long-term implications for fisheries stocks or populations, their habitats, and ecosystems that extend beyond the primary effects on targeted species (Althaus et al., 2009; Freese et al., 1999; Hall and Mainprize 2004). Addressing the overall impact of fisheries on the ecosystem as a whole, focusing on both the target and the non-target (bycatch) species, is a daunting task for fishery managers. This is even more challenging for nations located in the tropics, where multispecies and multi-gear fisheries exist, which regularly capture hundreds of bycatch species and their target stocks (FAO, 1999). The data (e.g., time series catch statistics, effort, different life-history parameters, etc.) required for the quantitative assessment is lacking for most of these captured species. Consequently, several risk-based methods, including ecological risk assessments (ERA), have been considered for data-constrained and multi-species situations. The amount of quantitative information needed by ERA methods is one way to differentiate one method from another. A qualitative risk assessment method is required, in particular for fisheries with inadequate data and limited understanding of ecological interactions (e.g., Astles et al., 2006; Fletcher, 2005). A semi-quantitative or fully quantitative risk evaluation method can be utilized where additional data is accessible (e.g., Stobutzki et al., 2001, 2002; Zhou and Griffiths, 2008).

A single-level analysis is the most common practice in the existing ERA methods (Scandol et al., 2009). Given the above situation, Hobday et al. (2011) proposed a single framework, the Ecological Risk Assessment for the Effects of Fishing (ERAEF), which includes a hierarchy of tools or methods (Figure 1.2). Based on the amount of information available on fisheries stocks or populations, this hierarchical methodology is employed to explore how fishing impacts fisheries stocks by starting with a largely qualitative analysis of risk, which could involve stakeholders' opinions (level 1). Species categorized as medium to high risk in the level 1 analysis are then evaluated with the semi-quantitative approach (Level 2; e.g., PSA). Finally, species determined to be medium or high risk in the level 2 assessment are then further assessed with a quantitative risk assessment tool in level 3 (e.g., conventional stock assessment technique).

A semi-quantitative risk assessment approach situated in Hobday's hierarchy framework is known as productivity susceptibility analysis (PSA). Hobday et al. (2011) argued that risk to fishing for five ecological units (e.g., target stock, bycatch species, threatened, endangered, and protected species, habitat, and ecological communities) could be evaluated independently by PSA based on the hypothesis that the vulnerability of the ecological units largely depends on the two measurable characteristics and score ranking, productivity (P) and susceptibility (S).

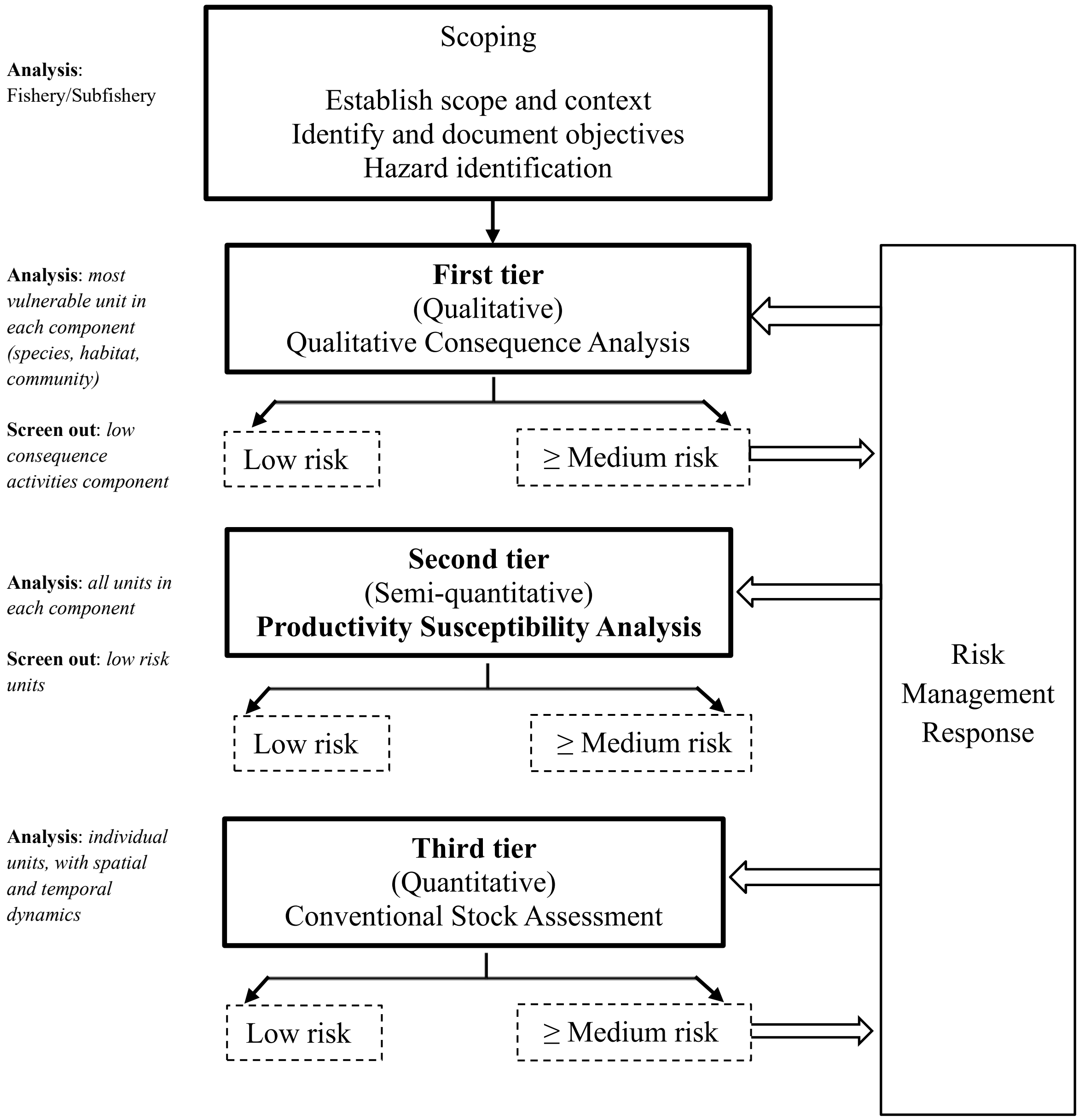

Figure 1.2 An overview of the Ecological Risk Assessment for the Effect of Fishing (ERAEF) (adopted from Hobday et al., 2011) showing the focus of analysis for each level in the hierarchy at the left in italics. Before moving to the next level in the hierarchy, each level's risk management response requires to be considered.

Productivity is the intrinsic potential (i.e., life-history traits) of the species or stocks to sustain or recover once depleted by fishing activities, and susceptibility refers to the likely impact of the fishing type on the species or stocks. A set of predefined productivity (e.g., maximum size, size at maturity, and so on) and susceptibility (e.g., the vertical overlap of species with fishing gear; market demand and value of the fish, and so on) attributes are commonly employed for scoring on a three-point scale to determine the overall vulnerability (briefly described in Chapter 3). Species are considered to be most vulnerable when they receive a low *P* and a high *S* score, whereas species or stocks with a high *P* score and low *S* score are characterized as the least vulnerable stocks (Figure 1.3). PSA has already been applied for multispecies complexes, including both the target and non-target (i.e., bycatch) species worldwide (Patrick et al., 2009). Over thousands of stocks have been successfully evaluated by this assessment tool, primarily in data-limited situations (briefly described in Chapter 2).

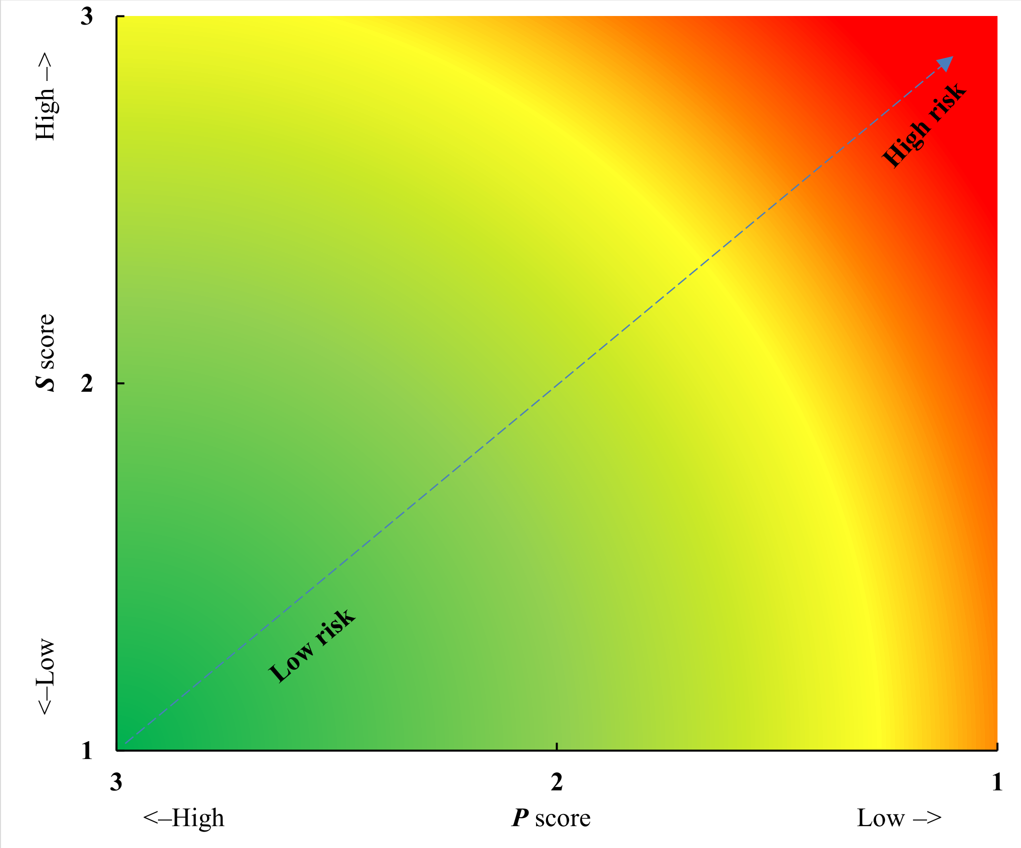

Figure 1.3 A two-dimensional PSA plot depicts the relative risk estimated by the product of productivity and susceptibility score. The Euclidean distance from the point of origin quantifies the species' vulnerability. Productivity scores (*P*) are plotted on a high to low scale (3–1 on x-axis), whereas susceptibility scores (*S*) are plotted on a low to high scale (1–3 on y-axis).

1.3 Hilsa fishery: Its importance in Bangladesh

Hilsa (*Tenualosa ilisha*), commonly known as Hilsa shad or Indian shad or Tropical Hilsa shad, is a herring-like fish belonging to the family Clupeidae. This species has been reported from seventeen different countries and islands of the world (Table 1.1), although the occurrence of Hilsa in China and Viet Nam is questionable (Froese and Pauly, 2021). Hilsa has a wide range of distribution but is abundant largely in the Bay of Bengal, a part of the north Indian ocean (Hossain et al., 2019). The global average production of Hilsa from both inland and marine habitat is approximately 0.72 million tonnes, with an estimated value of two billion US dollars; over six million South Asian people's food security and livelihoods are directly or indirectly related to Hilsa fishery (Hossain et al., 2019; Rahman et al., 2010; Sahoo et al., 2018).

Table 1.1 A list of countries or islands that reported Hilsa from their water areas (Source: Froese and Pauly, 2021).

Continent	Country	Occurrence	Inhabiting ecosystem
Asia	Bahrain	Native	Seawater, Brackishwater, Freshwater
Asia	Bangladesh	Native	Seawater, Brackishwater, Freshwater
Asia	China	Questionable	Seawater
Asia	India	Native	Seawater, Brackishwater, Freshwater
Asia	Iran	Native	Seawater, Brackishwater, Freshwater
Asia	Iraq	Native	Seawater, Brackishwater, Freshwater
Asia	Kuwait	Native	Seawater, Brackishwater, Freshwater
Africa	Madagascar	Native	Seawater
Asia	Malaysia	Native	Seawater
Asia	Myanmar	Native	Seawater, Brackishwater, Freshwater
Asia	Oman	Native	Seawater
Asia	Pakistan	Native	Seawater, Brackishwater, Freshwater
Asia	Qatar	Native	Seawater, Brackishwater, Freshwater
Asia	Saudi Arabia	Native	Seawater, Brackishwater, Freshwater
Asia	Sri Lanka	Native	Seawater, Brackishwater, Freshwater
Asia	United Arab Emirates	Native	Seawater, Brackishwater, Freshwater
Asia	Viet Nam	Questionable	Seawater

This transboundary anadromous fish mostly migrate from the seawater to the freshwater for breeding purposes (Ahsan et al., 2014). Additionally, they also undertake feeding migration between sea and freshwater habitats (Hasan et al., 2016). Most of the Hilsa producing nations have reported Hilsa from their inland and marine habitats. Some countries have reported them from marine habitats only, but none have reported them from brackish or freshwater habitats only (Froese and Pauly, 2021). Among Hilsa producing countries, over 95% of the share in global Hilsa catch comes from the top three countries, Bangladesh, India, and Myanmar. According to FAO (2021) global capture fisheries statistics, Bangladesh ranked 1st in terms of the total production of Hilsa globally. There has been an increasing trend of Hilsa production in Bangladesh over the past twenty-five years (Figure 1.4). However, Hilsa production in most other Hilsa fishing countries is declining (FAO, 2021).

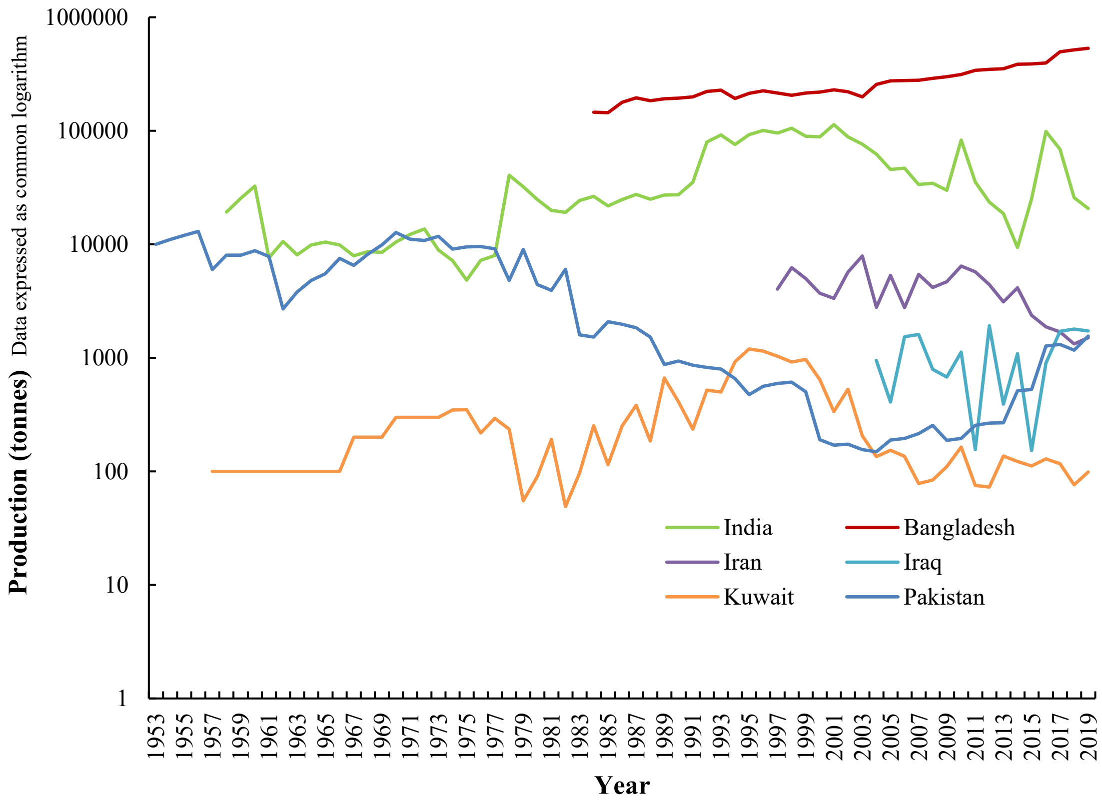

Figure 1.4 An overview of global Hilsa production (Data source: FAO, 2021).

Hilsa is commonly found all year-round in Bangladeshi water areas (Ahsan et al., 2014). However, the abundance of Hilsa in the inland areas (mostly in the riverine habitat) becomes higher during their breeding season. In Bangladesh, from 1984 to 2019, the landed weight of Hilsa ranged 144.4 to 532.8 thousand tonnes, with a yearly average of 271.1 thousand tonnes (FAO, 2021). The average contribution of Hilsa production in the country's total fish production over the same period was 15.3%. Once, Hilsa was abundantly found in the upstream part of the country's riverine ecosystem; recent statistics show that Hilsa has become relatively abundant in the downstream part of the rivers and wider areas of the Bay of Bengal (BoBLME, 2012). In the last fiscal year (2018–2019), the landed volume from marine and inland habitats accounted for 290.3 and 242.5 thousand tonnes, respectively (Figure 1.5). Hilsa contributed 41.6% to marine and 14.6% to inland capture fisheries on average between 1984–2019. As a single species fishery, Hilsa contributes over 1% to Bangladesh's GDP (DoF, 2019).

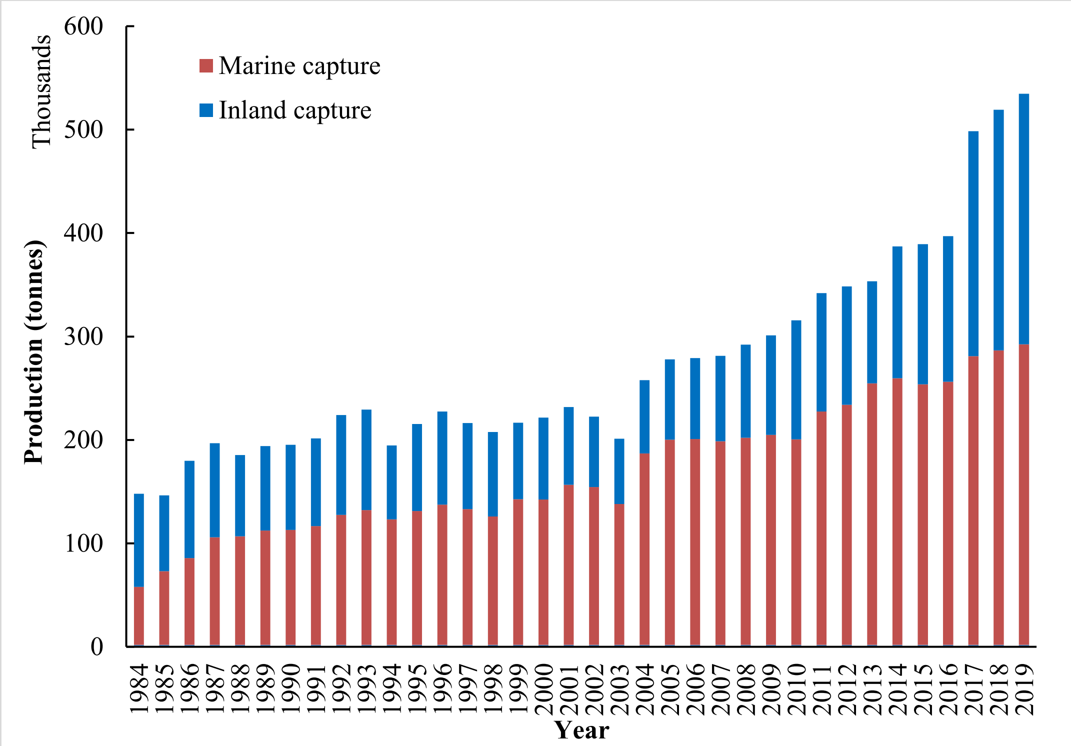

Figure 1.5 The production of Hilsa (*Tenualosa ilisha*) fishery from the inland and marine habitats of Bangladesh during the period 1984 to 2019 (Data source: FAO, 2021).

Hilsa fishing activity in Bangladesh takes place in both marine and riverine environments throughout the year (BOBP-IGO, 2008). However, the bulk (60–70%) of Hilsa is harvested in rivers and nearshore areas of the Bay of Bengal during their upward migration for breeding (Rahman et al., 2012). Hilsa fisher, whose livelihood solely depends on the Hilsa fishery of Bangladesh, are used to catching Hilsa with different kinds of fishing gears. The fisher's preference for various types of fishing nets to catch Hilsa relies on several factors, such as the seasonality of the fishing operation, water current and velocity, size of the Hilsa in their nearby water areas, and their economic capability (Hossain et al., 2019). Some fishing nets preferred by fishers in Bangladesh and the west part of India are gillnets, purse seine net, and beach seine net (Figure 1.6). These nets are mainly operated from non-mechanized and mechanized wooden boats. Gillnets with varying mesh sizes often capture the adult Hilsa as well as the juvenile Hilsa, and senine nets are commonly used to capture the juvenile Hilsa. Gillnets in Bangladesh account for the vast majority (almost 95 percent) of Hilsa supply (DoF, 2019). Consequently, the Hilsa gillnet fishery is regarded as the most valuable open water fishery in Bangladesh, directly supporting over half a million Hilsa fishers and over 2.5 million people indirectly via their involvement in the Hilsa value chain and distribution (DoF, 2019; Hossain et al., 2019).

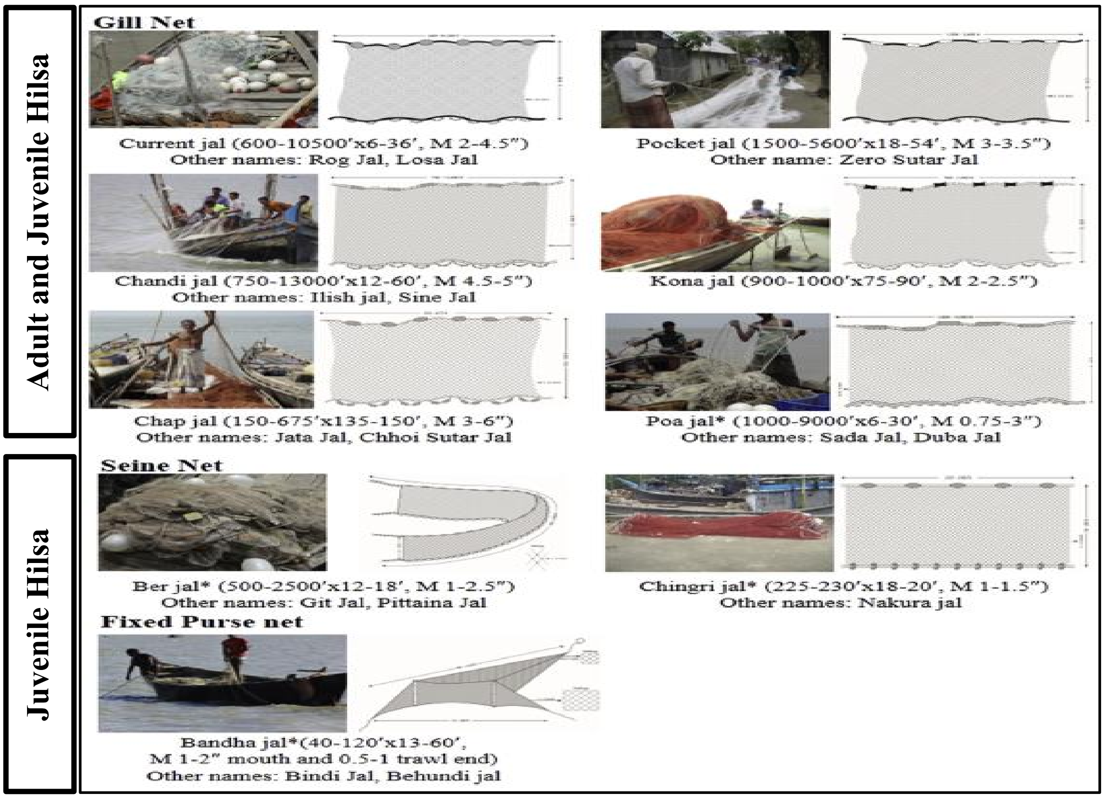

Figure 1.6 Fishing gears (with local names) commonly used in Bangladesh and India to catch Hilsa from its riverine and marine habitat with artisanal fishing boats. Gillnets of different kinds are used to catch both juvenile and adult Hilsa, while seine net and purse nets are used to catch juvenile Hilsa. (adopted from Hosssain et al., 2019).

1.4 Rationale of this study

The degree to which landed catch represents stock abundance is a continuing dispute in fisheries science (Pauly et al., 2013), although landed catch of fish is occasionally considered a proxy for their abundance (Puga et al., 2018). Typically, catch reasonably reflects abundance if management interventions do not substantially alter fishing effort or if the distribution and behavior of fish do not significantly change due to environmental variables. Even though the catch size of Hilsa in Bangladesh is rising, recent studies show that Hilsa is increasingly threatened by excessive fishing pressure (Mozumder et al., 2019) that leads toward overexploitation. Since the sudden decline in Hilsa catch in 2003 (Figure 1.5), the Bangladesh government has imposed some regulations (e.g., mesh size restrictions, seasonal and temporal banning of Hilsa catch, and so on) to reduce the overall fishing pressure, and to thus protect Hilsa from overfishing. However, even after these regulations, the catch per unit effort (CPUE), a good proxy of stock abundance, of Hilsa in Bangladesh has declined over the past few years (Figure 1.7, left panel). Moreover, the outcomes of the several quantitative stock assessments, including the recent estimates, suggested that Hilsa is subjected to an overfishing problem as the exploitation rate is higher than the critical value of 0.5 (an indicator of overexploitation) (Figure 1.7, right panel).

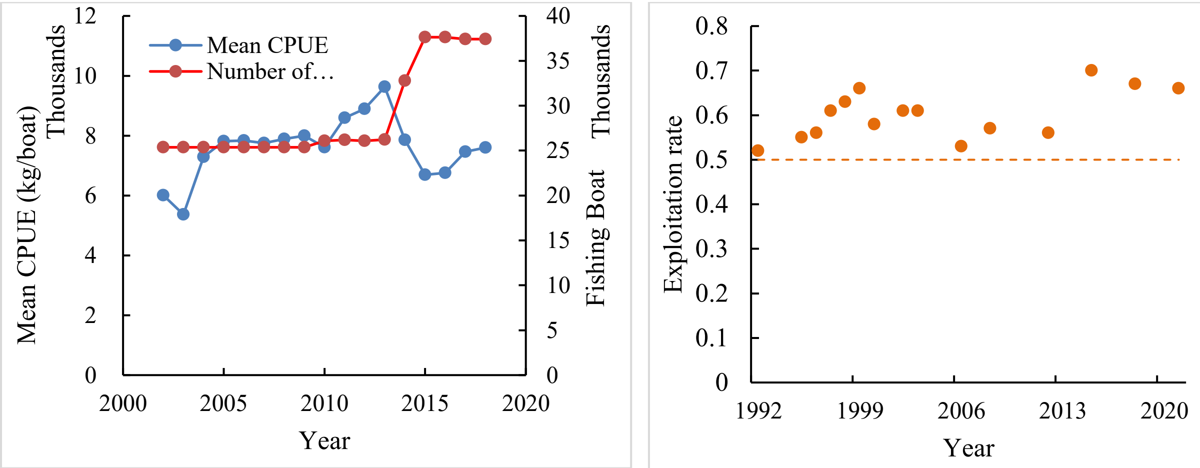

Figure 1.7 Yearly mean catch per unit effort (left panel; Data source: DoF, 2018) and exploitation rate (right panel; Data source: Ahmed et al., 2008; Alam et al., 2021; Amin et al., 2008; Halder and Amin, 2005; Miah et al., 2015; Milton, 2010; Rahman and Cowx, 2008; Rahman et al., 2012; Rahman et al., 2018; Rahman et al., 2020) of Hilsa in Bangladesh water areas.

In Bangladesh, Hilsa is predominantly captured by gillnets, and these gillnets are less selective in nature. Consequently, Hilsa gillnets often capture a large number of other species (bycatch), and the majority of which are landed by the fishers. Thus, overfishing of Hilsa may not only have an adverse effect on its abundance, it may also put the bycatch species at risk. However, all current fisheries regulations of Bangladesh are primarily focused on protecting Hilsa populations, with other species receiving less protection (Islam et al., 2017). In recent years, the Bangladesh government has started some initiatives to implement the ecosystem approach to Hilsa fisheries by promoting community participation in Hilsa resource management, enforcing gear restrictions, restoring fishing habitats, among other measures (Rahman et al., 2020). One of the key steps to implement the ecosystem approach to fisheries is to better understand the magnitude of fishing impact on the target stocks and other ecosystem components. In the case of Bangladesh, no former risk-based assessment was carried addressing the impact of Hilsa gillnet fishing on the bycatch stocks. This is because of the lack of information (e.g., biological parameters of bycatch, catch, efforts, and so on) on a large number of bycatch species.

The International Union for Conservation of Nature and Natural Resources (IUCN, 2015) has assessed the vulnerability of 253 fishes from Bangladesh waters, including some species captured by the Hilsa gillnets. The IUCN's assessment does not consider the susceptibility of the fisheries stocks due to fishing activities; instead, they used other indicators (e.g., declining population from past or future projections, population size, extreme population fluctuations) while evaluating the species' vulnerability. In that situation, a comprehensive risk assessment would be useful, which considers both the life history parameters and their susceptibility to fishing for evaluating the species' vulnerability in the data-limited situation. In this regard, the productivity susceptibility analysis approach (a risk assessment tool that considered both the potential of species to recover from depleted state and the susceptibility of fishing) was used to assess the risk of the Hilsa and its bycatch stocks impacted by Hilsa gillnet fishing. The baseline information of our current study could assist the fishery managers in formulating a better management plan for the sustainability of Hilsa and the bycatch stocks.

1.5 Objectives of this Study

1.5.1 Overall objective

This study was designed to assess the impact that Hilsa (*Tenualosa ilisha*) gillnet fishing has on the target stock, Hilsa, and its data-limited bycatch stocks. Therefore, this study assessed the relative vulnerability of Hilsa and its bycatch stocks due to Hilsa gillnet fishing for the first time from Bangladesh water areas using the productivity susceptibility analysis (Chapter 3). The comparison of the PSA outcomes from two different scoring approaches (conservative and alternative scoring approach) was also made to reveal the more reliable and recommendable scoring approach for PSA, which could minimize the false estimate of species vulnerability in future studies (Chapter 4).

1.5.2 Specific objective

To meet the overall objective of this current study, the specific objectives were defined as-

i. to identify the Hilsa gillnet-specific bycatch up to their species level from Bangladesh water areas.
ii. to assess the relative risk for the identified bycatch species impacted by Hilsa gillnet fishing with target stock, Hilsa, using PSA.
iii. to compare the vulnerability scores with other analytical assessments in two different scoring approaches to find out the more reliable scoring approach for PSA.

1.6 Outline of this thesis

Thesis outline

Chapter No	Chapter Name	Key features in each chapter
1	**General Introduction**	Background of the study, importance of risk assessment with productivity susceptibility analysis, and the research objectives are described in this chapter
2	**Literature Review**	Pertinent literature regarding the application of Productivity Susceptibility Analysis (PSA), selection of attributes, adjustment and modification in PSA tools are reviewed
3	**Vulnerability Assessment for Hilsa Gillnet Fishery**	A procedure on Hilsa-gillnet specific bycatch species identification and their relative vulnerability with PSA are described in detail. Finally, a comprehensive list of bycatch species from Hilsa-gillnet fishing of Bangladesh and their relative vulnerability along with target stock, Hilsa are reported for the first time in Bangladesh
4	**Conservative Scoring Approach in Productivity Susceptibility Analysis Leads to an Overestimation of Vulnerability**	Different scoring approaches of PSA are discussed, and the findings of the PSA for some selected bycatch of Hilsa gillnet fishing in two different scoring approach (conservative and alternative scoring approach) are compared, and finally a recommendation are made on the selection of reliable scoring approach for the treatment of missing information in PSA that could minimize the false estimates in species vulnerability for future studies
5	**Current Study's Limitations, Future Research Needs, and Conclusion**	Limitations of the current study, the potential study ares, summery of the results and conclusion are made in this chapter
	Appendix	Supporting information for the various chapters are included in this section

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Chapter 2

Literature Review

2. Literature review

2.1 Background

The population size of a large number of fish species in freshwater and marine environments has significantly decreased or they have become entirely commercially extinct (Dulvy et al., 2003; Reynolds et al., 2005). Among the many other factors that may lead to a decline in fisheries stocks, fishing is widely believed to be the primary cause since the majority of the world's marine fisheries are either fully exploited or overexploited (Jennings et al., 1998; Reynolds et al., 2001). Fishing influences fish populations in a direct manner through the killing of targeted species and indirectly through a substantial impact on non-target species, habitat degradation, changes in ecosystem functionality, and so on (Archambault et al., 2015; Pikitch et al., 2004;). In response to the growing concern over the impact of many extrinsic drivers, including fishing activities on target stocks as well as the other components of the ecosystem, continuous development of vulnerability-based assessment may enhance our ability to assess the stock status, thus supporting the decision making for fisheries management and conservation.

Vulnerability depends on how well populations can respond to the presence of potentially threatening drivers (Reynolds et al., 2005; Tingley et al., 2013). The intrinsic characteristic of fish (life-history traits) is often considered the most important indicator that determines the species vulnerability. For instance, species with low intrinsic rates of population increase often have high vulnerability (Abesamis et al., 2014). Since the intrinsic rate of population increase is difficult to estimate for many species, scientists usually employ an array of other quantitative life-history parameters as proxy measures of vulnerability (Abesamis et al., 2014). For example, species with a longer lifespan, greater maximum body size, slower growth rate, lower natural mortality, and delayed maturity are considered more vulnerable (Jennings et al., 1998; Reynolds et al., 2001). Similarly, some ecological traits and behavior of fishes and other factors, such as restricted geographical distribution, schooling or aggregation behavior at a particular location and time, higher interactions with fishing nets, higher market demand, among others, make the species relatively more vulnerable to exploitation (Cheung et al., 2005, 2007; Jennings et al., 1999; Patrick et al., 2009).

Stock evaluations through quantitative analyses may assist decision-makers in developing strategies for achieving management goals for fisheries. However, often, data, financial capability, and knowledge to thoroughly analyze multispecies assemblages occupying vast regions, especially in the tropics, are lacking (Dulvy et al., 2003; Fujita et al., 2014). Prioritizing species for further study and management in multispecies fisheries based on the use of common vulnerability assessments that estimate the risk of extinction (e.g., the IUCN Red List) may not be recommended (Pontón-Cevallos et al., 2020). IUCN's assessment used limited life-history information, and they do not consider the susceptibility of stocks to fishing (Hobday et al., 2011; Mace et al., 2008). Moreover, standard biological reference points used in stock assessment usually conflict with the extinction risk thresholds (Sadovy de Mitcheson et al., 2013). Other methods proposed by the American Fisheries Society (AFS) to calculate the resilience of the stocks are mostly limited to the US stocks (Froese et al., 2000). The AFS's method can be equivocal for data-poor fisheries, which leads to an underestimation of extinction risk. These risk assessment methods are related to species extinction but not exploitation. (Sadovy de Mitcheson et al., 2013). A risk-based assessment method that considers both the biological traits of the stocks and the susceptibility of stocks to exploitation due to fishing is known as productivity susceptibility analysis (PSA) (Hobday et al., 2007; Patrick et al., 2009).

2.2 Productivity Susceptibility Analysis (PSA): Application cases

Productivity susceptibility analysis (PSA) is one of the most commonly used fisheries risk assessment tools worldwide. PSA is more practical than any other existing risk assessment tool for fisheries impacts assessment in data and capacity-constrained settings (Fujita et al., 2014). This tool can assist the fisheries manager in assessing the relative risk of the wide range of fisheries stocks from an ecosystem impacted by fishing activities. This tool is typically considered a set of measurable life-history traits related to the productivity or biological sensitivity of the stocks and the set of factors associated with the susceptibility of the stocks due to fishing (Stobutzki et al., 2001). Although this tool was developed for risk assessment for the bycatch stocks, the inclusion of target species to PSA is essentially important for better understanding the relative vulnerability of the bycatch species with respect to the vulnerability of target species (Ormseth and Spencer, 2011). The impact of different fisheries (e.g., purse seine net, gillnets, longliners, and so on) on the target and bycatch species from different water areas has already been evaluated by PSA, which includes a substantial number of finishes, sharks, rays, and skates. Moreover, a good number of mammalian species, sea snakes, turtles, and other species (e.g., crabs, squid, octopus) have also been assessed by PSA to know their relative vulnerability due to particular fishing types (Table 2.1).

Table 2.1 Representative examples of PSA's application over the wide range of fisheries stocks.

Number of stocks or populations								
Marine Mammals	**Sharks**	**Sea Birds**	**Skates and Rays**	**Sea Turtles**	**Teleosts**	**Others (e.g., Crab, Squid, Octopus, etc.)**	**Primary PSA reference**	**Application reference**
20	50+	21	14	7	150+		Kirby et al., 2006	Kirby et al., 2006
	11		1				Hobday et al., 2007	Simpfendorfer et al., 2008
	8		1	3	17		Kirby et al., 2006	Murua et al., 2009
	11						Hobday et al., 2007; Walker et al., 2004	Cortés et al., 2010
	55		13		98		Patrick et al., 2009	Patrick et al., 2010
	26		2	4	34		Kirby et al., 2006	Arrizabalaga et al., 2011
		41					Hobday et al., 2007	Tuck et al., 2011
					7		Hobday et al., 2007; Patrick et al., 2009	Roux et al., 2011
	5		17		63		Patrick et al., 2009	Ormseth and Spencer, 2011
					90		Patrick et al., 2009	Cope et al., 2011
		70					Waugh et al., 2012	Waugh et al., 2012
		14					Hobday et al., 2007	Jiménez et al., 2012
	11		18		49		Hobday et al., 2007	McCully et al., 2013
14							Hobday et al., 2007	Brown et al., 2013
3	5	1	11		46		Hobday et al., 2007	Micheli et al., 2014
				7			Hobday et al., 2007; Patrick et al., 2009	Angel et al., 2014
					21		Patrick et al., 2009	Fujita et al., 2014
	6		15				Patrick et al., 2009	McCully Phillips et al., 2015
					151		Patrick et al., 2009	Osio et al., 2015
					102		Hobday et al., 2007	Okemwa et al., 2016
	2				21		Patrick et al., 2009	Swasey et al., 2016
					60		Patrick et al., 2009	Lucena-Frédou et al., 2017
	29						Patrick et al., 2009	Furlong-Estrada et al., 2017
	5		20				Patrick et al., 2009	Clarke et al., 2018
	17		9		14		Hobday et al., 2007	Moura et al., 2018
					34		Patrick et al., 2009	Puga et al., 2018
3	8				16		Patrick et al., 2009	Duffy et al., 2019
	14		14		4		Patrick et al., 2009	Temple et al., 2019
					6		Hobday et al., 2007	Roux et al., 2019
	13		2				Hobday et al., 2007; Walker et al., 2004	Mejía-Falla et al., 2019
	5		7		42	13	Hobday et al., 2007; Patrick et al., 2009	Altuna-Etxabe et al., 2020
	3						Patrick et al., 2009	Carreón-Zapiain et al., 2020
	13						Patrick et al., 2009	Martínez-Candelas et al., 2020
					6		Patrick et al., 2009	Noegroho et al., 2021

2.3 Selection of productivity and susceptibility attributes for PSA

The birth, growth, and mortality rates of stocks are all factors that influence the productivity of stocks (http://www.fao.org/fi/glossary/). A highly productive stock is distinguished by high rates of birth, growth, and death. A highly productive stock can often withstand greater rates of exploitation and, if depleted, may recover more quickly than stocks relatively less productive in comparison (Kirby et al., 2006). Therefore, different life-history parameters of fish are considered as proxies of productivity in PSA. The selection of productivity attributes largely depends on its potentiality in defining species' productivity and the availability of data for that given attribute for selected species. A list of productivity attributes employed in PSA by different authors in vulnerability assessment has been provided in Table 2.2.

The number of productivity attributes considered for PSA can vary between authors. The most commonly used life-history parameters of species as the proxy of productivity are: maximum size (e.g., Altuna-Etxabe et al., 2020, Hobday et al., 2007; Patrick et al., 2010), maximum age (e.g., Carreón-Zapiain et al., 2020; Duffy et al., 2019; Furlong-Estrada et al., 2017), age at first maturity (e.g. McCully Phillips et al., 2015; Noegroho et al., 2021; Osio et al., 2015), length at first maturity (e.g., Martínez-Candelas et al., 2020; Temple et al., 2019; Zhou et al., 2016), von Bertalanffy growth coefficient (e.g., Mejía-Falla et al., 2019; Noegroho et al., 2021; Patrick et al., 2010), intrinsic rate of population increase (e.g., Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017), natural mortality (e.g., Osio et al., 2015; Patrick et al., 2010; Stobutzki et al., 2001), mean trophic level (e.g., Osio et al., 2015; Patrick et al., 2010; Zhou et al., 2016), measured fecundity (e.g., Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020), breeding cycle of the female (e.g., Carreón-Zapiain et al., 2020; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020), and breeding strategy (Patrick et al., 2010; Stobutzki et al., 2001; Temple et al., 2019). The use of other relevant productivity attributes in PSA such as the recruitment pattern and age (McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010; Roux et al., 2019), maturity size ratio (McCully Phillips et al., 2015; Mejía-Falla et al., 2019), maturity age ratio (Mejía-Falla et al., 2019), genetic distinctness (McCully Phillips et al., 2015), hermaphroditism (Stobutzki et al., 2001), breeding probability (Stobutzki et al., 2001) are also found.

Table 2.2 Productivity attributes used by different authors in their productivity susceptibility analysis.

Productivity attributes	Application references
Maximum size	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Roux et al., 2019; Stobutzki et al., 2001; Temple et al., 2019; Zhou et al., 2016
Measured fecundity	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Temple et al., 2019; Zhou et al., 2016
Mean trophic level	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Zhou et al., 2016
Age at first maturity/average age at first maturity	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Hobday et al., 2007; McCully Phillips et al., 2015; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Zhou et al., 2016
Maximum age	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; Mejía-Falla et al., 2019; Noegroho et al., 2021; Patrick et al., 2010; Roux et al., 2019; Zhou et al. 2016
Reproductive strategy	Altuna-Etxabe et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Hobday et al., 2007; McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010; Stobutzki et al., 2001; Temple et al., 2019; Zhou et al., 2016
von Bertalanffy growth coefficient	Carreón-Zapiain et al., 2020; Duffy et al., 2019; Furlong-Estrada et al., 2017; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010
Intrinsic growth	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Lucena-Frédou et al., 2017; McCully Phillips et al., 2015; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010
Natural mortality	Carreón-Zapiain et al., 2020; Duffy et al., 2019; Furlong-Estrada et al., 2017; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Stobutzki et al., 2001
Size at first maturity/ average length at first maturity	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Furlong-Estrada et al., 2017; Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; Temple et al., 2019; Zhou et al., 2016
Breeding cycle (female)	Carreón-Zapiain et al., 2020; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019
Recruitment pattern	McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010
Maturity size ratio	McCully Phillips et al., 2015; Mejía-Falla et al., 2019
Genetic distinctness	McCully Phillips et al., 2015
Hermaphroditism	Stobutzki et al., 2001
Maturity age ratio	Mejía-Falla et al., 2019
Probability of breeding	Stobutzki et al., 2001
Recruitment age	Roux et al., 2019
Removal rate	Stobutzki et al., 2001

Conversely, susceptibility is defined as the degree to which a species interacts with and is affected by a fishery. Susceptibility should take into account the consequences of fisheries encounters, particularly those that result in direct or indirect fishing mortality; however, it may also take into account the concept of catchability, which refers to the behavior and distribution of a species in relation to the distribution and other technical characteristics of a fishing operation (Kirby et al., 2006). Some susceptibility attributes are found to be extensively used (e.g., vertical overlap of species with fishing gear, survival probability after capture and release, selectivity of the gear, and so on) in PSA and some are used to a lesser extent (e.g., size of fishing fleets, target of the fishery, among others) (Table 2.3).

Table 2.3 Susceptibility attributes used by different authors in their productivity susceptibility analysis.

Susceptibility attributes	Application references
Vertical overlap	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Roux et al., 2019; Stobutzki et al., 2001; Zhou et al., 2016
Areal overlap	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; Lucena-Frédou et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Roux et al., 2019; Zhou et al., 2016
Morphological characteristics affecting capture/Selectivity	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Furlong-Estrada et al., 2017; Hobday et al., 2007; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Roux et al., 2019; Temple et al., 2019; Zhou et al., 2016
Survival after capture and release	Altuna-Etxabe et al., 2020; Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Hobday et al., 2007; McCully Phillips et al., 2015; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Stobutzki et al., 2001; Zhou et al., 2016
Desirability or value of the fishery	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010; Temple et al., 2019
Geographic concentration	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Furlong-Estrada et al., 2017; Hobday et al., 2007; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010; Stobutzki et al., 2001; Temple et al., 2019
Management strategy	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Lucena-Frédou et al., 2017; Mejía-Falla et al., 2019; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010
Schooling, aggregation, and other behavioral responses	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010
Seasonal migrations	Carreón-Zapiain et al., 2020; Clarke et al., 2018; Duffy et al., 2019; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020; McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010
Fishing rate relative to natural mortality	Lucena-Frédou et al., 2017; Noegroho et al., 2021; Osio et al., 2015; Patrick et al., 2010
Impact of fisheries on essential fish habitat	Furlong-Estrada et al., 2017; McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010
Biomass of spawners or other proxies	McCully Phillips et al., 2015; Noegroho et al., 2021; Patrick et al., 2010
Seasonality of fishery	Carreón-Zapiain et al., 2020; Furlong-Estrada et al., 2017; Martínez-Candelas et al., 2020
Catch relative to productivity	Temple et al., 2019
Day/night catchability	Stobutzki et al., 2001
Diet	Stobutzki et al., 2001
Female mortality	Temple et al., 2019
Management regulations	Temple et al., 2019
Monitoring (or assessment) of stocks	McCully Phillips et al., 2015
Overlap with small-scale fisheries	Temple et al., 2019
Preferred habitat	Stobutzki et al., 2001
Size of the fishing fleet	Furlong-Estrada et al., 2017
Target of the fishery	Carreón-Zapiain et al., 2020
Total mortality/growth coefficient	Lucena-Frédou et al., 2017

2.4 Adjustment and modification in PSA and determination of vulnerability

Different modifications and adjustments have evolved in the PSA. These include the addition of several new attributes to the initial attributes list, determination of cutoff values for attributes ranking, modification of the weighted schemes for attributes, which depends on their relative importance (not all attributes are equally likely), the inclusion of data quality index to interpret the uncertainty of vulnerability scores, scoring approach for missing information for selected attributes, and the inclusion of additive approach for combining the attributes scores.

Two standard PSA versions have been used by different authors and organizations for assessing the vulnerability of fisheries stocks, one proposed by Hobday et al. (2007; based on the initial approach of Stobutzki et al., 2001) and another one by Patrick et al. (2009) (which is sometimes referred to as an extended version of PSA). There is some underlying difference between these two versions of PSA. First, Hobday et al. (2007) considered seven life history parameters as the proxy of productivity (average age at maturity, average maximum age, fecundity, average maximum size, average size at maturity, reproductive strategy, and tropic level) and four susceptibility attributes (availability, encounterability, selectivity of gear and post-capture mortality of species). Patrick et al. (2009) updated the productivity and susceptibility criteria, which resulted in ten productivity attributes, including several of those used by Hobday et al. (2007) as well as some new ones: intrinsic growth rate, growth coefficient, and natural mortality. Similarly, Patrick et al. (2009) included few new susceptibility attributes (e.g., fishing mortality relative to natural mortality, management strategy, impacts of the fishery on the habitats, and so on). However, they agreed that the scoring criteria for each of the attributes could be determined or adjusted based on the regional fisheries' characteristics. In determining the scoring threshold for productivity attributes, the quantile and k-mean clustering methods form the two most common methods. In quantile methods, each attribute is divided into three equal-sized groups (Hobday et al., 2007; Lucena-Fredou et al., 2017). However, with regard to the variance of each species' attribute value and each group mean value, the k-mean clustering technique groups the most similar species together (Patrick et al., 2009). The k-mean clustering approach produced overly narrow thresholds, emphasizing only species with extreme values and putting the majority of species into the same productivity category. Therefore, to produce higher productivity differentiation limits between all assessed species with diversified groups, the quantile technique is more useful than k-mean clustering methods (Altuna-Etxabe et al., 2020). In addition to these two common techniques, some PSA approaches calculate productivity and susceptibility scores through mathematical formulae (Arrizabalaga et al., 2011; Kirby, 2006).

The relative importance of each of the selected attributes for assessing the vulnerability of the stock is not equal and varies from fisheries to fisheries (Patrick et al., 2009). Higher weightage was accorded to the more important attributes in earlier versions of the PSA (Rosenberg et al., 2007; Stobutzki et al., 2001). For instance, among the productivity attributes, probability of breeding, maximum size of fish, and removal rate were given the highest weight of 3, while hermaphroditism and mortality index were given the lowest weight of 1. Similarly, for susceptibility attributes, the position of fish in the water column and preferred habitat were given the highest weight (Stobutzki et al., 2001). Patrick et al. (2009) chose a default weight of 2 for all productivity and susceptibility attributes. However, they argued that attribute weights can be customized on a 0–4 scale to tailor PSA's applications to the specific needs of each fishery. The importance of an attribute for defining productivity or susceptibility should be taken into consideration rather than the availability of data for that attribute when deciding the appropriate weighting of each attribute. Additionally, in certain rare instances, it is expected that some characteristics will be assigned a weighting of zero, resulting in their exclusion from the study since the attribute has no relationship to the fishery and its stocks (Patrick et al., 2009). Following Patrick's et al. (2009) weighting scheme, Fujita et al. (2014) considered the highest weight of 4 for the attributes of 'survival after capture and release' to assess the vulnerability of ornamental species of Indonesian coral reefs. Fish collected for the aquarium trade must stay alive to retain their worth, and species differ in their vulnerability to post-capture mortality; moreover, a species' high death rate after capture may demand a further collection to fulfill demand (Fujita et al., 2014). Likewise, many other existing works of PSA include the weighing scheme in their vulnerability assessments (e.g., Duffy et al., 2019; Furlong-Estrada et al., 2017; Lucena-Frédou et al., 2017).

In combining the attributes score, the overall score for both the productivity attributes (*P*) and susceptibility attributes (*S*) were assumed to be the additive function (arithmetic mean value) of individual attributes (Patrick et al., 2009). However, to calculate the overall susceptibility score, Hobday et al. (2007) used the multiplication approach (geometric mean value). They advocated that the multiplicative approach is more suitable for generating the overall susceptibility score over the additive approach because any attribute with a low-risk value reduces the total risk to a low value. For instance, if a species is present in fishing locations, comes into contact with the fishing gear, is captured by the gear, but is released to the water uninjured (post-capture mortality is low), the species' overall sensitivity should be considered low. In comparison, Patrick et al. (2009) and Osio et al. (2015) stated that using a multiplicative method to combine susceptibility scores would underestimate a species or stocks' overall vulnerability.

In the case of the treatment of missing information for selected attributes for a given species, Hobday et al. (2007) used the precautionary scoring approach (highest risk score assigned for missing data). The primary goal of Hobday et al.'s (2007) proposed PSA is to rapidly screen out the high-risk species, which are then further evaluated with a quantitative assessment tool at level 3. Besides, they argued that if a species is in the high-risk category due to missing attributes, further data collection should be considered instead of moving to level 3 assessment. Conversely, Patrick et al. (2010) used a different strategy, opting to exclude missing attributes from the analysis and developing a data quality rating system to interpret PSA outcomes.

The general feature of all PSA is ranking each of the productivity and susceptibility attributes with a numerical score of 1, 2, and 3. Hobday et al. (2007) assigned the risk scores for both productivity and susceptibility in a similar manner, with the score 3 indicating the highest risk (low productivity and high susceptibility) and score 1 representing the lowest risk (high productivity and low susceptibility). Finally, the overall vulnerability score (*V*) is determined by the following formula:

$$V=\sqrt{P^2+S^2},$$

where *P* indicates the arithmetic mean score of productivity attributes and *S* the geometric mean score of susceptibility attributes. The *V* score ranging from 1.41 (when all attributes were ranked 1) to 4.24 (when all attributes scored 3). Assuming that all *P* and *S* scores are equally probable, a third of the *V* score will be less than 2.64 and a third will be more than 3.18; these values serve as the thresholds for defining risk categories: Low, Moderate, and High. In contrast, Patrick et al. (2009) assigned the scores for productivity attributes in a manner opposite to Hobday et al. (2007), with a high value (i.e., 3) of *P* corresponding to low risk and a low score (i.e., 1) of *P* representing high risk; finally, the overall (*V*) score is computed as follows:

$$V=\sqrt{(P-3)^2+(S-1)^2},$$

where P and S represent the weighted arithmetic mean score of productivity attributes and susceptibility attributes respectively. Assuming that the exploitation status of stock is associated with the vulnerability score, Patrick et al. (2009) categorized the risk into four categories (based on the assessed stock's relative V score ($V < 1.8$, low; $1.8 \leq V < 2.0$, moderate; $2.0 \leq V < 2.2$, high; and $V \geq 2.2$, very high). Based on the explicit definition of risk (i.e., risk of a stock is directly related to overfishing), other authors also customized the risk ranking considering the characteristics of the assessed fisheries (e.g., Duffy et al., 2019; Furlong-Estrada et al., 2017; Ormseth and Spencer, 2011; Osio et al., 2015; Puga et al., 2018). For instance, Osio et al. (2015) classified the species into four groups based on the computed V scores for Mediterranean demersal stocks as least concern ($V < 1.6$), medium concern ($V < 1.8$), high concern ($1.8 \leq V < 2.0$), and major concern ($V \geq 2.0$). The resulting vulnerability scores for bycatch species in the tuna purse-seine fisheries of the eastern Pacific Ocean were grouped into three risk groups ($V \leq 1.0$, low; $1 < V < 2$, moderate; and $V \geq 2$, High) (Duffy et al., 2019). Lin et al. (2020) defined the risk as high ($V > 1.8$), moderate ($1.5 \leq V \leq 1.8$), and low ($V < 1.5$) for the species impacted by fisheries in waters off eastern Taiwan. Four risk categories ($V < 1.7$, low; $1.7 \leq V < 1.9$, moderate; $1.9 \leq V \leq 2.1$, high; and $V > 2.1$, very high) were considered for the assessment of the vulnerability of nearshore tropical finfish in Cuba (Puga et al., 2018).

2.5 Conclusion

This chapter primarily focused on PSA applications to evaluate the risk of species impacted by fisheries and included the list of productivity and susceptibility attributes employed by different authors in their assessment with PSA. Moreover, different modifications and adjustments in PSA and the manner in which the vulnerability scores are calculated were included in this chapter. The introductory sections of chapters 3 and 4 contain the specific reviews in detail, focusing on each of those chapters' objectives.

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Chapter 3

Vulnerability Assessment for Hilsa Gillnet Fishery

Publication base on this chapter

Hasan Faruque and Hiroyuki Matsuda (2020). Assessing the vulnerability of bycatch species from Hilsa gillnet fishing using productivity susceptibility analysis: Insights from Bangladesh. *Fisheries Research*, 234, 105808. https://doi.org/10.1016/j.fishres.2020.105808

Assessing the vulnerability of bycatch species from Hilsa gillnet fishing using productivity susceptibility analysis: Insights from Bangladesh

Abstract

Productivity susceptibility analysis (PSA) is being widely used as a semi-quantitative risk assessment tool in data and capacity-limited situations. This tool rapidly and cost-effectively assists in identifying the potential risk of a fishing type regarding its bycatch stocks. The Hilsa (*Tenualosa ilisha*) is an iconic flagship species and geographical indication product of Bangladesh. We performed a PSA to evaluate the relative risk to bycatch stocks in gillnet fishing (gillnet shares > 95% of Hilsa catch in Bangladesh) along with target stock, Hilsa. Of the 130 identified species, Hilsa and 74 bycatch stocks were subjected to a PSA depending on data availability and the magnitude of capture. We validated our vulnerability results by comparing them with two other empirically derived assessment outcomes, the IUCN Red List and the exploitation rate. We also compared PSA scores with the catch trend of stocks from fishers' subjective recognition. Hilsa was found to be moderately vulnerable to gillnet fishing. The majority of the bycatch were found to be highly susceptible to fishing, with 17 bycatch species found to be in the high-risk category. Five species classified as high-risk group were known to be threatened species listed in the national IUCN Red List. Our finding revealed 82% accordance level between the exploitation rate and PSA-derived vulnerability scores. It implies that the exploitation rate associated with overfishing corresponds to the vulnerability scores. Moreover, with few exceptions, we found that species with vulnerability score over 1.8 showed decreasing catch trend. Our result also revealed that around 55% of inland bycatch and 42% of marine bycatch is associated with overfishing (vulnerability score > 1.8). Data quality analysis indicated that the majority of bycatch species received low data quality scores. It emphasizes the need for improved data collection on species-specific life-history traits. However, the baseline information of our current study could assist the fishery managers to formulate a better management plan for the sustainability of Hilsa and the bycatch stocks.

Keywords: Risk assessment; Data poor; Non-target stock; Multi-species fisheries; Focus group discussions

3.1 Introduction

The ecosystem approach to fisheries, gradually replacing the single-stock-oriented management approach (Link et al., 2002; Norse, 2010). However, adapting to this approach is challenging, especially in developing countries where the multi-gears and multi-species fisheries exist with little or even no information on the status of aquatic biological resources (Gardiner and Viswanathan, 2004). Bangladesh, a south Asian developing country, has recently introduced the ecosystem approach, especially focusing on Hilsa shad (*Tenualosa ilisha;* henceforth referred to as Hilsa) (van Brakel et al., 2018). The Government is implementing ecosystem approach by promoting communitys' participation in resource management, enforcing gear restrictions, imposing spatial and temporal fishing bans, and restoring fishing habitats (Rahman et al., 2020). However, biological information on a particular species or on stock status, which is often limited, is required to ensure effective management (Pikitch et al., 2004).

The Hilsa is an iconic flagship species of Bangladesh. Hilsa fishing is valuable to the countrys' economy as it strengthens food security and promotes employment and foreign trade opportunities (Mome and Arnason, 2007). This transboundary species lives in waters belonging to sixteen different countries distributed across the North Indian Ocean and the Bay of Bengal (Froese and Pauly, 2019). Bangladesh is responsible for 86% of the global Hilsa catch. India (8%) is the second-largest, followed by Myanmar (4%), with the remaining countries contributing 2% (Rahman et al., 2018). Hilsa is largely an anadromous fish, i.e., it migrates from marine to inland waters to spawn, and shows amphidromous migration, i.e., migrating between marine and inland waters to feed. This migratory species exploits both its inland and marine habitats. Of the total catch, marine catch contributes to around 55%, and the rest comes from inland waters (DoF, 2018).

Given the multi-species nature of Bangladeshi fisheries, it is nearly impossible to catch Hilsa selectively, with significant numbers of both riverine and marine species being caught. Hilsa is typically caught by gillnets (e.g., drift gillnet, set gillnet) and seine nets of varying types and sizes depending on the season, fish sizes, and habitat types across its fishing ranges. All these fishing nets are mostly operated from artisanal mechanized and non-mechanized wooden boats (M.A.R. Hossain et al., 2019). Recent studies suggest that this geographical indication product of Bangladesh, owing to its high economic value (the market is worth about 4 billion USD per year) and socio-cultural importance (Mohammed et al., 2016; Rahman et al., 2020), is becoming increasingly threatened by excessive fishing pressure (Mozumder et al., 2019).

Bangladesh government has already imposed regulations on the minimum mesh size of gillnets and the minimum length of the Hilsa allowed for the catch. The government has introduced seasonal and temporal bans to reduce overall fishing pressure on fish stocks. All these measures mainly focus on protecting Hilsa stocks, while other species have not been provided the same level of protection (Islam et al., 2016; Islam et al., 2017). Even though many other species are caught using Hilsa gillnet fishing, no risk assessment has been carried out to identify the relative vulnerability of bycatch stocks of Hilsa gillnets, either by Bangladesh or any other Hilsa fishing nation. This is mainly because of the lack of information on bycatch species. Given the limited availability of data, any biological reference points are not possible for bycatch species. However, extensive research has been conducted to assess the stock levels of Hilsa (e.g., Milton, 2010; M.A.R. Hossain et al., 2019) and some other species (Ara et al., 2019; Mustafa et al., 2019). Given these circumstances, our study outlines a semi-quantitative risk assessment tool to evaluate the relative vulnerability of a species to fishing.

Productivity susceptibility analysis (PSA) is one such risk assessment tool that has been proven useful in fishery sciences. This tool has widely been used globally, particularly in multi-species and multi-gear scenarios where data are limited (e.g., Duffy et al., 2019; Patrick et al., 2009; Stobutzki et al., 2001) to support multi-species fisheries management (Fujita et al., 2014) as well as ecosystem-based approach for fisheries management (Smith et al., 2007; Zhou et al., 2009). PSA was developed in 2001 to assess the impact of Australian prawn fishing on the sustainability of its bycatch (Stobutzki et al., 2001). Some improvements in PSA typically included expanding the number of attributes rated, developing additive and multiplicative models for combining scores, and testing a range of alternative treatments for missing data (Patrick et al., 2010). The PSA uses both the biological productivity, i.e., the intrinsic capacity of fish stocks to recover their numbers once depleted, and a set of susceptibility, i.e., the impact of fishing on stocks, factors to assess the relative vulnerabilities of species to fishing activities (Patrick et al., 2010). PSA is more practical than any other semi-quantitative vulnerability assessment tool. This tool rapidly and cost-effectively assists in identifying appropriate management action for species in higher-risk categories and supports fishery managers in finding potential candidates for stock assessment using conventional quantitative tools (Hobday et al., 2011). The outcomes of PSA could recommend actions to management and identify the gaps in data that must be filled in order to conduct further assessments.

Our research was designed to identify the species interacting with Hilsa gillnets for the first time and to perform PSA to identify the relative vulnerability of target stock (Hilsa) and bycatch species. We validated our vulnerability results by comparing them with two other empirically derived assessment outcomes, the IUCN Red List (IUCN, 2015; 2020) and the exploitation rate, and we also compared our PSA results with the catch trends of stock. Finally, we intuitively discussed how improvement in existing regulations and enforcement to protect target stock (e.g., Hilsa) and bycatch species could reduce vulnerability.

3.2 Materials and methods

3.2.1 Study area

Out of the 64 administrative units (or districts) of Bangladesh, Hilsa has been reported from different inland and marine habitats of 43 districts (DoF, 2018). Nine districts contribute in both inland and marine Hilsa production, while the rest of the districts contribute only in the inland production (Figure 3.1).

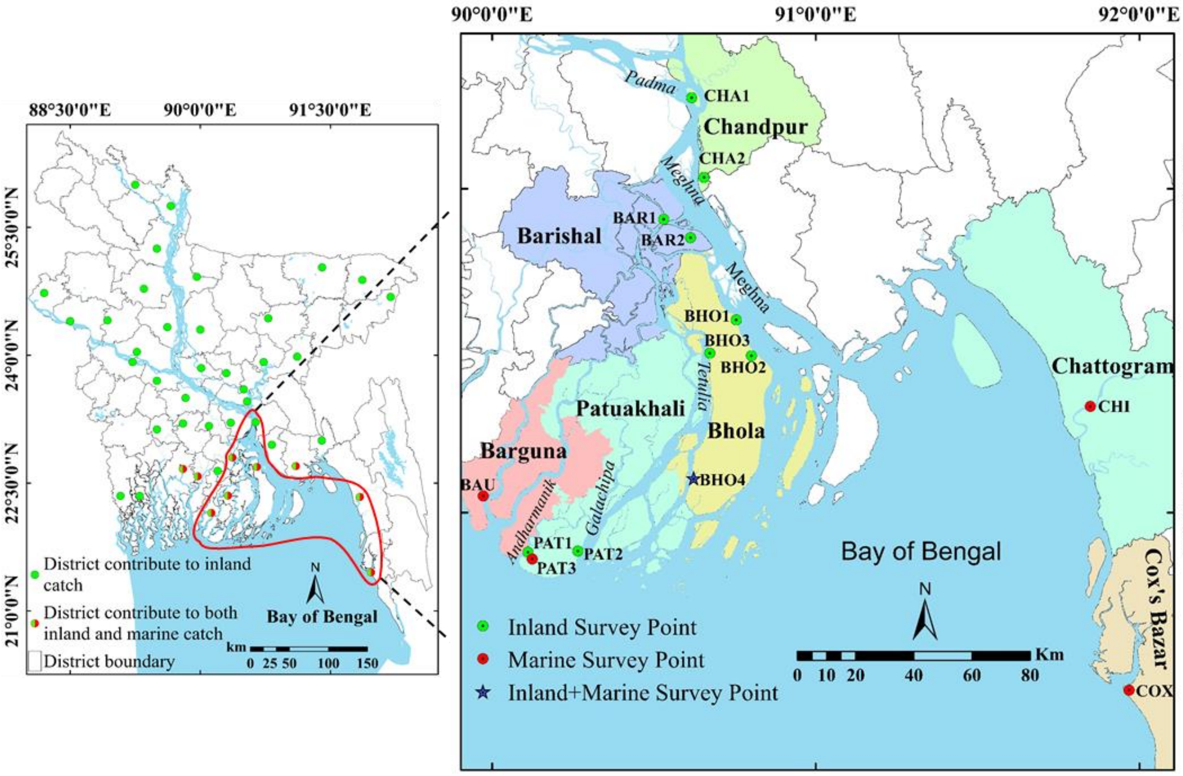

Figure 3.1 Maps denoting the survey points. The map on the left displays the nationwide Hilsa catching district; The right map displays the survey stations and specific survey points. Full survey point names are provided in the Appendix (Table A.1).

Two factors were taken into account while selecting the survey districts: i) each districts' Hilsa catch contribution, and ii) the number of Hilsa fishers engaged in Hilsa fishing activities in each of the districts. We considered the top seven districts based on each of the districts' relative catch contributions in countrys' total Hilsa production. These seven districts account for around 90% of the total Hilsa catch. Moreover, around 72% of the countrys' total registered Hilsa fishers are engaged in Hilsa gillnet fishing from the selected seven districts of Bangladesh (DoF, 2018). Among seven selected districts, we considered four districts (Barishal, Bhola, Chandpur, and Patuakhali) as our inland survey stations and five (Barguna, Bhola, Chattogram, Cox's Bazar, and Patuakhali) as the marine survey stations (Figure 3.1 and Table A.1). The overall contribution of the selected inland and marine survey stations to countrys' total Hilsa production is around 77% and 95%, respectively (Figure 3.2).

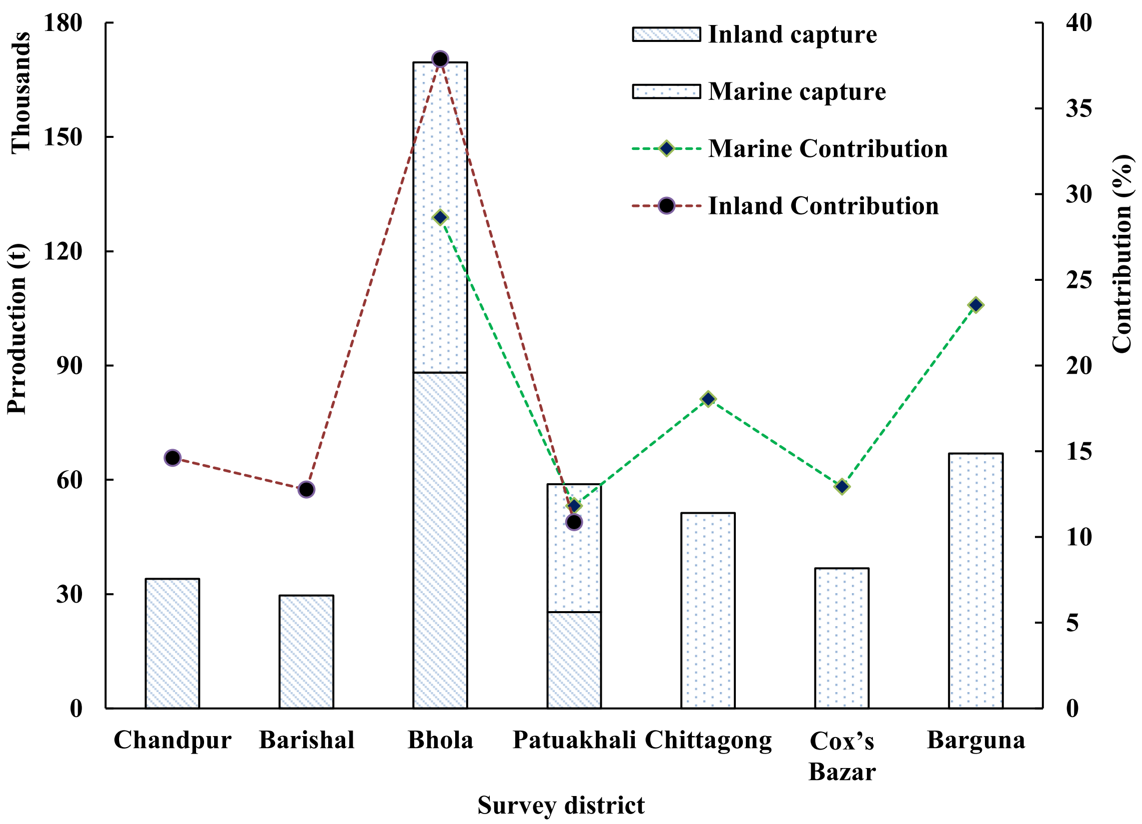

Figure 3.2 Contributions of the study areas relative to the country's total Hilsa production in terms of landed biomass (primary axis: thousand tonnes; secondary axis: percentage share).

There are six Hilsa sanctuaries (fishing ban imposed for 2–3 months) in the inland habitats—river and estuarine areas—of Bangladesh to protect the juvenile Hilsa fish from overfishing (Islam et al., 2016). Juvenile Hilsa graze for 6–8 months inside or adjacent sanctuaries areas before migrating downstream toward the sea to attain final maturity (Ahsan et al., 2014). Species abundance and composition in some Hilsa sanctuaries are richer than other Hilsa habitats (Kundu et al., 2019). Moreover, most of the inland Hilsa catch is now restricted to the downstream areas of rivers, mainly in the river Meghna (M.S. Hossain et al., 2019). Therefore, ten inland Hilsa survey points were selected; nine of these—CHA1–CHA2, BAR1–BAR2, BHO1–BHO4, and PAT1—were located within Hilsa sanctuaries (mostly in the Meghna, Padma, Tetulia, and Andharmanik rivers). One survey point—PAT2—was situated in the Galachipa river of the Patuakhali district, adjacent to the Hilsa sanctuary located in the Tetulia river (Figure 3.1 and Table A.1). One marine landing site at each marine station—BHO4, PAT3, CHI, COX, and BAU—was designated as the marine survey point.

Most of our inland survey points located in Hilsa sanctuary areas, and we chose sanctuary areas because the fishing pressure inside the sanctuary is immense than other sites. In Bangladesh, over 90% of Inland Hilsa fishers are engaged in Hilsa fishing for years, except the fishing ban period, inside and adjacent to the Hilsa sanctuaries areas. The effect of Hilsa gillnet fishing on Hilsa and bycatch stock are likely to be substantial than the other in-river points.

3.2.2 The selection of Hilsa fishers from surveyed stations

Half a million Hilsa fishers in Bangladesh are involved in Hilsa fishing (M.S. Hossain et al., 2019). These Hilsa fishers generally use different fishing gear to catch Hilsa depending on the habitat, the season, and the fish size (M.A.R. Hossain et al., 2019). However, more than 95% of the total Hilsa catch comes from gillnet fishing (DoF, 2018). Professional Hilsa fishers are more likely to possess more in-depth knowledge on Hilsa fishery than the occasional and subsistence fishers (Faruque and Ahsan, 2014). Therefore, we selected professional Hilsa fishers using gillnets to catch Hilsa at each of the survey points using the snowball sampling technique (Goodman, 1961), until the saturation point was reached (Table A.1). A total of 300 professional Hilsa gillnet fishers (150 inland fishers and 150 marine fishers) were selected across the selected survey stations. The first potential professional Hilsa fishers from each of the survey points were identified with the help of local fishery officials.

Existing literature lacked information about Hilsa gillnet-specific bycatch species from Bangladesh water areas. Hence, we asked all those selected professional Hilsa gillnet fishers to identify the species that interacted with their gillnets, which is described in Section 3.2.3. We also observed and sampled the bycatch species from their landed catch for proper identification of the bycatch species up to the species level using the taxonomic keys.

3.2.3 Identification of bycatch species

In Bangladesh, the gear-specific fish composition and abundance data to the species level are often limited. Therefore, to identify the fish caught by Hilsa gillnets across our survey stations, we applied three techniques. First, we compiled data on the common species found in the countrys' riverine ecosystem and the commercially important marine fish frequently caught by fishers from the relevant literature (e.g., Barua et al., 2014; Mohsin et al., 2014; Rahman et al., 2017). Since our inland survey points mostly covered five Hilsa fishing rivers (Meghna, Padma, Tetulia, Andharmanik, and Galachipa), and the Bay of Bengal as the marine habitat, we produced river-specific and marine fish photo albums. Fish photo albums included the local names along with common and scientific names of the fishes. At each survey point, fishers were asked to identify the fish caught in their Hilsa fishing gillnets using the habitat-specific fish photo albums across all fishing seasons (as surveys were conducted from February to March and November to December 2019). We also instructed these fishers to report fish caught in their nets that were not included in our lists with the complete list and photos of all the fishes found in Bangladesh water areas (Rahman et al., 2009; Siddiqui et al., 2007).

Figure 3.3 Representative photographs of data collection on bycatch and Hilsa gillnet fisheries through the face-to-face interview (**A–D**), focus group discussions (**E–H**), and key informants interview (**I**).

After collecting this data on bycatch species at each survey point, we summarized and shortened the list. We prepared a Hilsa gillnet-specific bycatch species list (rough list), which was then validated by a second method of species identification. Selected fishers' landed catch were observed for three or four consecutive days in each sampling period at each of the Inland survey points. For the onboard identification of marine bycatch, we randomly selected ten individual fishers among the fishers selected earlier from each marine survey point and monitored their landed catch. In both cases, we sampled the bycatch species from selected catches and identified species following the taxonomic key proposed by Quddus and Shafi (1983), Rahman (2005), Shafi and Quddus (1982), and Talwar and Jhingran (1991). Finally, species not found in the landed catch at a particular surveyed point, i.e., species that are generally caught at other times of the year, but reported by the fishers during the-survey time were then checked, confirmed, and selected following key informant interviews with local fishery officers for further analysis by PSA. However, during the survey time, we did not find any fish (reported by fishers) that were completely absent in the landed catch across the surveyed points. Moreover, fishers did not report any fish that were not listed in either of our habitat-specific photo albums or complete fish list. We divided the selected bycatch species into two categories: inland bycatch and marine bycatch, as based on the species' habitat preference (Rahman et al., 2009; Siddiqui et al., 2007). All scientific names of bycatch species were validated using FishBase (Froese and Pauly, 2019).

3.2.4 Focus group discussions

Focus group discussions (FGDs) are frequently used in research as a qualitative approach for attaining an in-depth understanding of an issue of interest (Nyumba et al., 2018). However, FGDs can also be used to gather quantitative data (Calder, 1977). Of the fishers initially selected from each of the surveyed points, one-third were selected for FGDs. We used purposive sampling (also referred to as selective or judgmental sampling) technique for the selection of knowledgeable and experienced Hilsa fishers for FGDs (Cresswell and Plano Clark, 2011). Those selected possessed a minimum of ten years of Hilsa fishing experience. One FGD was held at each survey point, and the discussions lasted for three to four hours (Table A.1).

In each FGD, we provided fishers with final Hilsa gillnet-specific bycatch species lists containing photos and the local names of fish. We asked them to rank the bycatch species based on catch frequencies in Hilsa gillnets on a scale of 1 to 4, with "1" denoting the lowest level of frequency and "4" representing the highest frequency. Species that received a majority of "1" scores across survey points (listed in Table A.2) were excluded and were not considered for further analysis by PSA. Their inclusion would raise the potential for false positives, in which a species is wrongly classified as highly susceptible (Arrizabalaga et al., 2011). The catch frequency of the fishing gears depends on the fish abundance, fishing effort and catchability. The catchability is largely affected by body shape and size of fishes, and vertical overlap with fishing nets (Rincón-Sandoval et al., 2019). Most of the Hilsa fishers argued that such infrequent capture of the excluded fishes in Hilsa gillnets might be attributed to the different fish shape and size from Hilsa and/or their infrequent overlap with the Hilsa fishing areas. We observed that the excluded fishes—rarely caught in Hilsa gillnets—from our PSA analysis caught by other fishing gear such as seine nets, hooks and lines, trawl nets, other gillnets whose target were not Hilsa. Therefore, we assumed that bycatch by the Hilsa gillnet fishery is not a major threat for these rare species, although some species excluded from our PSA were globally categorized as the threatened fishes (e.g. *Aetomylaeus nichofii, Esphyra blochii, Himantura uarnak, Rhinobatos granulatus, Rhynochobatus djiddensi*s) by the IUCN Red List (IUCN, 2020).

Time series of catch data, efforts data, length-frequency data, and yearly average size or weight data are unavailable for bycatch stocks of Hilsa gillnet fishing in Bangladesh. Therefore, we qualitatively gathered the catch trend information on each of the bycatch stocks during FGDs. We compared this catch trend information with the vulnerability scores and categories (e.g., high, moderate, low). We asked fishers to score the bycatch species on a scale of 1 to 3, with "1", "2", and "3" denoting the decreasing, stable, and increasing trends, respectively (Table A.3). Other data on Hilsa gillnet fishery included the market demand for bycatch species, supply prices, the selectivity of gillnets, the depth fished, fishing zones and seasons, the bycatch species discard tendency by fishers, gillnet mesh sizes, net dimensions, the types of fishing boats, the enforcement of fisheries regulation, and the fishers' degree of compliance with fisheries regulation, were obtained from FGDs and from direct observations. This information was considered while scoring the susceptibility attributes such as vertical overlap, morphological characteristics that affect capture rates, migration behaviors, management strategies, and survival rates after capture and release, and also used to support some points in the Discussion section.

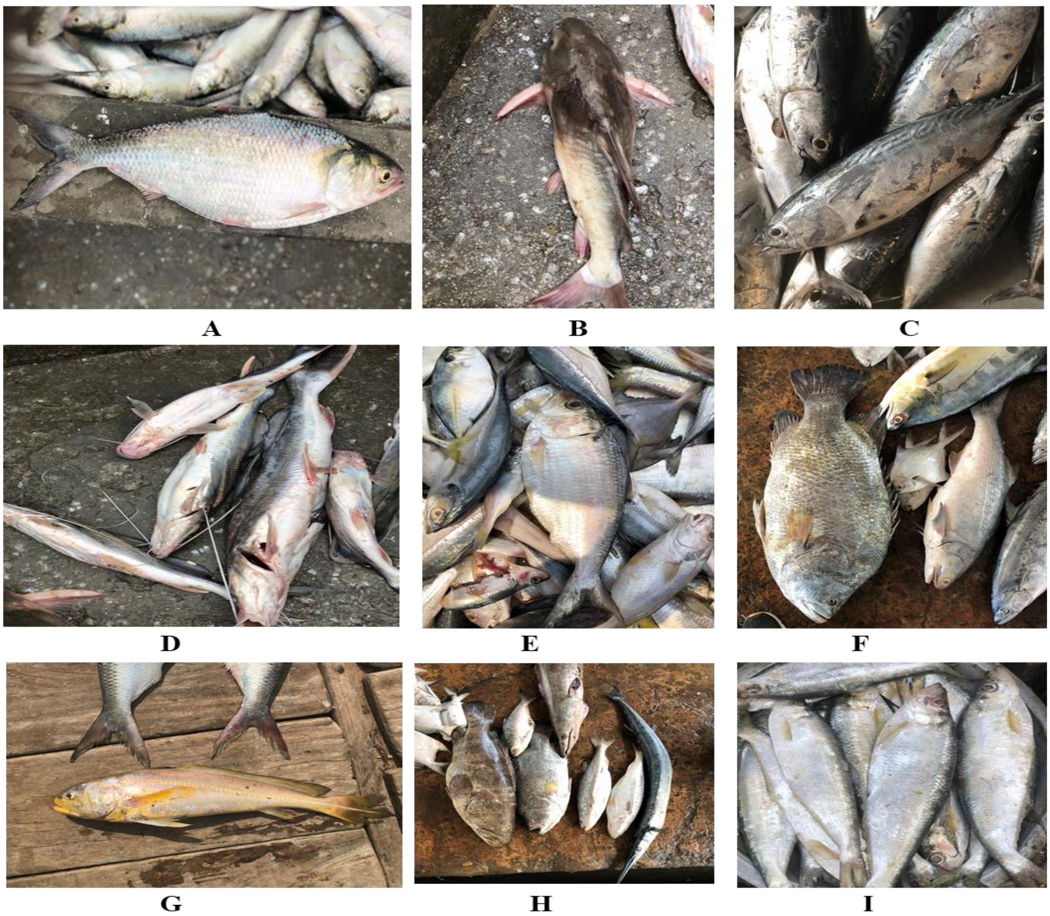

Figure 3.4 Representative photographs of Hilsa (**A**) and bycatch species (**B–I**) of Hilsa gillnet fishery of Bangladesh.

3.2.5 Productivity susceptibility analysis

3.2.5.1 Productivity and susceptibility attributes

Twelve productivity attributes (*P*) related to the life-history traits of the species and ten susceptibility attributes (*S*) were used in our study (Tables 3.1 and 3.2). The definitions of these attributes are provided in Table A.4. The selection of attributes was mostly determined by data availability and its representativeness to vulnerability (Patrick et al., 2010). The inherent characteristics of the species or population largely influence the productivity of that given species or population (Hobday et al., 2011). Among the twelve selected productivity attributes, attributes 1–8 (maximum age, maximum size, growth coefficient, natural mortality, fecundity, breeding strategy, age at maturity, and mean trophic level) were taken from Patrick et al. (2010). These eight attributes are often use in PSA analysis because of their strong correlation with the productivity of the stocks (Ormseth and Spencer 2011). We also chose size at maturity (Hobday et al., 2011), breeding cycle (McCully Phillips et al., 2015), maturity size ratio and maturity age ratio (Mejía-Falla et al., 2019) as candidates of attributes from other works, all these attributes have a direct influence on species productivity. For instance, the breeding cycle directly reflects the productivity of the stocks; and species with protracted annual breeding season tend to be more productive than the species with bi/triennial breeding cycle (McCully Phillips et al., 2015). Consequently, maturity size tends to be positively associated with the maximum size. Smaller species tend to reach maturity at larger sizes relative to their maximum body sizes, while larger species tend to mature at relatively smaller sizes (Hobday et al., 2011).

Data on life-history parameters were mainly compiled from published and unpublished grey literature and web-based libraries (e.g., FishBase). We used species-specific information whenever possible. Where species-specific details were unavailable, we considered the attribute values of members of the same genus or confamilial taxon in Bangladesh or the Indian subcontinent, or globally when necessary. Since life-history parameters are correlated (Jensen, 1996), we used the empirical relationships between the life history parameters to calculate the productivity values for given attributes proposed by Froese and Binohlan (2000) and Pauly (1980). For instance, when data on fish age were unavailable, we used $t_{max} = 3/k$ (where k is the von Bertalanffy growth parameter and t_{max} is maximum age), and the length at maturity, $L_{mat} = L_{\infty}10^{(0.8979 - 0.0782T)}$ where L_{∞} is the asymptotic maximum length and T is the water temperature, $t_{mat} = -\text{Log}_e(1 - L_{mat}/L_{\infty})/k$ was used to calculate the age at maturity, and $M = 0.985\ L_{\infty}^{-0.279} k^{0.6543} T^{0.4634}$ estimates the natural mortality at a temperature of 28°C. Lin et al. (2020) used the same approach in their assessment (i.e., use of empirical equation to estimate correlated life-history parameters) when the data are unavailable. Previously, Hobday et al. (2011) suggested the precautionary approach, i.e., considered the species at the high risk in the absence of data, for identifying and categorizing ecological risk, which would bias toward more false positive results. Since precautionary approach in PSA appears to overestimate species vulnerability (Osio et al. 2015), we estimated several correlated life-history parameters using the empirical equations referred to earlier. We then used the values for scoring. However, the estimated data we used for scoring did not violate the further calling for data collection as in the attributes data quality scoring we used scored 4 (i.e., very limited data; Table 3.3) for data derived by empirical equations.

Table 3.1 A set of attributes and scoring thresholds used to determine the productivity of the stocks caught by Hilsa gillnets.

Productivity attributes	Low risk (3)	Moderate risk (2)	High risk (1)
Maximum age (t_{max}, year)	<4	4–8	>8
Von Bertalanffy growth coefficient (k, yr^{-1})	<38	38–85	>85
Estimated natural mortality (M, yr^{-1})	>0.78	0.33–0.78	<0.33
Measured fecundity (MF)	>1.21	0.74–1.21	<0.74
Breeding strategy (BS)	>64136	10663–64136	<10663
	Release eggs into the water column	Lay eggs in a nest and guard those eggs until hatching	Internal fertilization (/Live bearer) mouth brooding, or other strategies that involve full parental care
Age at first maturity (t_{mat}, years)	<1.0	1–2	>2
Mean trophic level (MTL)	<3.50	3.50–3.90	>3.90
Size at first maturity (L_{mat}, cm)	<19	19–38	>38
Breeding cycle (female)	Annual cycle with protracted breeding season	Annual cycle with a seasonal peak	Bi/Triennial
t_{mat}/ t_{max}	<0.25	0.25–0.30	>0.30
L_{mat} / L_{max}	<0.52	0.52–0.59	>0.59

Each of the productivity attributes except the breeding strategy and breeding cycle were scored on a ordinal scale of 1 to 3, with "1" denoting low productivity (high risk), "2" indicating moderate productivity (moderate risk) and "3" representing high productivity (low risk) (Table 3.1). The boundaries of the scoring threshold values were determined by dividing the attribute values into 1/3 and 2/3 quantiles, i.e., dividing the range of frequencies with almost equal probabilities (Duffy et al., 2019; Lucena-Frédou et al., 2017) (Table 3.1; Tables A.5a and A.5b). For example, if the size at first maturity data ranged between 22 and 35 cm, the data range classes may be defined as < 25 (high productivity = 3), 25–30 cm (moderate productivity = 2), and > 30 (low productivity = 1). Although the breeding strategy was considered as productivity attribute as recommended by Patrick et al. (2010), the scoring criterion was modified according to the authors' experience of the stocks considered for assessment. We assigned a score of 3 (highly productive) for broadcast spawners, that freely release eggs into the water column, a score of 2 for fish that release eggs into nests and guard them until they hatch, and a score of 1 (low productivity) for live-bearing fish or other species that demonstrate strategies that involve full parental care. The scoring criterion for the breeding cycle of females was based on the work of McCully Phillips et al. (2015).

Ten susceptibility attributes were considered for scoring depending on the availability of data. With some exceptions, most of the susceptibility attributes were taken from Patrick et al. (2010), with the same scoring criteria retained (Table 3.2). Like productivity attributes, all susceptibility attributes were scored on a scale of 1 to 3 (Table 3.2; Tables A.6a and A.6b). In our study, we split the "desirability of the fishery" attribute into two attributes, namely the "market demand for fish" and "market value of fish". Species with high market demand and high market values tend to be more susceptible to fishing. For the market demand for fish, we set the scoring criteria as a high market demand equal to 3, a moderate market demand equal to 2, and a low market demand equal to 1, whilst also using the same scoring criteria for the market value of fish. The cut-off values for market value of fishes (USD) for scoring were determined considering the fishers' subjective perception on fish price. Species with a greater than 3.50 USD per kg selling price (with an assigned score of 3) were assumed to be highly susceptible to fishing pressure. Conversely, species with a lower than 1.50 USD per kg selling price (with an assigned score of 1) were assumed to be less susceptible to fishing pressure, with values of between 1.50 and 3.50 USD per kg assigned a score of 2. For the scoring of "Morphological characteristics affecting capture" attribute, we considered the fish body shape, and incorporated the fishers' local knowledge. For instance, flatfish are less prone to get entangled with gillnets, whereas the fish with torpedo-shaped or bilaterally flattened body with deeper girth shows high selectivity to Hilsa fishing gillnets. Data on fishing rate relative to natural mortality (F/M) were not available for most of the assessed species. Therefore, we only scored this attribute for species with available data on fishing rates.

Hordyk and Carruthers (2018) quantitatively evaluated the underlying assumptions of PSA, and demonstrated that no all P and S attributes contribute equally to predict risk. For example, the intrinsic rate of population increase is most important attributes, and selectivity (the size of capture relative to the size of maturity) is the strongest susceptibility attribute. However, due to the lack of the information on intrinsic rate of population increase and selectivity for most of the assessed species, we did not consider these attributes for scoring in our study. They also described that S score is more important than the P score in determining the overall risk. However, in our PSA, productivity and susceptibility attributes were given equal importance, and thus weighted with the default score of 2, as in Patrick et al. (2010). We used the weighted average scores of the productivity and susceptibility because it avoids underestimation of vulnerability (i.e., if there is a low rank in one attribute, then the species is not considered to be at risk) than the multiplicative method (ICES, 2013; Osio et al., 2015).

Table 3.2 A set of attributes and scoring thresholds used to determine the susceptibility of the stocks caught by Hilsa gillnets.

Susceptibility attributes	High risk (3)	Moderate risk (2)	Low risk (1)
Areal overlap	>50% of the stock occurs in the area fished	Between 25% and 50% of the stock occurs in the area fished	<25% of stock occurs in the area fished
Vertical overlap	>50% of the stock occurs in the depths fished	Between 25% and 50% of the stock occurs in the depths fished	<25% of stock occurs in the depths fished
Seasonal migrations	Seasonal migrations increase overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations decrease overlap with the fishery
Schooling, aggregation, and other behavioral responses	Behavioral responses increase the catchability of the gear	Behavioral responses do not substantially affect the catchability of the gear	Behavioral responses decrease the catchability of the gear
Morphological characteristics affecting capture	Species shows high selectivity to the fishing gear (e.g., torpedo-shaped or bi-laterally flattened with deeper girth fishes)	Species shows moderate selectivity to the fishing gear (e.g., elongated body shaped fishes)	Species shows low selectivity to the fishing gear (e.g., flatfishes)
Management strategy	Stocks do not have input and/or output control measures, and target and bycatch species are not monitored	Stocks have input and/or output control measures, and measures in place to conserve the stocks occasionally monitored and enforced	Stocks have input and/or output control measures, and measures in place to conserve the stocks regularly monitored and enforced by balancing carrots and sticks
Survival after capture and release	Probability of survival <33%	Between 33% and 67% probability of survival	Probability of survival >67%
Market value of fish (USD/kg)	>3.5	1.5-3.5	<1.5
Market demand for fish	High	Moderate	Low
Fishing rate relative to natural mortality	>1	0.5-1.0	<0.5

The elimination of either of two attributes with the correlation coefficient over 0.9 was recommended to avoid double-counting (Hobday et al., 2011). We checked the autocorrelation between the attributes we have selected for PSA. We did not find any strong correlation between any set of attributes, except for the attribute group maximum size and size at first maturity. We did not remove either of these biological attributes because the sensitivity test indicated that, exclusion of either of two attributes made insignificant changes in the overall vulnerability category.

3.2.5.2 Vulnerability

In PSA, vulnerability (*V*) is defined as a function of productivity and susceptibility. It is quantified as the Euclidean distance of the weighted productivity (*P*) and weighted susceptibility (*S*) scores from the origin of a two-dimensional x-y scatter plot of the equation $V = \sqrt{(P-3)^2 + (S-1)^2}$ (Patrick et al., 2010). Productivity scores are depicted on the horizontal axis on a high (3) to low (1) scale, and susceptibility scores are plotted along the vertical axis on a low (1) to high (3) scale. Finally, the calculated vulnerability scores were used to define vulnerability categories (where low <1.8, moderate: $1.8 \leq V < 2$, and high ≥ 2).

3.2.5.3 Data quality

To provide an estimate of uncertainty, each productivity and susceptibility attribute was assigned a data quality (DQ) score for each species. Quality scores were assigned on an ordinal scale from 1 to 5, where 1 denoted the highest level of data reliability, and 5 indicated a complete lack of available information. A detailed description of data quality is provided in Table 3.3. Overall data quality scores were measured as weighted means of individual productivity and susceptibility scores. Data quality scores were classified as high (when DQ < 2), moderate (when 2 ≤ DQ < 3), or low (when DQ ≥ 3), following the structure used by Ormseth and Spencer (2011).

Table 3.3 Scoring structure for data quality used in the PSA of Hilsa gillnet fishing, as adapted from Patrick et al. (2010).

Data quality	Description	Example
1 (Best data)	Information is based on collected data for the stock and area of interest that is established and substantial	Data rich stock assessment; published literature for which multiple methods are used, etc.
2 (Adequate data)	Information is based on limited coverage and corroboration, or for some other reason is deemed not as reliable as tier-1 data	Limited temporal or spatial data, relatively old information, etc.
3 (Limited data)	Estimates with high variation and limited confidence, and may be based on studies of similar taxa or life history strategies	Similar genus or family, etc.
4 (Very limited data)	Information based on expert opinion or general literature reviews from a wide range of species, or from outside of region, or data derived by equation using the corelated life-history parameter	General data not referenced
5 (No data)		

3.2.6 Comparison of vulnerability results with IUCN extinction risk, exploitation rate, and catch trend

Nevertheless, the PSA's bias toward false positive vulnerability results and its semi-quantitative nature can result in credibility issues among knowledgeable stakeholders (Hobday et al., 2011). This credibility issue can be mitigated by comparing the PSAs' vulnerability results with other assessment methods for fish species that can be assessed by other methods (Osio et al., 2015). In our analysis, the findings of the PSA were compared with the results of three analytical approaches to gain an in-depth understanding of the relative risks faced by bycatch species of Hilsa gillnet fishing, including the Hilsa as the target species. These were (i) the IUCN Red List of threatened species, which evaluates the relative risk of extinction and the status of threatened species using comprehensive quantitative and qualitative criteria, (ii) the exploitation rate E (i.e., fishing mortality relative to total mortality), which reflects the overfishing or underfishing status of a given stock, and (iii) catch trend data of bycatch species from FGD.

This analysis included seven categories within the IUCN Red List: not evaluated (NE), data deficient (DD), least concerned (LC), near threatened (NT), vulnerable (VU), endangered (EN), and critically endangered (CR). All the bycatch species listed in our study from inland habitats (i.e., rivers and estuaries) and a proportion of bycatch species from the marine habitats (those also found in estuaries and tidal rivers) were previously assessed at the national level (IUCN, 2015) using the IUCN assessment tool. However, no form of national or regional assessment was available for most of the marine bycatch. Given this situation, we used the global assessment categories (IUCN, 2020) where national IUCN Red List categories were unavailable. Our PSA risk categories were compared with the IUCN Red List categories to investigate the relationship of PSA scores and IUCN Red List classification as in Fujita et al. (2014) and Osio et al. (2015). This means species classified as high risk by PSA are expected to be ranked as threatened categories by IUCN. The concordance between these two approaches corroborates the PSA result.

In our PSA analysis, we assessed 75 stocks to know their relative vulnerability to Hilsa gillnet fishing. Not all bycatch species assessed by PSA were included in the comparative analysis of the exploitation rate. Only 22 species (the Hilsa, 17 marine bycatch species, and 4 inland bycatch species) affected by Hilsa gillnets listed in our study have been assessed previously by FAO-ICLARM stock assessment tools (Tables A.6a and A.6b) to calculate the exploitation rate, thus to determine the stock statuses (i.e., overfishing or underfishing). Previously, Patrick et al. (2009) examined the relative vulnerability scores with the stocks' status for some American Fisheries and found that stocks with vulnerability scores greater than 1.8 were overfished or had undergone overfishing problem. Based on the definition of Patrick et al. (2009), we compared the PSA-derived vulnerability score (*V* score) with the exploitation rate (E). It is empirically established that species having an exploitation rate over 0.5 are associated with overfishing (Gulland, 1971). To make this comparison, we assumed that the exploitation rates derived from the length of the given stocks using the FAO-ICLARM stock assessment tool were true.

We also compared the vulnerability scores with the catch trend data (gathered during FGDs) of the bycatch stocks. We assumed that fishers' opinion on the bycatch species catch trend reflects the relative stock status of the bycatch species. For a particular bycatch species, if over 30 fishers, which means the majority is 5% statistically significant, perceived that catch trend are "increasing (2)", "increasing or stable (1)" or "decreasing (-1)", then we scored "increasing", "stable" or "decreasing", respectively (Table A.3). If any category does not reach 31 fishers, then we scored "insignificant (0)". The catch trend does not always mean the stock trend because several factors are responsible for catch trend, including the change in fishing effort or improvement of catchability or subjective decision.

3.3 Results

3.3.1 Species composition

A total of 130 species were found to interact with Hilsa gillnet fishing (including Hilsa as the target stock) across habitats. The inland bycatch comprised of 36 teleosts belonging to 16 different families, and the marine bycatch included 84 teleosts and 9 elasmobranches (3 sharks and 6 rays) belonging to 44 families (Figure 3.5 and Tables 3.4 and 3.5, and Table A.2). Sciaenidae, Arridae, Clupeidae, Scombridae, Carangidae, and Engraulidae appeared to be the most interacted families with Hilsa gillnets from marine habitat, whereas catfish belonging to the Bagridae, Schilbeidae, Sisoridae, Siluridae, Plotosidae, and Pangasidae families were the most common bycatch in inland habitats.

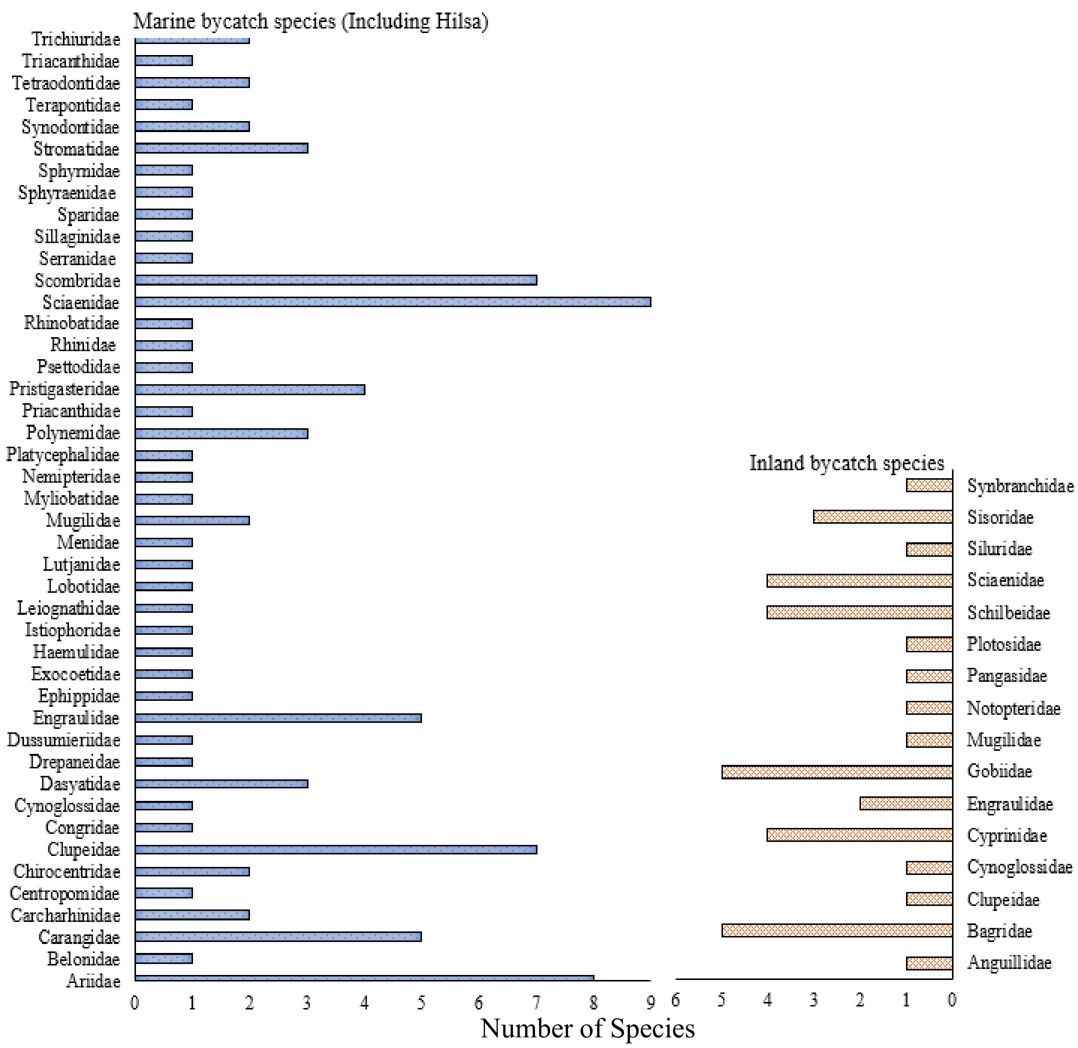

Figure 3.5 Bycatch species composition of Hilsa gillnet fishing in both marine and inland habitats by family.

3.3.2 Productivity susceptibility analysis

Among the 130 identified species from Hilsa gillnet fishing, target stocks Hilsa and 74 bycatch species of Hilsa gillnet fishing (Table 3.4 and Table 3.5) were assigned productivity and susceptibility scores. 41 marine and 14 inland bycatch species being excluded from the PSA as they are infrequently caught by Hilsa gillnets (Table A.2). The resulting vulnerability scores are given in Tables 3.4 and 3.5. The target stock, Hilsa, received a vulnerability score of 1.95 (moderately vulnerable) from its productivity score of 2.58 and its susceptibility score of 2.9. For the marine bycatch, productivity and susceptibility scores ranged from 1.33 to 2.75 and 2.0 to 2.8, respectively (Table 3.4). Based on the productivity scores, 38.3% of the bycatch species were of moderate productivity, followed by 35.4% of high productivity and 26.3% of low productivity. However, the majority of stocks (53%) received higher susceptibility scores (Figure 3.6). For inland bycatch species, productivity scores had a higher range, 1.42 to 2.83, than susceptibility scores, 2.11 to 2.89 (Table 3.5). Although 37.50% of the inland bycatch had lower productivity scores, the majority were highly susceptible to fishing (Figure 3.6).

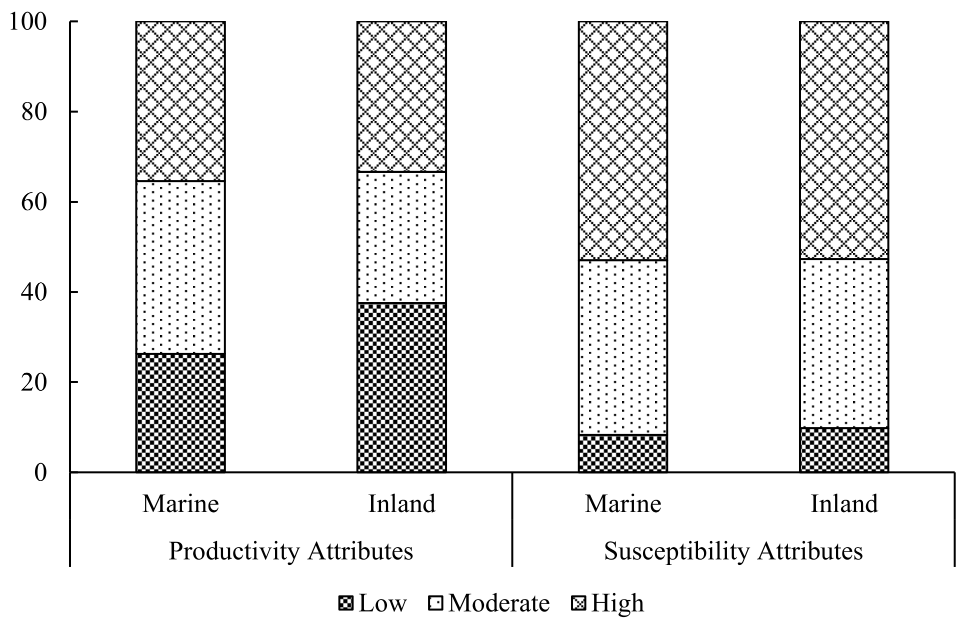

Figure 3.6 Overall productivity and susceptibility of marine and inland bycatch species from Hilsa gillnets fishery (%) of Bangladesh.

The relative risks faced by bycatch species are displayed in Figures 3.7 and 3.8. Three tiers of vulnerability emerged from our PSA analysis. Ten bycatch species (*Arius arius, Eleutheronema tetradactylum, Leptomelanosoma indicum, Nemapteryx caelata, Netuma thalassina, Polynemus paradiseus, Protonibea diacanthus, Sciades sona, Scomberoides* *commersonnianus,* and *Trichiurus lepturus*) from marine habitats and seven bycatch species (*Anguilla bengalensis, Chitala chitala, Pangasius pangasius, Plotosus canius, Silonia silondia, Sperata aor,* and *Wallago attu*) from inland habitats were placed in higher risk categories. Twenty nine marine bycatch and seven inland bycatch received the low vulnerability scores. Rest of the species were at the moderate risk category.

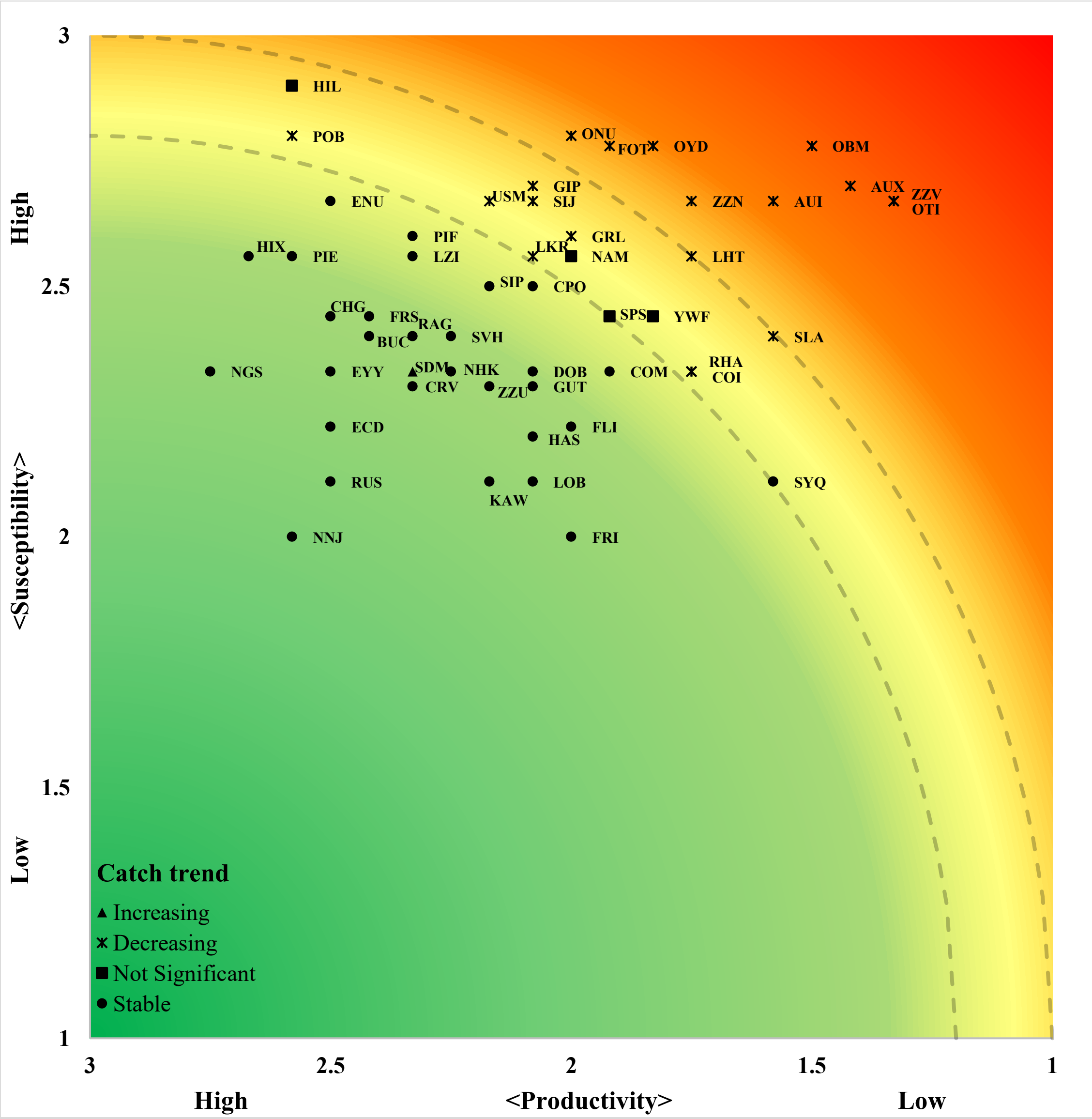

Figure 3.7 Two-dimensional PSA chart for the target species (Hilsa, HIL) and other marine bycatch species. Contour lines denote vulnerability values (V) of 1.8 and 2.0, with vulnerability categories defined as low ($V < 1.8$), moderate ($1.8 \leq V < 2$), and high ($V \geq 2$). The scientific and common names associated with species identification codes (3-alpha FAO codes) are provided in Table 3.4. Different marker shows the catch trend of the species.

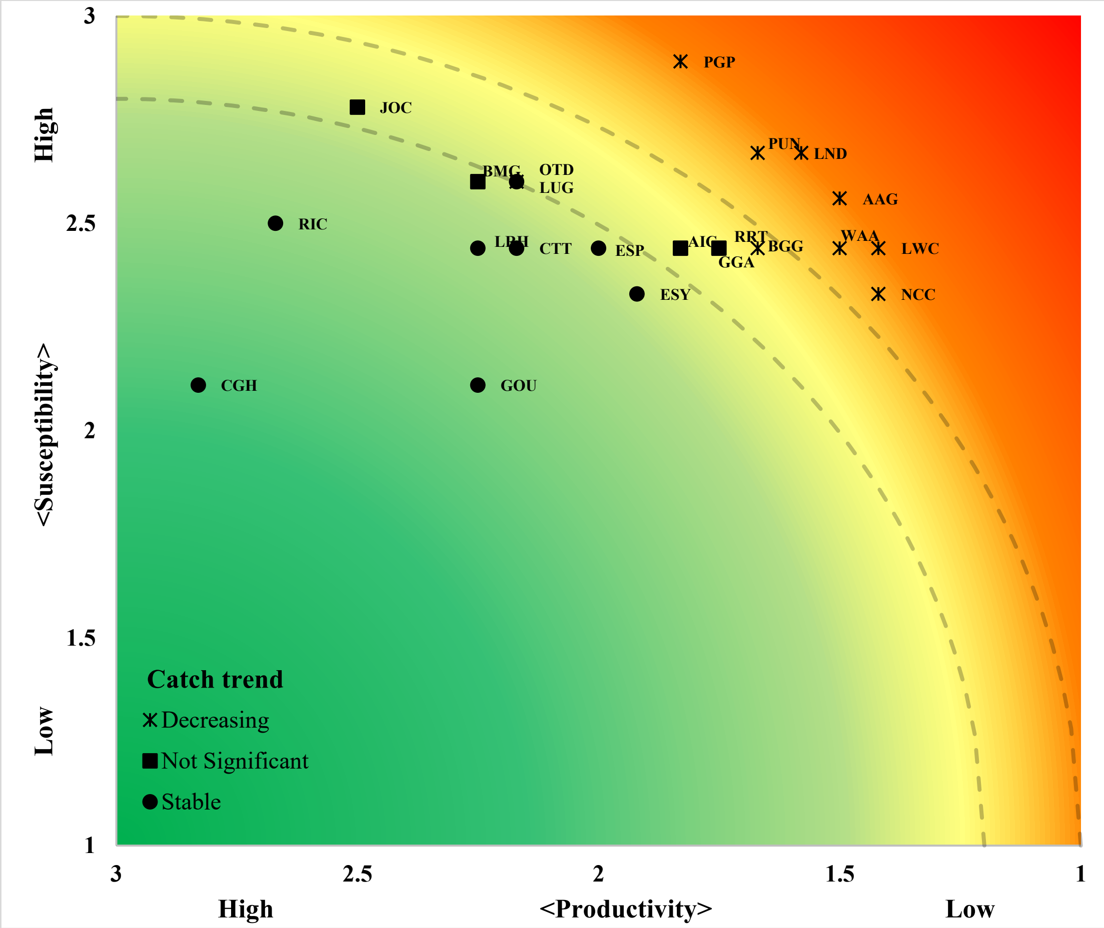

Figure 3.8 Two-dimensional PSA plot for inland bycatch species. Contour lines denote vulnerability values (V) of 1.8 and 2.0 with vulnerability categories defined as low ($V < 1.8$), moderate ($1.8 \leq V < 2$), and high ($V \geq 2$)**.** The scientific and common names associated with species identification codes (3-alpha FAO codes) are provided in Table 3.5. Different marker shows the catch trend of the species.

The overall data quality value for the vulnerability of Hilsa was 1.74, indicating high data quality (Table 3.4). For the marine bycatch, 83% of the stocks received low data quality scores for productivity attributes, ranging from 3.0 to 3.67. However, data quality scores for susceptibility did not exceed 3.0, and most (92%) were categorized as being of moderate data quality. This indicates that the data quality for susceptibility attributes was greater than the data quality for productivity attributes. Overall data quality for vulnerability in the marine bycatch varied between 2.18 and 3.11, denoting moderate to low data quality. Likewise, the majority (59%) of the inland bycatch received low data quality scores for productivity attributes, with the rest being categorized as being of moderate data quality. However, the data quality scores for susceptibility attributes varied between 1.67 and 2.33 (Table 3.5), reflecting a high to moderate data quality. Finally, the overall data quality scores for 95% of the inland bycatch ranged between 2.05 and 2.93, denoting moderate data quality.

Table 3.4 PSA results for marine bycatch including Hilsa as the target species of the Hilsa gillnet fishery of Bangladesh.

Scientific Name	Common Name	Family	FAO code	*P*	*S*	*V*	VC	VSER	DQSP	DQCP	DQSS	DQCS	ODQS	ODQC	IUCN N/G*	CT	EXS	E
Tenualosa ilisha	Indian/Hilsa shad	Clupeidae	HIL	2.58	2.90	1.95	M	2.04	1.67	M	1.80	H	1.74	H	LC	NS	OF	0.59
Acanthopagrus latus	Yellowfin seabream	Sparidae	YWF	1.83	2.44	1.86	M	1.90	3.50	L	2.44	M	2.97	M	DD*	NS	OF	
Anodontostoma chacunda	Chacunda gizzard shad	Clupeidae	CHG	2.50	2.44	1.53	L	1.58	3.50	L	2.11	M	2.81	M	LC	S	UF	
Arius arius	Spotted catfish	Ariidae	AUI	1.58	2.67	2.19	H	2.25	3.42	L	2.11	M	2.76	M	LC*	D	OF	
Auxis thazard	Frigate tuna	Scombridae	FRI	2.00	2.00	1.41	L	1.41	3.42	L	2.22	M	2.82	M	LC*	S	UF	
Carangoides malabaricus	Malabar trevally	Carangidae	NGS	2.75	2.33	1.36	L	1.40	3.17	L	2.44	M	2.81	M	LC*	S	UF	
Chelon subviridis	Greenback mullet	Mugilidae	LZI	2.33	2.56	1.69	L	1.76	3.25	L	2.11	M	2.68	M	LC	S	UF	
Chirocentrus dorab	Dorab wolf-herring	Chirocentridae	DOB	2.08	2.33	1.62	L	1.65	3.58	L	2.44	M	3.01	L	LC*	S	UF	
Coilia dussumieri	Goldspotted grenadier anchovy	Engraulidae	ECD	2.50	2.22	1.32	L	1.35	3.08	L	1.78	H	2.43	M	LC	S	UF	
Coilia ramcarati	Ramcarat grenadier anchovy	Engraulidae	**ZZU**	2.17	2.30	1.54	L	1.57	2.67	M	1.80	H	2.23	M	LC	S	UF	0.87
Conger cinereus	Conger eel	Congridae	COI	1.75	2.33	1.83	M	1.86	3.67	L	2.56	M	3.11	L	LC*	D	OF	
Decapterus russelli	Indian scad	Carangidae	RUS	2.50	2.11	1.22	L	1.23	3.50	L	2.56	M	3.03	L	LC*	S	UF	
Dendrophysa russelii	Goatee croaker	Sciaenidae	ENU	2.50	2.67	1.74	L	1.82	3.67	L	2.44	M	3.06	L	NE*	S	UF	
Drepane punctata	Spotted sicklefish	Drepaneidae	SPS	1.92	2.44	1.81	M	1.85	3.67	L	2.44	M	3.06	L	LC*	NS	OF	
Eleutheronema tetradactylum	Fourfinger threadfin	Polynemidae	FOT	1.92	2.78	2.08	H	2.17	3.17	L	2.11	M	2.64	M	NE*	D	OF	
Euthynnus affinis	Kawakawa	Scombridae	KAW	2.17	2.11	1.39	L	1.40	3.42	L	2.11	M	2.76	M	LC*	S	UF	
Harpadon nehereus	Bombay-duck	Synodontidae	BUC	2.42	2.40	1.52	L	1.56	3.08	L	2.00	M	2.54	M	NT*	S	UF	0.58
Hilsa kelee	Kelee shad	Clupeidae	HIX	2.67	2.56	1.59	L	1.66	3.42	L	2.00	M	2.71	M	LC	S	UF	
Ilisha filigera	Coromandel ilisha	Pristigasteridae	PIF	2.33	2.60	1.73	L	1.80	3.08	L	1.80	H	2.44	M	LC	S	UF	0.40
Ilisha melastoma	Indian ilisha	Pristigasteridae	PIE	2.58	2.56	1.61	L	1.68	3.58	L	1.78	H	2.68	M	DD	S	UF	
Lates calcarifer	Giant perch	Centropomidae	GIP	2.08	2.70	1.93	M	2.00	2.67	M	2.20	M	2.44	M	LC*	D	OF	0.37
Leptomelanosoma indicum	Lakhua	Polynemidae	OYD	1.83	2.78	2.13	H	2.21	3.50	L	2.56	M	3.03	L	NE*	D	OF	
Lepturacanthus savala	Savalani hairtail	Trichiuridae	SVH	2.25	2.40	1.59	L	1.63	3.25	L	2.20	M	2.73	M	NE*	S	UF	0.43
Lobotes surinamensis	Tripletail	Lobotidae	LOB	2.08	2.11	1.44	L	1.45	3.67	L	2.33	M	3.00	L	LC*	S	UF	
Megalaspis cordyla	Torpedo scad	Carangidae	HAS	2.08	2.20	1.51	L	1.53	3.00	L	2.20	M	2.60	M	LC*	S	UF	0.33
Nemapteryx caelata	Thickspined catfish	Ariidae	**ZZN**	1.75	2.67	2.08	H	2.15	3.42	L	2.22	M	2.82	M	NE*	D	OF	
Nemipterus japonicus	Japanese threadfin bream	Nemipteridae	NNJ	2.58	2.00	1.08	L	1.08	3.33	L	2.20	M	2.77	M	LC*	S	UF	0.41
Netuma thalassina	Giant catfish	Ariidae	AUX	1.42	2.70	2.32	H	2.38	2.92	M	2.10	M	2.51	M	NE*	D	OF	0.62

Scientific Name	Common Name	Family	FAO code	*P*	*S*	*V*	VC	VSER	DQSP	DQCP	DQSS	DQCS	ODQS	ODQC	IUCN N/G*	CT	EXS	E
Otolithes ruber	Tigertooth croaker	Sciaenidae	LKR	2.08	2.56	1.81	M	1.87	3.67	L	2.33	M	3.00	L	NE*	D	OF	
Pampus argenteus	Silver pomfret	Stromatidae	SIP	2.17	2.50	1.72	L	1.76	2.83	M	2.00	M	2.42	M	NE*	S	UF	0.23
Pampus chinensis	Chinese silver pomfret	Stromatidae	CPO	2.08	2.50	1.76	L	1.81	3.00	L	2.00	M	2.50	M	NE*	S	UF	0.36
Panna microdon	Panna croaker	Sciaenidae	NAM	2.00	2.56	1.85	M	1.91	3.58	L	2.33	M	2.96	M	NE*	NS	OF	
Parastromateus niger	Black pomfret	Stromatidae	POB	2.58	2.80	1.85	M	1.93	2.58	M	2.10	M	2.34	M	LC*	D	OF	0.56
Pennahia anea	Tigertooth croaker	Sciaenidae	NHK	2.25	2.33	1.53	L	1.57	3.67	L	2.11	M	2.89	M	NE*	S	UF	
Pennahia argentata	Silver croaker	Sciaenidae	CRV	2.33	2.30	1.46	L	1.49	3.50	L	2.30	M	2.90	M	NE*	S	UF	0.29
Platycephalus indicus	Bartail flathead	Platycephalidae	FLI	2.00	2.22	1.58	L	1.60	3.42	L	2.33	M	2.88	M	LC	S	UF	
Polynemus paradiseus	Paradise threadfin	Polynemidae	ONU	2.00	2.80	2.06	H	2.14	2.58	M	2.20	M	2.39	M	LC*	D	OF	0.72
Pomadasys argenteus	Silver grunt	Haemulidae	GRL	2.00	2.60	1.89	M	1.94	3.33	L	2.10	M	2.72	M	LC*	D	OF	0.51
Protonibea diacanthus	Blackspotted croaker	Sciaenidae	OTI	1.33	2.67	2.36	H	2.42	3.50	L	2.33	M	2.92	M	NE*	D	OF	
Pterotolithus maculatus	Blotched tiger-toothed croaker	Sciaenidae	USM	2.17	2.67	1.86	M	1.94	3.25	L	2.56	M	2.90	M	LC*	D	OF	
Rastrelliger kanagurta	Indian mackerel	Scombridae	RAG	2.33	2.40	1.55	L	1.59	2.25	M	2.10	M	2.18	M	DD*	S	UF	0.65
Rhizoprionodon acutus	Grey sharpnose shark	Carcharhinidae	RHA	1.75	2.33	1.83	M	1.86	3.42	L	2.22	M	2.82	M	LC*	D	OF	
Sardinella fimbriata	Fringescale sardinella	Clupeidae	FRS	2.42	2.44	1.56	L	1.61	3.50	L	2.22	M	2.86	M	LC*	S	UF	
Sardinella melanura	Blacktip sardinella	Clupeidae	SDM	2.33	2.33	1.49	L	1.53	3.67	L	2.22	M	2.94	M	LC*	I	UF	
Sciades sona	Dusky catfish	Ariidae	**ZZV**	1.33	2.67	2.36	H	2.42	3.50	L	2.33	M	2.92	M	NE*	D	OF	
Scoliodon laticaudus	Spadenose shark	Carcharhinidae	SLA	1.58	2.40	1.99	M	2.02	2.92	M	2.20	M	2.56	M	NT*	D	OF	0.57
Scomberoides commersonnianus	Doubledotted queenfish	Carangidae	OBM	1.50	2.78	2.33	H	2.40	3.67	L	2.33	M	3.00	L	LC*	D	OF	
Scomberomorus commerson	Narrow-barred spanish mackerel	Scombridae	COM	1.92	2.33	1.72	L	1.75	3.50	L	2.22	M	2.86	M	NT*	S	UF	
Scomberomorus guttatus	Indo-pacific king mackerel	Scombridae	GUT	2.08	2.30	1.59	L	1.62	2.58	M	2.20	M	2.39	M	DD*	S	UF	0.45
Sillaginopsis panijus	Flathead sillago	Sillaginidae	SIJ	2.08	2.67	1.90	M	1.98	3.00	L	2.22	M	2.61	M	LC	D	OF	
Strongylura leiura	Banded needlefish	Belonidae	SYQ	1.58	2.11	1.80	M	1.81	3.50	L	2.44	M	2.97	M	NE*	S	UF	
Thryssa mystax	Moustached thryssa	Engraulidae	EYY	2.50	2.33	1.42	L	1.46	3.67	L	2.33	M	3.00	L	LC*	S	UF	
Trichiurus lepturus	Largehead hairtail	Trichiuridae	LHT	1.75	2.56	2.00	H	2.05	3.67	L	2.44	M	3.06	L	LC*	D	OF	

P = weighted average of productivity attributes scores; *S* = weighted average of susceptibility attributes scores; *V* = vulnerability score; VC = vulnerability categories (low (L): $V < 1.8$, moderate (M): $1.8 \le V < 2$, and high (H): $V \ge 2$); VSER = vulnerability scores excluded regulations; DQSP = weighted average data quality scores for productivity attributes; DQCP = data quality categories for productivity attributes (high (H): DQ < 2, moderate (M): 2 ≤ DQ < 3, and low (L): DQ ≥ 3); DQSS = weighted average data quality scores for susceptibility attributes; DQCS = data quality categories for susceptibility attributes; ODQS = overall (mean) data quality scores computed from DQSP and DQSS; ODQC = overall data quality categories for vulnerability; and CT = catch trend (D = decreasing; I= increasing; NS = not significant; S = stable). The IUCN Red List refers to a species' risk of extinction (where IUCN N/G* = IUCN national/global extinction risk). The exploitation status (EXS) of the given species is computed using *V* (underfishing (UF): $V \le 1.8$ and overfishing (OF): $V > 1.8$); E = exploitation rate, as derived from fishing mortality as a proportion of total mortality. We assign codes for *Coilia ramcaratic* (ZZU), *Nemapteryx caelata* (ZZN), and *Sciades sona* (ZZV) (in bold) as no 3-alpha FAO codes were available for these species.

Table 3.5 PSA results for inland bycatch species of the Hilsa gillnet fishery of Bangladesh.

Scientific Name	Common Name	Family	FAO code	*P*	*S*	*V*	VC	VSER	DQSP	DQCP	DQSS	DQCS	ODQS	ODQC	IUCN N	CT	EXS	*E*
Ailia coila	Gangetic ailia	Schilbeidae	AIC	1.83	2.44	1.86	M	1.90	3.00	L	1.78	H	2.39	M	LC	NS	OF	
Anguilla bengalensis	Indian mottled eel	Anguillidae	AAG	1.50	2.56	2.16	H	2.21	2.92	M	2.00	M	2.46	M	VU	D	OF	
Bagarius bagarius	Goonch	Sisoridae	BGG	1.67	2.44	1.97	M	2.01	3.75	L	2.11	M	2.93	M	CR	D	OF	
Chitala chitala	Clown knifefish	Notopteridae	NCC	1.42	2.33	2.07	H	2.10	3.00	L	2.11	M	2.56	M	EN	D	OF	
Clupisoma garua	River catfish	Schilbeidae	LUG	2.17	2.60	1.80	M	1.86	2.58	M	1.90	H	2.24	M	EN	D	UF	0.34
Gagata gagata	Yellow spotted trevally	Sisoridae	GGA	1.75	2.44	1.91	M	1.95	3.75	L	2.33	M	3.04	L	LC	NS	OF	
Gibelion catla	Catla	Cyprinidae	CTT	2.17	2.44	1.67	L	1.72	2.67	M	1.67	H	2.17	M	LC	S	UF	
Glossogobius giuris	Tank goby	Gobiidae	GOU	2.25	2.11	1.34	L	1.35	2.58	M	2.22	M	2.40	M	LC	S	UF	
Gudusia chapra	Indian river shad	Clupeidae	CGH	2.83	2.11	1.12	L	1.14	2.25	M	1.89	H	2.07	M	VU	S	UF	
Johnius coitor	Coitor croaker	Sciaenidae	JOC	2.50	2.78	1.85	M	1.94	3.17	L	2.22	M	2.69	M	LC	NS	OF	
Labeo rohita	Roho labeo	Cyprinidae	LRH	2.25	2.44	1.63	L	1.68	2.42	M	1.67	H	2.05	M	LC	S	UF	
Mystus gulio	Long whiskers catfish	Bagridae	BMG	2.25	2.60	1.77	L	1.83	2.58	M	1.80	H	2.19	M	NT	NS	UF	0.47
Otolithoides pama	Pama croaker	Sciaenidae	OTD	2.17	2.60	1.80	M	1.86	2.83	M	2.20	M	2.52	M	LC	S	UF	0.27
Pangasius pangasius	Yellowtail catfish	Pangasidae	PGP	1.83	2.89	2.22	H	2.32	3.33	L	2.00	M	2.67	M	EN	D	OF	
Plotosus canius	Gray eel catfish	*Plotosidae*	PUN	1.67	2.67	2.13	H	2.20	3.17	L	2.11	M	2.64	M	NT	D	OF	
Rhinomugil corsula	Corsula mullet	*Mugilidae*	RIC	2.67	2.50	1.54	L	1.59	2.58	M	2.10	M	2.34	M	LC	S	UF	0.42
Rita rita	Rita	Bagridae	RRT	1.75	2.44	1.91	M	1.95	3.25	L	2.11	M	2.68	M	EN	D	OF	
Setipinna phasa	Gangetic hairfin anchovy	Engraulidae	ESP	2.00	2.44	1.76	L	1.80	3.42	L	1.89	H	2.65	M	LC	S	UF	
Setipinna taty	Scaly hairfin anchovy	Engraulidae	ESY	1.92	2.33	1.72	L	1.75	3.50	L	1.89	H	2.69	M	LC	S	UF	
Silonia silondia	Silond catfish	Schilbeidae	LND	1.58	2.67	2.19	H	2.25	3.00	L	1.89	H	2.44	M	LC	D	OF	
Sperata aor	Long whiskered catfish	Bagridae	LWC	1.42	2.44	2.14	H	2.18	3.58	L	2.11	M	2.85	M	VU	D	OF	
Wallago attu	Wallago	Siluridae	WAA	1.50	2.44	2.08	H	2.12	3.42	L	2.11	M	2.76	M	VU	D	OF	

P = weighted average of productivity attributes scores; *S* = weighted average of susceptibility attributes scores; *V* = vulnerability scores; VC = vulnerability categories (low (L): $V < 1.8$, moderate (M): $1.8 \leq V < 2$, and high (H): $V \geq 2$); VSER = vulnerability scores excluded regulations; DQSP = weighted average data quality scores for productivity attributes; DQCP = data quality categories for productivity attributes (high (H): DQ < 2, moderate (M): 2 ≤ DQ < 3, and low (L): DQ ≥ 3; DQSS = weighted average data quality scores for susceptibility attributes; DQCS = data quality categories for susceptibility attributes; ODQS = overall (mean) data quality scores computed from DQSP and DQSS; ODQC = overall data quality categories for vulnerability; and CT = catch trend (D = decreasing; I= increasing; NS = not significant; S = stable). The IUCN Red List refers to species' risk of extinction (where IUCN N = IUCN national extinction risk). The exploitation status (EXS) of a given species is computed using *V* (underfishing (UF): $V \leq 1.8$ and overfishing (OF): $V > 1.8$). *E* = exploitation rate, as derived from fishing mortality as a proportion of total mortality.

3.3.3 Comparison of the vulnerability results with the IUCN extinction risk, the exploitation rate, and catch trend

According to the IUCN Red List, among the recorded inland bycatch species nine were in the "threatened" category (one CR species, four EN Species, four VU species); two species were categorized as "near threatened" (NT); and the rest were in the "least concern" (LC) category (Table 3.5 and Figure 3.9a). Five species, namely *Anguilla bengalensis* (P score of 1.50)*, Chitala chitala* (1.42)*, Pangasius pangasius* (1.83)*, Sperata aor* (1.42)*,* and *Wallago attu* (1.50) were found to be in the high-risk category that were also in threatened categories by IUCN Red List. *Bagarius bagarius* was categorized as the CR by IUCN; however, our analysis evaluated this species as moderately vulnerable (V = 1.97). All the "least concern" species except *Silonia silondia,* which was recognized as a highly vulnerable bycatch species, were placed in the low to moderate risk categories. *Plotosus canius* and *Mystus gulio* received high and low vulnerability scores, respectively, but were classified as "near threatened" species by the IUCN. We assessed *Gudusia chapra* as moderately vulnerable species due to Hilsa gillnet fishing, although it was categorized as the VU species in IUCN Red List.

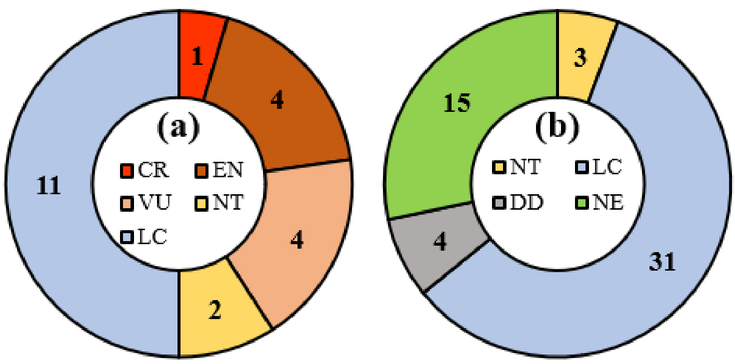

Figure 3.9 Pie chart showing the IUCN Red List categories for Hilsa and bycatch species: (a) inland bycatch species; (b) Hilsa and marine bycatch species. Values represent the number of species in each category (NE = not evaluated, DD = data deficient, LC = least concerned, NT = near threatened, VU = vulnerable, EN = endangered, and CR = critically endangered).

Around 58% (n = 31) of the marine bycatch species (but also including Hilsa) were in the LC category, followed by 28% (n = 15) in the NE category, 8% (n = 4) in the DD category, and 6% (n = 3) in the NT category (Figure 3.9b). *Arius arius, Polynemus paradiseus, Scomberoides commersonnianus*, and *Trichiurus lepturus* of the LC category, and *Eleutheronema tetradactylum, Leptomelanosoma indicum, Nemapteryx caelata, Netuma thalassina, Protonibea diacanthus,* and *Sciades sona* of the NE category were found to be at high risk. *Harpadon nehereus* (V = 1.52) and *Scomberomorus commerson* (V = 1.72) were found to be at low risk category, whereas and *Scoliodon laticaudus* (V = 1.99) were classified as moderately vulnerable species in our PSA. However, these three species were placed in NT category by IUCN global assessment.

We compared the exploitation status of 22 species using our vulnerability scores and exploitation rates. We found an accordance level of 82% (Figure 3.10, and Tables 3.4 and 3.5). Our study also revealed that around 55% of the inland bycatch and 42% of the marine bycatch was associated with overfishing (V > 1.8) based on the definition of Patrick et al. (2009) (Tables 3.4 and 3.5).

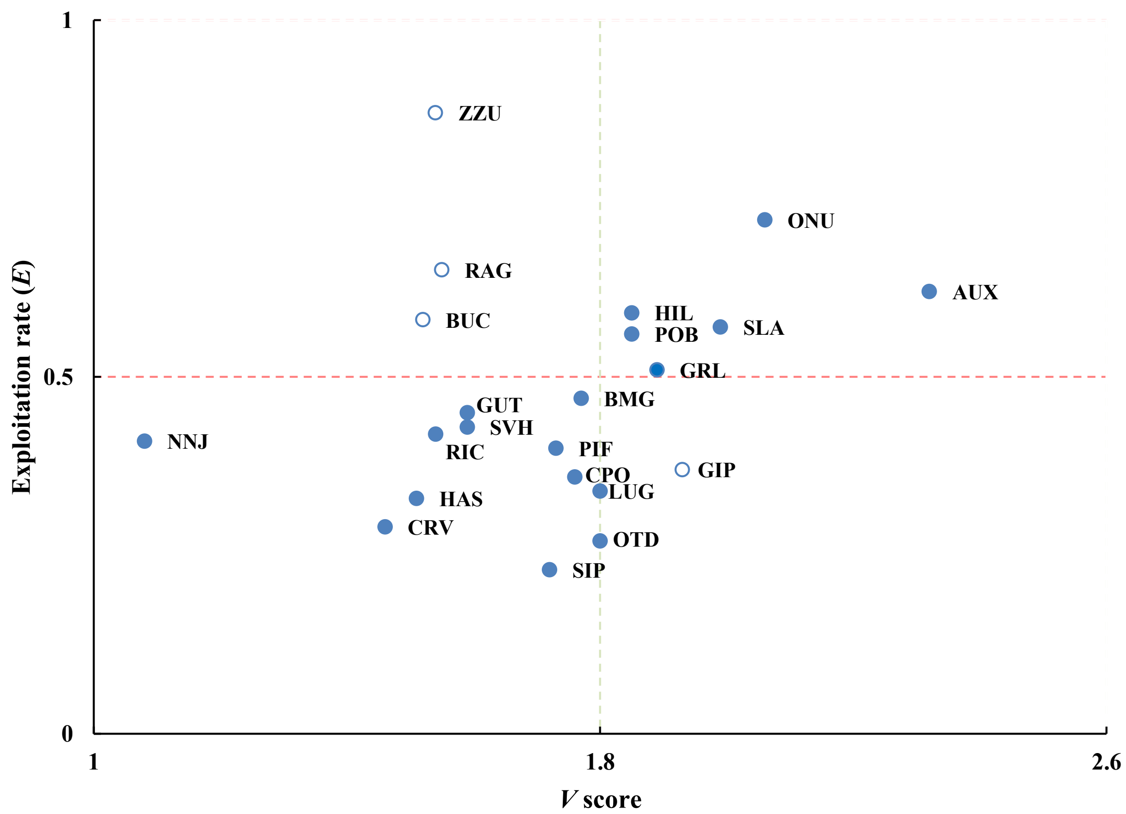

Figure 3.10 A comparison of the exploitation rate (E) and the vulnerability scores (V score) of the assessed species. An exploitation rate above 0.5 denotes overfishing and a rate below 0.5 denotes underfishing. For Hilsa (*Tenualosa ilisha*), we used the mean value to derive the exploitation rate. Based on the definition of Patrick et al. (2014), V score over 1.8 reflects overfishing condition and $V \leq 1.8$ denotes the underfishing condition. Solid points represent similarity condition between the E and V score (when $V > 1.8$ and $E > 0.5$ = overfishing, or $V \leq 1.8$ and $E < 0.5$ = underfishing). The scientific and common names associated with species identification codes (3-alpha FAO codes) are provided in Table 3.4 and 3.5.

Our finding also indicated that vulnerability scores of species with “stable or increasing”, “insignificant” and “decreasing” catch trends ranged from 1.08–1.8, 1.77–1.95, and 1.8–2.36, respectively (Tables 3.4 and 3.5). There was only one species, *Sardinella melanura*, in “increasing” catch trend with V score of 1.49. There was only one species in split evaluation, in which $V \leq 1.8$ with decreasing catch trend (*Clupisoma garua*), if we choose V=1.80 as threshold. There were three species whose V score were 1.8, *Clupisoma garua*, *Otolithoides pama* from marine, and *Strongylura leiura* from inland, the latter two of which had “stable or increasing” catch trend. Therefore, the catch trends met the vulnerability scores very well if we assume V=1.8 as threshold. Our analysis revealed that species with V score over 1.8 were mostly at stock depleted state.

3.4 Discussion

3.4.1 Species composition

We recorded 130 species of fish that were interacted with Hilsa gillnets across major Hilsa fishing zones. Number of species interacted with a particular gear type is affected by the relative abundance of the fish in that particular habitat besides other factors like depth fished and relative position of the fish in water column, gears efficiency, etc. (Rincón-Sandoval et al., 2019). Catfish from various families made up the largest proportion of bycatch species from surveyed inland areas. Knowledge about the affected species within a particular fishing practice is crucial for achieving a better understanding of an ecosystem’s well-being and the level of impact on non-target species (Lin et al., 2020).

3.4.2 Productivity susceptibility analysis

Hilsa, as the target species, had higher susceptibility scores than any of the other species affected by Hilsa gillnet fishing, similar to Ormseth and Spencer’s (2011) report of higher susceptibility scores for their target stock of Alaskan groundfish. In our study, both the inland and marine bycatch species displayed a wide range of life-history traits, which suggest diverse productivities within bycatch stocks. However, susceptibility scores clustered at higher levels (Figure 3.6). This was likely due to the species’ shapes and morphological characteristics, the positioning and depth of the species in the water and the depths fished by gillnets, the grouping of stocks in fishing areas, fisher’s tendency to retain bycatch, and the commercial values of the bycatch species (Raby et al., 2011; Skomal, 2007; Stein et al., 2004).

According to our PSA, catfish were in the high vulnerability category. This was because of their intrinsic biological characteristics, such as their larger maximum size, delayed maturity, slow growth rate, longer lifespan, and low natural mortality, coupled with their moderate to high market demand, vertical and areal overlap with Hilsa gillnets fishing. A sharp declining trend in the volume of landed catfish from 1987 to 2016 was reported by Roy et al. (2019).

The target stock, Hilsa, possessed the highest data quality score because the biological attributes of Hilsa have been extensively studied (Milton, 2010). However, the majority of the bycatch, either from inland or marine habitats, received low data quality scores for productivity, indicating lack of species-specific biological information within Bangladeshs' water areas (Hussain et al., 2017). For susceptibility scoring, we used the data available in the existing literature as well as the data (e.g., the depth of fishing, market demand, and value of fishes) collected from experienced Hilsa fishers and through direct observation. The inclusion of the stakeholder knowledge, particularly in the case of susceptibility scoring, improved the reliability and consistency of PSA results (Roux et al., 2019).

3.4.3 Comparison of the vulnerability results with other assessment methods

In our analysis, five inland bycatch species were in the high-risk category by PSA, also known to be at threatened species listed in the national IUCN Red List (IUCN, 2015). Fujita et al. (2014) reported that species classified as threatened group (VU, EN or CR) by IUCN Red List mostly appeared at higher risk category in PSA outcomes. Osio et al. (2015) found consistency in their analysis when comparing the vulnerability scores from PSA with IUCN Red List for Mediterranean demersal stocks.

Despite being categorized as the vulnerable species by IUCN Red List (IUCN, 2015), *Gudusia chapra* were assessed as moderately vulnerable (V = 1.12) in our PSA. Overexploitation due to use of fine meshed net (e.g., seine net) and habitat loss (e.g., wetland habitat) are the major causes of *Gudusia chapra* population decline (IUCN, 2015). *Gudusia chapra* is smaller in size and is more regularly caught by other fishing methods, including the use of seine nets (Shafi and Quddus, 1982), and mostly forages in the middle and upper reaches of rivers (Rahman, 2005), such that our research only captures a small proportion of this fishing, related to Hilsa gillnet fishing. Global and national assessments of IUCN Red List do not necessarily match. For instance, IUCN Bangladesh marked *Sperata aor* as a vulnerable species (IUCN, 2015), but the same species is placed within the "least concern" category by the IUCN at the global level (Devi and Raghavan, 2011). Therefore, PSA and IUCN Red List cannot be effectively compared in marine bycatch species.

Lates calcarifer was identified as being overexploited by our PSA result, but they received an underfishing status based on the exploitation rate (Figure 3.10). This gap could be attributed to limited coverage of sample areas (Mustafa et al., 2019). Conversely, our study identified *Coilia ramcarati*, *Harpadon nehereus* and *Rastrelliger kanagurta* as being underfished ($V \leq 1.8$), despite these species being categorized as subject to overfishing by previous research based on exploitation rate ($E > 0.5$) (Figure 3.10) (Parvez and Nabi, 2015; Sarker et al., 2017). *Coilia ramcarati* and *Harpadon nehereus* are typically caught by set bag nets and seine nets, and *Rastrelliger kanagurta* is mostly exploited by the trawl net (Rahman et al., 2009). The exploitation rate is conventionally calculated as the ratio of fishing mortality to total mortality (Gulland 1971), where fishing mortality can vary across gear types, gear efficiency, and fish abundance (Fraser et al., 2007; Walker et al., 2017). Hence, a lack of comparability could explain this result. Our analysis suggested that around half of the species assessed were associated with the overfishing problem (when $V > 1.8$).

With few exceptions, species with vulnerability scores over 1.8 are mostly showed the decreasing catch trend. This finding that most commercially important fish stocks are either overexploited or threatened is consistent with that of Islam (2003) and Hussain et al. (2017).

3.4.4 How did existing fisheries regulation reduce susceptibility and overall vulnerability scores?

Several management measures are in place to protect the Hilsa stocks of Bangladesh. However, during our field survey, we observed extensive usage of the illegal Hilsa fishing gillnet—monofilament gillnet locally called as Current Jal— or gillnets with the unauthorized mesh size of < 4.5 cm, particularly in the inland Hilsa fishing areas. In addition, the effectiveness of some management measures is also uncertain. For instance, while the use of Hilsa gillnets with a mesh size ≥ 4.5 cm is permitted in Bangladesh, during our survey time, we found around 34% of undersized fish and immature, i.e., juvenile Hilsa, were being captured with those legal meshed gillnets (data available on request). We presume that protection of juvenile of target species will reduce bycatch of smaller vulnerable fish like *Septipinna phasa, Strongylura leiura*. However, some precautionary management action are needed to protect the highly vulnerable species like catfishes as these species are low productive but highly susceptible to Hilsa gillnet fishing.

The number of high-risk species ($V \geq 2$) without the existing fisheries regulations increased from 17 species to 21 species (Table 3.4 and 3.5). Furthermore, existing regulations decreased the number of overfished stock ($V > 1.8$) from 41 species to 35 species (Table 3.4 and 3.5). Strict enforcement of the existing regulations, and amendment of mesh size regulations (i.e., increase of gillnet mesh size) and finally the fishers willingness to follow the rules can further improve the susceptibility score for some individual attributes (e.g., management strategy, fishing mortality relative to natural mortality, bycatch discard tendency), and reduce the overall risk directly to Hilsa stock and bycatch species.

3.5 Conclusion

The level of harmony across the results of different approaches (PSA, IUCN Red List, the exploitation rate, and catch trend) supports the validity of our findings. However, most bycatch stocks possessed low data quality index scores. It emphasizes the need for improved data collection on species-specific life-history traits. Unless more data are available for further assessment with a quantitative risk assessment approach, the baseline information of our PSA-derived outcomes could assist the fisheries manager in setting management measures to protect the vulnerable stocks from being collapse.

Acknowledgments

We would like to thank Dr. Kendra Karr of the Oceans Program at the Environmental Defense Fund for providing us with the Excel version of the PSA tool and associated guidance notes. We are also grateful to all the local fishery authorities in our surveyed areas for their support when conducting surveys. We are indebted to all the Hilsa fishers for providing valuable information about Hilsa fishery and its bycatch by taking part in face-to-face interviews and in FGDs. We also thank two anonymous reviewers for their insightful comments and suggestions that enhanced the quality of this article. This work was partially supported by the Joint Research Promotion Program (grant No 65A0515b), Graduate school of Environment and Information Sciences, Yokohama National University, Japan.

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Chapter 4

Conservative Scoring Approach in Productivity Susceptibility Analysis Leads to an Overestimation of Vulnerability

Publication base on this chapter

Hasan Faruque and Hiroyuki Matsuda (2021). Conservative Scoring Approach in Productivity Susceptibility Analysis Leads to an Overestimation of Vulnerability: A Study from the Hilsa Gillnet Bycatch Stocks of Bangladesh. *Fishes*, 6(3), 33. https://doi.org/10.3390/fishes6030033

Conservative Scoring Approach in Productivity Susceptibility Analysis Leads to an Overestimation of Vulnerability: A Study from the Hilsa Gillnet Bycatch Stocks of Bangladesh

Abstract

Despite different approaches used to assign the risk scores for missing information in productivity susceptibility analysis (PSA)—a widely used semi-quantitative risk assessment tool for target and non-target fisheries stocks—for the selected attributes of a given species, no formal comparison has been made between scoring approaches in terms of how well they can predict species vulnerability. The present study evaluated the PSA findings of 21 bycatch stocks of the Hilsa (*Tenualosa ilisha*) gillnet fishery of Bangladesh using two different scoring approaches (the conservative scoring approach, CSA; and the alternative scoring approach, ASA) to determine the most reliable approach to minimize false estimates of species vulnerability. Our analysis revealed that the vulnerability (V) scores increased by 0.0–0.20 with a mean value of 0.09 for 21 selected bycatches when CSA was applied. The inconsistency between the V-score-suggested fishing status ($V \leq 1.8$ = underfishing, $V > 1.8$ = overfishing) and the fishing status defined by exploitation rate ($E > 0.5$ = overfishing, $E < 0.5$ = underfishing) were 38.1% and 19.0% under CSA and ASA, respectively. Likewise, the consistency between the V-score-suggested fishing status and fishers' perceived catch trends was found to be higher when using ASA than when using CSA. Our analysis suggests that CSA could overestimate species vulnerability. Therefore, ASA is more reliable than CSA in PSA, which may increase the confidence of fisheries stakeholders in PSA.

Keywords: *Tenualosa ilisha;* Indian shad; gillnet fishery; data-limited fishery; bycatch stock; risk assessment; precautionary approach; life-history parameters

4.1. Introduction

The sustainable management of fisheries resources is a challenging issue for fisheries managers across the world (Sumaila et al., 2016). Fisheries management benefits from accurate stock status estimates to apply harvest control rules and meet management objectives (Mace, 1994; Patrick et al., 2010). The stock status compared to different biological reference points (e.g., maximum sustainable yield) can be adequately made by conventional quantitative stock assessment method, particularly in data- and capacity-rich settings (Carruthers et al., 2016; Fujita et al., 2014).

Generally, large-scale fisheries target species with high commercial value. These species are subject to more detailed analyses of their life-history traits, productivity, etc., and are recognized as data-rich stocks. In contrast, the majority of small-scale fisheries, which account for half of the global fishery catches, are treated as data-limited fisheries (Costello et al., 2012; FAO, 2020). These small-scale fisheries lack the biological and catch data, resources, and expertise required to estimate stock status using conventional quantitative stock assessment techniques (Costello et al., 2012). Therefore, the actual statuses of most global fish stocks from small-scale fisheries remain unknown (Jennings et al., 1999). Such fisheries remain unmanaged or managed with insufficient scientific guidance, leading to suboptimal catch rates and adverse social and economic consequences for those who depend on fishing (Costello et al., 2016). These cases are particularly evident in tropical and subtropical regions where multi-species and multi-gear fisheries exist, and diverse groups of species are often discarded or retained as bycatches with low commercial value (Leadbitter, 2013).

Fishing activities, by definition, have a direct effect on the abundance of targeted fish stocks and populations and may also have a negative effect on the status of bycatch stocks (Hall and Mainprize, 2005). While bycatches are recognized as an important biological component of the ecosystem, bycatch stock status is insufficiently assessed using traditional quantitative stock assessment methods (Hobday et al., 2007) due to a lack of information (e.g., time series catch and effort data, life history data, etc.) (Briscoe et al., 2014; Lucena-Frédou et al., 2017). Following the increased need to address fishing's impacts on the whole range of exploited stocks, including bycatch species, fishery scientists have sought to develop comprehensive methods to assess the potential risk of various fishing types (gillnet fishing, seine net fishing, longline fishing, etc.) in data- and capacity-constrained situations where quantitative assessment is not feasible due to data scarcity (Smith et al., 2007; Zhou et al., 2009).

Risk or vulnerability assessment typically follows a semi-quantitative approach for data-limited stocks (Patrick et al., 2010). The semi-quantitative methods designed for evaluating fisheries' impacts on target or bycatch stocks (Lane and Stephenson, 1998; Stobutzki et al., 2001), extinction risk (Cheung et al., 2005; Musick, 1999), and impacts on ecosystem sustainability (Astles et al., 2006; Fletcher et al., 2005) typically facilitate the inclusion of both qualitative and quantitative information and a wide range of variables. One of the most widely recognized and used semi-quantitative assessment tools is called Productivity Susceptibility Analysis (hereafter referred to as PSA) (Hobday et al., 2011; Patrick et al., 2009). The PSA is currently being used and recommended by several fisheries management agencies, including the AFMA (Australian Fisheries Management Authority), ICCAT (The International Commission for the Conservation of Atlantic Tunas), IOTC (Indian Ocean Tuna Commission), MSC (Marine Stewardship Council), NMFS (National Marine Fisheries Service, USA), and WCPFC (Western and Central Pacific Fisheries Commission) (Cortés et al., 2010; Hobday et al., 2011; Lucena-Frédou et al., 2017; Patrick et al., 2009). Thousands of stocks and populations across the world, including target and bycatch fish stocks, sea birds, sea turtles, squids, octopus, and marine mammals, have already been assessed by PSA (Altuna-Etxabe et al., 2020; Hordyk and Carruthers, 2018).

The most general feature of PSA is that it compares the inherent recovery potential of species once depleted (i.e., productivity attributes) with the attributes of susceptibility (i.e., the impact of the fishery on fish stock) to fishing activities in elucidating overall vulnerability Hobday et al., 2011; Stobutzki et al., 2001). Since its first use in 2001 for evaluating the risk of an Australian Prawn fishery in terms of bycatch stocks, different modifications and improvements have been made to the PSA tool. These include increases in the number of attributes rated, the development of additive methods for calculating the weighted average score for productivity and susceptibility attributes, the inclusion of a five-tier data quality index, and the ability to test a range of alternative approaches for missing data (Patrick et al., 2009). Different scoring approaches, moreover, have been used by scientists to treat the missing data in PSA. One approach is to assign a score representing high risk when the data for a particular attribute is missing. This approach is known as the "precautionary or conservative scoring approach" in PSA (Hobday et al., 2011). In contrast, some authors have removed the missing attributes from PSA, and finally, PSA findings were interpreted using data-quality ratings (Patrick et al., 2009; 2010). Most recently, different empirical equations have been used to derive data from correlated life-history attributes when scoring the missing data for a particular attribute (Lin et al., 2020; Lucena-Frédou et al., 2017). For instance, the von Bertalanffy growth coefficient (*k*; how rapidly a fish reaches its maximum size) tends to be strongly related to fish's maximum age. Stocks with a long lifespan and low productivity tend to have a high *k*-value (Froese and Binohlan, 2000). In this way, it is possible to obtain the values for the growth coefficient of fish (if data on the growth coefficient is missing) by using an empirical relationship between the growth coefficient and the maximum age of the fish. While different approaches have been used to assign the scores for missing data for the attribute(s), to the best of our knowledge, no formal comparison has been made between the different scoring approaches for evaluating how well these approaches predict species vulnerability to fishing activities by judging the PSA outcomes through other analytical assessments (e.g., the exploitation rate, which indicates the overfishing or underfishing status of stocks, catch trends, etc.)

Under this background, the present study compared the results of PSA for the bycatch stocks of the Hilsa (*Tenualosa ilisha*) gillnet fishery of Bangladesh using two different scoring approaches to determine a more reliable and advisable approach that can reduce false estimates of species vulnerability. Two scoring approaches used in the PSA analysis were designated as conservative scoring approaches (CSAs), which assign the highest risk score based on missing information, and alternative scoring approaches (ASAs), which include expert opinions and/or the usage of an empirical relationship equation to derive missing data when the values of the correlated parameters are known, particularly for productivity attributes.

4.2 Materials and methods

4.2.1 Selection of bycatch species from Hilsa gillnet fishery of Bangladesh

Hilsa shad (*Tenualosa ilisha*), which constitutes the important fishery in the Bay of Bengal and Persian Gulf region, is the single most dominant species in Bangladeshi waters (Rahman et al., 2018). This transboundary species largely migrates from seawater to the estuarine and riverine ecosystem during its spawning time, and it is largely captured mostly by gillnets (Hossain et al., 2019). Gillnet fishing accounts for over 95% of the Hilsa catch in Bangladesh, which supports over 2.5 million peoples' livelihoods (DoF, 2019).

Hilsa fishers mainly focus on Hilsa as their target species. However, many other fishes are being captured by their gillnets due to the less selective nature of the gillnet itself and the multi-species characteristics of Bangladeshi fisheries. Faruque and Matsuda (2020) have recently identified and reported 129 bycatch species from Hilsa gillnet fishing in Bangladesh. This study considered 21 bycatch species from the Hilsa gillnet fishery for their vulnerability analysis with

PSA in two different scoring approaches. The species we have selected for PSA are given in Table 4.1.

Table 4.1 List of bycatch species from the Hilsa gillnet fishery of Bangladesh for vulnerability assessment with PSA.

Scientific Name	FAO species code	Common Name	Family	Order	Environment Preference
Clupisoma garua	LUG	River catfish	Ailiidae	Siluriformes	Freshwater, brackish
Coilia ramcarati	ZZU	Ramcarat grenadier anchovy	Engraulidae	Clupeiformes	Marine, brackish
Harpadon nehereus	BUC	Bombay-duck	Synodontidae	Aulopiformes	Marine, brackish
Ilisha filigera	PIF	Coromandel ilisha	Pristigasteridae	Clupeiformes	Marine, freshwater, brackish
Lates calcarifer	GIP	Giant Perch	Centropomidae	Carangiformes	Marine, freshwater, brackish
Lepturacanthus savala	SVH	Savalani hairtail	Trichiuridae	Scombriformes	Marine, brackish
Megalaspis cordyla	HAS	Torpedo scad	Carangidae	Carangiformes	Marine, brackish
Mystus gulio	BMG	Long whiskers catfish	Bagridae	Siluriformes	Freshwater, brackish
Nemipterus japonicus	NNJ	Japanese threadfin bream	Nemipteridae	Perciformes	Marine
Netuma thalassinus	AUX	Giant catfish	Ariidae	Siluriformes	Marine, freshwater, brackish
Otolithoides pama	OTD	Pama croaker	Sciaenidae	Perciformes	Marine, freshwater, brackish
Pampus argenteus	SIP	Silver pomfret	Stromatidae	Scombriformes	Marine
Pampus chinensis	CPO	Chinese silver pomfret	Stromatidae	Scombriformes	Marine, brackish
Parastromateus niger	POB	Black pomfret	Carangidae	Carangiformes	Marine, brackish
Pennahia argentata	CRV	Silver croaker	Sciaenidae	Perciformes	Marine
Polynemus paradiseus	ONU	Paradise threadfin	Polynemidae	Carangiformes	Marine, freshwater, brackish
Pomadasys argenteus	GRL	Silver grunt	Haemulidae	Perciformes	Marine, freshwater, brackish
Rastrelliger kanagurta	RAG	Indian mackerel	Scombridae	Scombriformes	Marine
Rhinomugil corsula	RIC	Corsula mullet	Mugilidae	Mugiliformes	Freshwater, brackish
Scoliodon laticaudus	SLA	Spadenose shark	Carcharhinidae	Carcharhiniformes	Marine, brackish
Scomberomorus guttatus	GUT	Indo-Pacific king mackerel	Scombridae	Scombriformes	Marine, brackish

The selected bycatch species belong to eight different orders in 17 families and most commonly inhabit marine and brackish water ecosystems, with some from freshwater habitats. We selected these 21 bycatch stocks for vulnerability evaluation because the exploitation status of these species from Bangladeshi waters was previously assessed from length-based data using a quantitative stock assessment tool (FAO-ICLARM stock assessment tools) (Table B.1). We compared this formal assessment outcome (i.e., exploitation rate, *E*) with our PSA assessment outcome to determine the consistency or inconsistency rate between two outcomes under two different scoring approaches, as described in Section 4.2.6.

4.2.2. Selection of productivity (*P*) and susceptibility (*S*) attributes for PSA

Flexibility in selecting the number of attributes makes the PSA more compatible than other semi-quantitative vulnerability assessment tools (Patrick et al., 2009). The selection of attributes for productivity or susceptibility scoring mainly depends on the availability of the data and its ability to represent vulnerability. However, a greater selection of attributes can help ensure that a sufficient number of attributes are rated (Patrick et al., 2010). We considered 12 productivity attributes (Table 4.2) and ten susceptibility attributes (Table 4.3) in our study.

Table 4.2 Productivity attributes and their scoring criteria were used to determine the productivity of the selected bycatch stocks from the Hilsa gillnet fishery in Bangladesh (adopted from Faruque and Matsuda, 2020).

Productivity attributes	**Low risk (3)**	**Moderate risk (2)**	**High risk (1)**
Maximum age (t_{max}, year)	<4	4–8	>8
Maximum size (L_{max}, cm)	<38	38–85	>85
Von Bertalanffy growth coefficient (k, yr^{-1})	>0.78	0.33–0.78	<0.33
Estimated natural mortality (M, yr^{-1})	>1.21	0.74–1.21	<0.74
Measured fecundity (MF)	>64136	10663–64136	<10663
Breeding strategy (BS)	Release eggs into the water column	Lay eggs in a nest and guard those eggs until hatching	Internal fertilization (/Live bearer) mouth brooding, or other strategies that involve full parental care
Age at first maturity (t_{mat}, years)	<1.0	1–2	>2
Mean trophic level (MTL)	<3.50	3.50–3.90	>3.90
Size at first maturity (L_{mat}, cm)	<19	19–38	>38
Breeding cycle (female)	Annual cycle with protracted breeding season	Annual cycle with a seasonal peak	Bi/Triennial
t_{mat}/ t_{max}	<0.25	0.25–0.30	>0.30
L_{mat} / L_{max}	<0.52	0.52–0.59	>0.59

The productivity of a species or population is heavily influenced by its intrinsic characteristics (Hobday et al., 2011). Among the 12 selected productivity attributes, the first eight attributes (e.g., maximum age, growth coefficient, and natural mortality) were taken from Patrick et al. (2010). These eight attributes are commonly used in PSA. Each of the selected attributes has an influence on species productivity. The remaining four productivity attributes—size at maturity (Hobday et al. 2011), breeding cycle (McCully Phillips et al., 2015), and maturity–size ratio and maturity–age ratio (Mejía-Falla et al., 2019)— were obtained from other works because of their strong correlation with the productivity of the stocks. Some attributes (maximum age, maximum size, and age and size of fish at maturity) are negatively correlated with species productivity, which means that species that attain a larger size, longer lifespan, and slower growth rate are less productive. Conversely, some attributes are positively correlated with population productivity (e.g., species with greater natural mortality tend to spawn more eggs to replenish the loss) (Roux et al., 2019). Likewise, among the 10 susceptibility attributes, the first eight attributes, which are commonly used in PSA (e.g., vertical overlap, seasonal migrations, management strategy, etc.), were chosen from Patrick et al. (2009). The market value of fish (USD/kg) and the market demand for fish were taken from Faruque and Matsuda (2020).

Table 4.3 A set of attributes and their scoring criteria were used to determine the susceptibility of the selected bycatch stocks from the Hilsa gillnet fishery in Bangladesh (adopted from Faruque and Matsuda, 2020).

Susceptibility attributes	**High risk (3)**	**Moderate risk (2)**	**Low risk (1)**
Areal overlap	>50% of the stock occurs in the area fished	Between 25% and 50% of the stock occurs in the area fished	<25% of stock occurs in the area fished
Vertical overlap	>50% of the stock occurs in the depths fished	Between 25% and 50% of the stock occurs in the depths fished	<25% of stock occurs in the depths fished
Seasonal migrations	Seasonal migrations increase overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations decrease overlap with the fishery
Schooling, aggregation, and other behavioral responses	Behavioral responses increase the catchability of the gear	Behavioral responses do not substantially affect the catchability of the gear	Behavioral responses decrease the catchability of the gear
Morphological characteristics affecting capture	Species shows high selectivity to the fishing gear (e.g., torpedo-shaped or bi-laterally flattened with deeper girth fishes)	Species shows moderate selectivity to the fishing gear (e.g., elongated body shaped fishes)	Species shows low selectivity to the fishing gear (e.g., flatfishes)
Management strategy	Stocks do not have input and/or output control measures, and target and bycatch species are not monitored	Stocks have input and/or output control measures, and measures in place to conserve the stocks occasionally monitored and enforced	Stocks have input and/or output control measures, and measures in place to conserve the stocks regularly monitored and enforced by balancing carrots and sticks
Survival after capture and release	Probability of survival <33%	Between 33% and 67% probability of survival	Probability of survival >67%
Market value of fish (USD/kg)	>3.5	1.5-3.5	<1.5
Market demand for fish	High	Moderate	Low
Fishing rate relative to natural mortality	>1	0.5-1.0	<0.5

Some biological parameters (e.g., maximum age and age at first maturity, maximum size, and size at first maturity) are highly correlated with each other. Therefore, the possibility of autocorrelation among the selected attributes cannot be ignored (Lin et al., 2020). The weighting for the biological parameters of the fish defined primarily by the productivity attributes can be increased implicitly if double counting occurs. It was previously suggested to exclude the attributes where correlation exists, and the value of the correlation coefficient is as high as 0.90 (Hobday et al., 2011). Our correlation matrix among the attributes showed no set of attributes for which the correlation coefficient was greater than 0.90, except for the attributed maximum size and size at first maturity. However, the exclusion of either of these two attributes did not significantly change the vulnerability score or category. Therefore, we left both attributes in our analysis.

4.2.3. Data collection for attributes scoring

Data on the productivity attributes (e.g., L_{max}, k, M, MF, and BS) were mostly collected from published journal articles, grey literature, and books (see Table B.2). We prioritized species-specific data collection from Bangladeshi water areas wherever possible. We also considered the attribute information, especially for information on the MF and BC attributes of some species, for members of the same genus in Bangladesh or the Indian subcontinent, or globally as appropriate, when species-specific data were unavailable (Cope et al., 2011). In cases where information was unavailable for some particular attributes, such as t_{max}, t_{mat} and L_{mat}, of a given species, we considered the empirical relationships (Froese and Binohlan, 2000; Pauly, 1980) between the attributes to calculate the missing attribute values from the values of known attributes of same species based on the assumption that some biological parameters of fish are highly correlated (Jensen, 1996; Reynolds et al., 2001; Roff et al., 1984). Lin et al. (2020) and Faruque and Matsuda (2020) used similar types of approaches in their assessments. For example, the equation of $t_{max} = 3/k$ (t_{max} = maximum age; k = the von Bertalanffy growth coefficient) was used to estimate t_{max} from the available data on k. We also considered the following equations to calculate the age at first maturity (t_{mat}) and length at first maturity (L_{mat}): $t_{mat} = -\log_e(1 - L_{mat}/L_\infty)/k$ (L_∞ = asymptotic maximum length) and $L_{mat} = L_\infty 10^{(0.8979 - 0.0782T)}$ (T = water temperature), respectively. Information on the "mean trophic levels" of all assessed bycatch stocks was borrowed entirely from the online open-access library FishBase (Froese and Pauly, 2021).

The information on the susceptibility attributes was also collected from published articles, reports, and books (Table B.3). In addition, data on the market demand and selling prices of bycatch species, gillnet selectivity to bycatch species, fishing areas and times, gillnet-deployed water depth, gillnet dimensions and mesh sizes, the tendency of fishers to release non-target species back into the water, fishery rules and regulations and their effectiveness, and the fishery's degree of compliance with fishery laws were mainly collected directly from field observations, in-person interviews, and focus group discussions with experienced and knowledgeable Hilsa fishers (i.e., those with at least 10 years of Hilsa fishing experience). The bycatch species data considered for the PSA in our study were reported from the inland and marine Hilsa habitats of Bangladesh. In total, 50 Hilsa gillnet fishers from an inland habitat adjacent to the Hilsa hotspot rivers (e.g., Meghna, Padam, Tetulia, Andharmanik, and Galachipa) and 50 Hilsa gillnet fishers from a marine habitat (e.g., Bay of Bengal) were selected using the judgmental sampling technique (Cresswell and Plano Clark, 2011), also known as purposive sampling, for face-to-face interviews and focus group discussions, mainly to gather information on the Hilsa fishery of Bangladesh. Specific survey points of the inland and marine habitats are provided in Table A.1. The information gathered on the Hilsa fishery and its bycatch stocks from interviews and direct observations was used to score some of the susceptibility attributes (vertical overlap, management strategy, bycatch species survival after release, management strategies, etc.).

The yearly catch data for the selected bycatch species were not available, except for data on *Harpodon nehereous* (DoF, 2019) from Bangladeshi waters. Therefore, to obtain qualitative information on the bycatch species' catch trends, we asked the Hilsa fishers to score the bycatch species on a scale of 1–3, with "1", "2", and "3" denoting decreasing, stable, and increasing trends, respectively (Table B.1). This species catch trend information was used to compare the vulnerability scores, as described in Section 4.2.6 (comparison of the species V score with E and the catch trend).

4.2.4 Conservative scoring and alternative scoring approaches

Typically, in PSA, all the productivity and susceptibility attributes are ranked on an ordinal scale. In this ordinal scale (i.e., a 1−3 scale), the scores "1", "2", and "3" represent the "low", "moderate", and "high" productivity (P) and susceptibility (S) of stocks. Bycatch stocks with low P and high S scores represent high vulnerability due to Hilsa gillnet fishing, whereas bycatch stocks with high P and low S scores indicate low vulnerability. In the conservative scoring approach, we assigned the lowest score to *P* and the highest score to *S* (i.e., the highest risk) when data were missing, as done in Hobday et al. (2011).

Alternatively, to collect missing information, we incorporated expert opinions (e.g., local fishery officials through key informant interviews) and used the empirical relationships (described in Section 4.2.3) between the productivity attributes (see Tables B.2 and B.3). The use of this approach for treating missing data while scoring the attributes was called the "alternative scoring approach" in our PSA. The scoring thresholds for quantitative data (t_{max}, *M*, etc.) and scoring criteria for qualitative data (management strategy, market demand for fish, etc.) were retained from Faruque and Matsuda (2020) (Tables 4.2 and 4.3). All the attributes were equally weighted with default values of 2, as in Patrick et al. 2009. We referred to Faruque and Matsuda (2020) for further details on how to determine scoring thresholds and set criteria for the bycatch stocks of the Hilsa gillnet fishery in Bangladesh. The data used for scoring each of the productivity and susceptibility attributes and the as-signed scores with the data references are provided in the appendix (Tables B.2 and B.3).

4.2.5 Determination of bycatch stocks' vulnerability (*V*)

Vulnerability (*V*) refers to the degree to which a species' biological capacity to regenerate is outstripped by its fishing mortality (Stobutzki et al., 2001). *V* is the result of combining productivity (*P*) and susceptibility (*S*) attributes to build a specific score that quantifies the vulnerability associated with a stock. Stocks found to be the most vulnerable to fishing were considered low in productivity and high in susceptibility, while stocks high in productivity and low in susceptibility were deemed the least vulnerable. The Euclidean distance of the weighted average 3–*P* and *S*–1 scores from the origin of a biplot of the equation $V=\sqrt{(3-P)^2+(S-1)^2}$ (Patrick et al., 2009) was used to quantify species vulnerability. In this equation, the weighted average *P* scores are shown on the x-axis using a high to low (3→1) scale, and the weighted average *S* scores are plotted on the y-axis using a low to high (1→3) scale. Finally, the vulnerability categories of the bycatches were defined based on the vulnerability scores ($V < 1.8$ = Low, $1.8 \leq V < 2$ = Moderate, $V \geq 2$ = High) proposed by Faruque and Matsuda (2020).

4.2.6 Comparison of species *V* Score with the exploitation Rate (*E*) and catch trend

The credibility issues of PSA have been addressed by some authors by comparing their PSA findings with the outcomes of other benchmark methods. PSA findings were previously confirmed, for example, by comparing them to the IUCN Red-List categories, under the premise that species with higher risk ratings belong to these categories (e.g., vulnerable, endangered, critically endangered) (Altuna-Etxabe et al., 2020; Fujita et al., 2014; Osio et al., 2015). In addition, PSA results were compared to a proxy of the stock abundance (e.g., catch per unit effort) (Arrizabalaga et al., 2011) and stock status based on the ratio of actual fishing mortality to the fishing mortality that yields the maximum sustainable yield (Lucena-Frédou et al., 2017; Osio et al., 2015), and historical catch trends (e.g., increasing and decreasing) under the assumption that species with higher risk ranks/values suffer from overfishing or stock depletion Martínez-Candelas et al., 2020).

Most of the bycatch species that we selected for our analysis lack national or regional IUCN assessments, although global IUCN risk ranks exist. However, the global IUCN assessment does not always correspond to the national IUCN Red List, and many global IUCN assessments downgraded the species threat rank compared to the national IUCN Red List (Faruque and Hasan, 2020; IUCN, 2015). In the present study, we did not compare our PSA results with the IUCN Red List since the evaluated species did not have national IUCN Red List ranks. Instead, the findings of our PSA (V score) were primarily compared with one empirically derived quantitative assessment outcome (i.e., exploitation rate, E). This kind of comparison is needed to minimize the uncertainty of PSA outcomes, which will eventually increase the confidence of knowledgeable stakeholders in PSA (Fujita et al., 2014). This comparison also supports a better understanding of the relative risks confronted by bycatch species due to particular fishing activities. According to Gulland's (1971) approximation, the estimated values of the exploitation rate (i.e., the ratio of fishing mortality to total mortality) can be used to assess the overfishing status of a given stock (i.e., when $E > 0.5$). It was previously suggested that the vulnerability of a stock is directly related to overfishing, and a stock with a V score above 1.8 is likely to be associated with an overfishing problem (Faruque and Matsuda, 2020; Patrick et al., 2009). However, it is not always necessarily true that stocks with $V > 1.8$ are overfished or undergoing overfishing conditions as the V score is a relative measure of risk rather than an absolute one and may vary across fisheries (Patrick et al., 2009). We found a direct relationship between the exploitation rate of the stocks (which quantitatively defines overfishing and underfishing condition) with their corresponding V score; therefore, in this analysis, we intuitively assumed that a V score of 1.8 is a critical value for the bycatch stocks of Hilsa gillnet fishery of Bangladesh.

The *E* value is typically calculated based on all gear types and thus describes the total fishing mortality of all gear types relative to total mortality. However, the *V* score for a given species is specific for a particular gear type (Hilsa gillnet in our case). Therefore, some inconsistency between the two outcomes (the *V* score and *E*) is inevitable. We also compared our *V* score with another qualitative indicator, the catch trends of bycatch stock. Species–species catch statistics are unavailable for the majority (20 species out of 21) of the selected bycatches in Bangladesh. Therefore, during the interviews with individual fishers, we asked each of the interviewees about the catch trends of the selected bycatch species. We presumed that experienced fishers' perceptions of catch trends for a given stock would reflect the relative status with greater certainty than other methods. If over 30 Hilsa gillnet fishers (a statistically meaningful majority of 5%) perceived the catch trend for a particular bycatch species to be "decreasing (–1)", "increasing or steady (1)", or "increasing (2)", then we ranked that species as "decreasing", "stable" or "increasing", respectively (Table B.1). Any category that did not achieve the consensus of 31 fishers was defined as "not significant (0)". To compare the *V* scores with the catch trends, we assumed that bycatch stocks with "stable", "increasing", or "not significant" trends were subject to underfishing or sustainable fishing, whereas bycatch

Finally, we assumed that the higher consistency between the pairs of outcomes (*V* score and *E*; *V* score and catch trends) under two different scoring approaches for PSA would be a useful method in determining the reliable scoring approach for PSA that could be able to minimize the overestimation of species vulnerability.

4.3 Results

The vulnerability scores (*V*) for the 21 bycatch species of the Hilsa gillnet fishery ranged 1.08–2.32 and 1.16–2.38 in ASA and CSA, respectively (Figure 4.1). The resulting vulnerability scores were used to categorize the bycatch stocks into three distinct vulnerable categories. In CSA, the number of highly vulnerable bycatches increased from two to three compared to ASA (Figure 4.2b). In addition, for two bycatch species (i.e., *Mystus gulio*, BMG; *Pampus chinensis*, CPO), the risk category changed from low to moderate. Ultimately, when CSA was applied to the 21 bycatches, the *V* scores increased by 0–0.20, with a mean value of 0.09 (Figure 4.1).

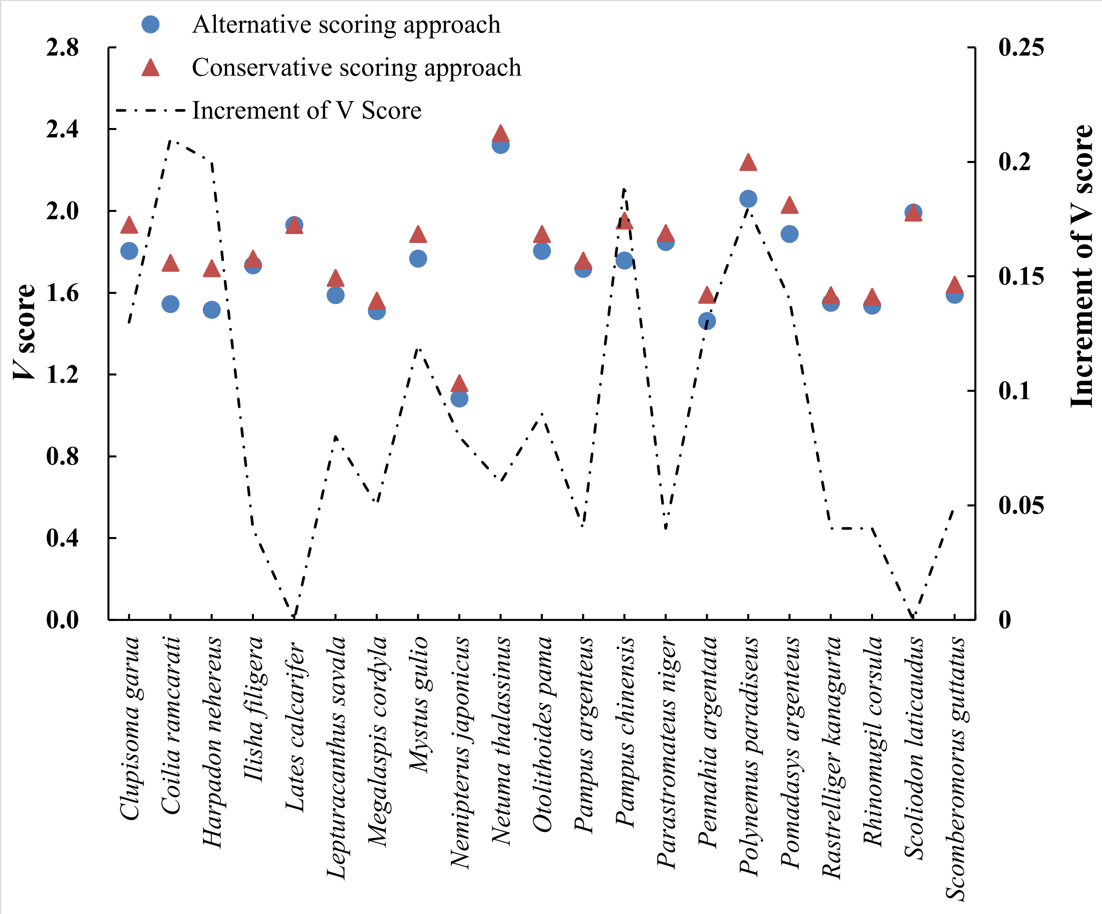


Figure 4.1 Vulnerability (*V*) scores (left y-axis) for the selected bycatch species of the Hilsa gillnet fishery in Bangladesh using conservative and alternative scoring approaches. Values on the right y-axis indicate an increase in the *V* score after applying the conservative scoring approach in PSA.

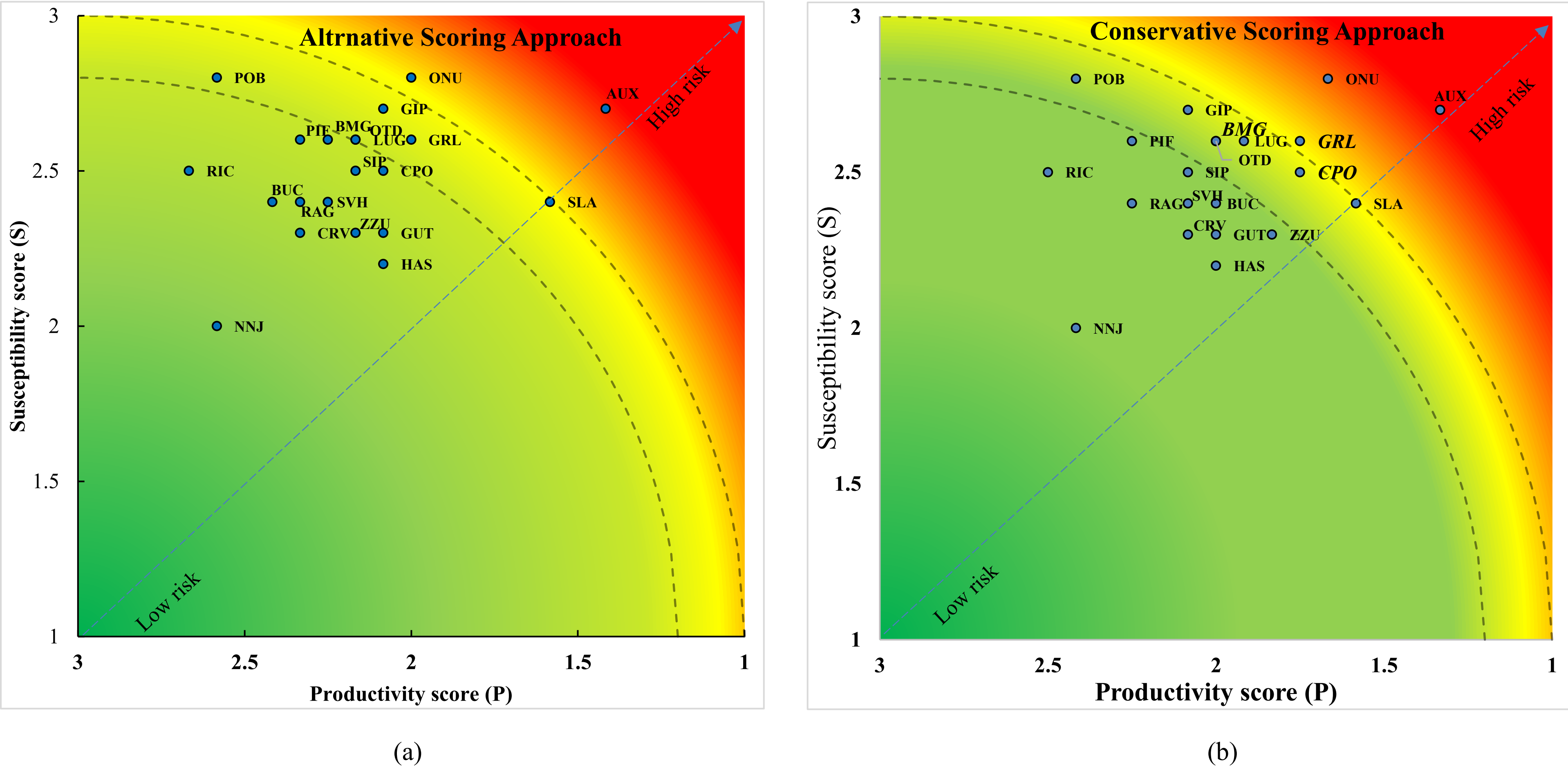
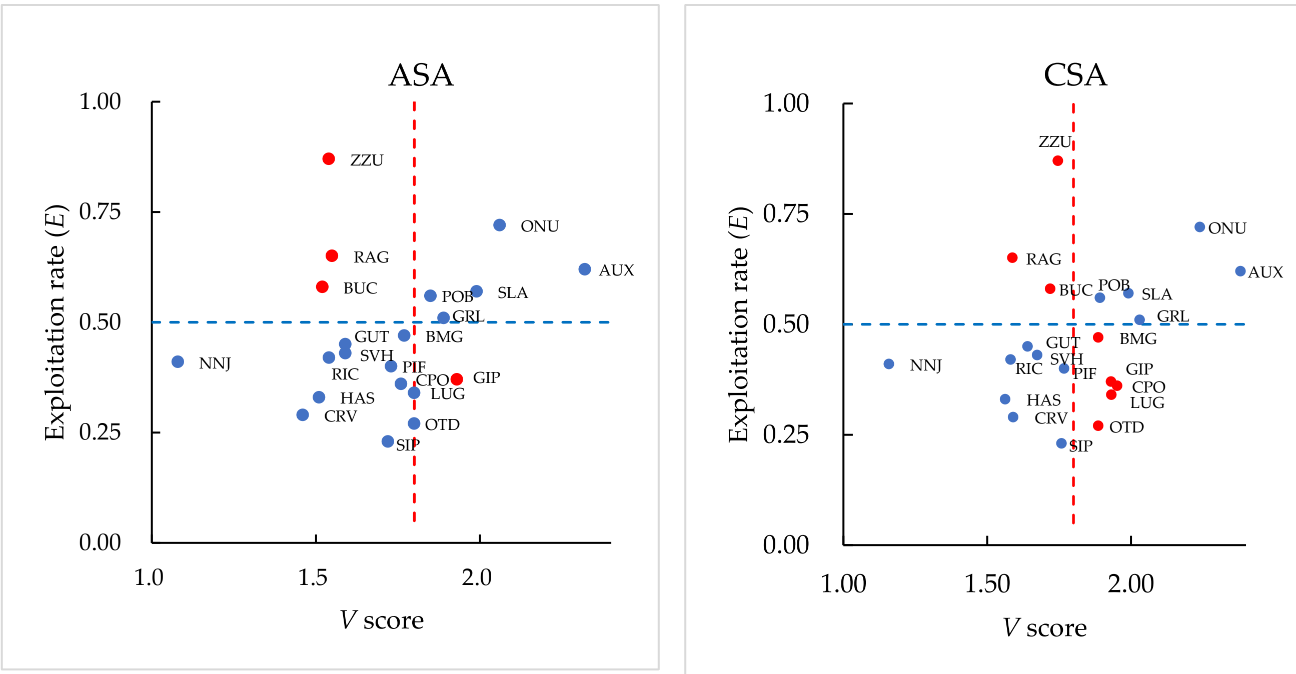


Figure 4.2 Two-dimensional productivity–susceptibility plot for the selected bycatches of the Hilsa gillnet fishery in Bangladesh using an alternative (**a**) and conservative (**b**) scoring approach. The dashed contour lines define the boundaries of the vulnerability categories ($V < 1.8$ = low, $1.8 \leq V < 2$ = moderate, $V \geq 2$ = high). The 3-alpha FAO species identification codes are provided in Table 4.1. The species codes in italic font (Figure 4.2b) indicate changes in the species vulnerability ranks between the two scoring approaches.

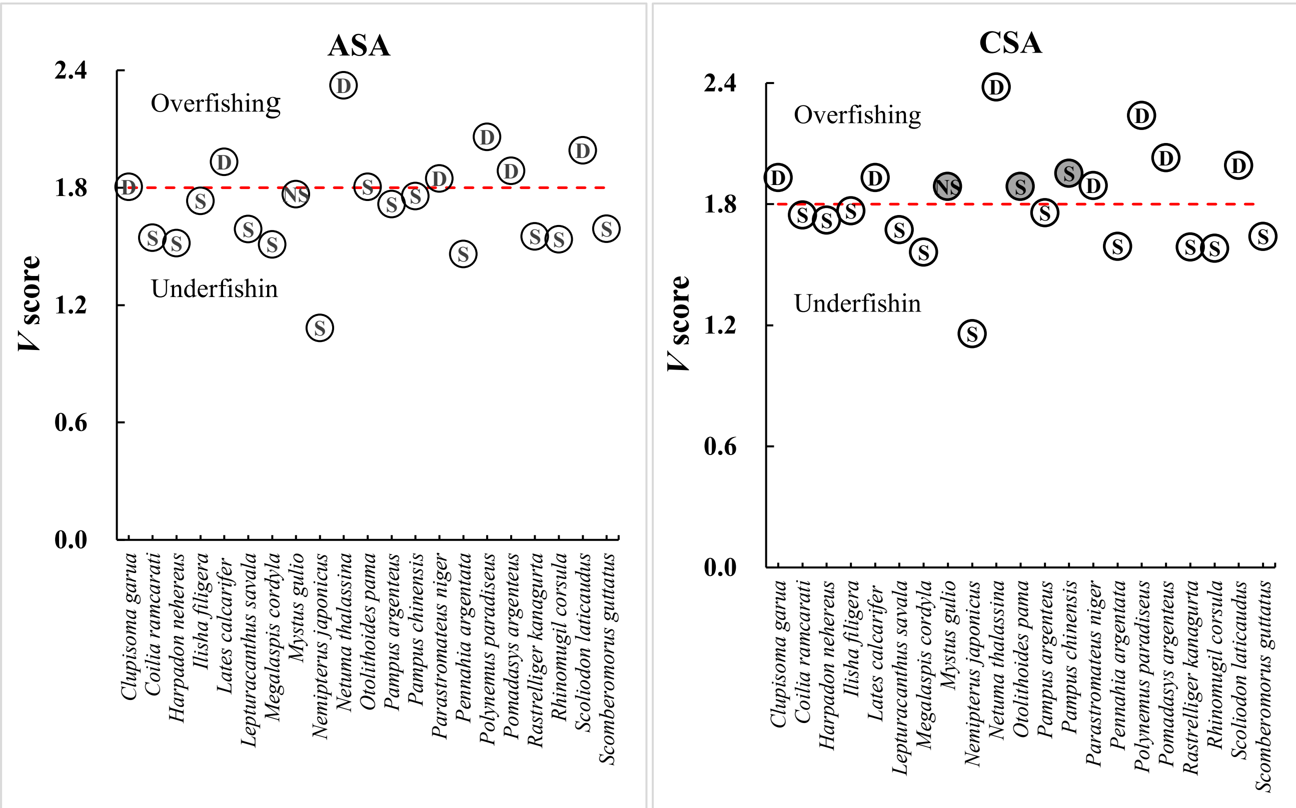
Figure 4.3 illustrates a comparison between the *V* score and *E* in ASA and CSA, respectively. Based on the formal stock assessments for the 21 selected bycatch stocks, eight by-catch species (38%) were found to suffer from overfishing, while the remainder 62% (13 in number) suffer from underfishing (when $E > 0.5$, overfishing; $E < 0.5$, underfishing) (Figure 4.3a). Following the *V* score and its likely association with the exploitation status, six bycatch species (28.6%) were suggested to have overfishing status, while the remainder of the 15 by-catch species (71.4%) were suggested to have underfishing status when we considered ASA (Figure 4.3a). Despite being classified as overfished by previous studies based on exploitation rate ($E > 0.5$), our analysis suggests that *Coilia ramcarati* (ZZU), *Harpadon nehereus* (BUC), and *Rastrelliger kanagurta* (RAG) are found to suffer from overfishing. In contrast, our PSA results suggested an overfishing status for *Lates calcarifer* (GIP), but this species was instead given an underfishing ($E < 0.5$) classification based on the exploitation rate. The inconsistency between these two outcomes was 19.0% (four cases out of 21).



(a) (b)

Figure 4.3 A comparison of the exploitation rates (*E*) and vulnerability scores (*V* scores) for the selected bycatches of the Hilsa gillnet fishery in Bangladesh, where the V scores were derived from the productivity susceptibility analysis (PSA) under the alternative scoring approach (a) and conservative scoring approach (b). Blue- and red-colored solid points represent the consistent and inconsistent cases, respectively, between the *E* and *V* scores (when $V > 1.8$ and $E > 0.5$ = overfishing, and $V \leq 1.8$ and $E < 0.5$ = underfishing). The 3-alpha FAO species identification codes are presented in Table 4.1.

On the contrary, when we applied CSA, a total of ten bycatch species (47.6%) were suggested to suffer from overfishing, and the underfishing stock decreased from 15 to 11 (Figure 4.3b). Our results also suggest that CSA overclassified the fishing status for an additional four species—*Clupisoma garua* (LUG), *Mystus gulio* (BMG), *Otolithoides pama* (OTD), and *Pampus chinensis* (CPO). Eight inconsistent cases (38.1%) were found when we compared the fishing statuses determined by the *E* score and the likely association of *V* with the fishing statuses of the selected bycatch species.



(a) (b)

Figure 4.4 A comparison of the catch trends and vulnerability scores (*V* scores) for the selected bycatches of the Hilsa gillnet fishery in Bangladesh, where the *V* score is derived from productivity susceptibility analysis (PSA) using the alternative scoring approach (a) and conservative scoring approach (b). The red-colored dashed line represents the demarcation between overfishing and underfishing based on the *V* score (where $V > 1.8$ = overfishing and $V \leq 1.8$ = underfishing). The points (circle) indicate the *V* score corresponding to each of the assessed stocks, and the letter inside the circle defines the catch trend (D = decreased, NS = not significant, S = stable). Figure 4.4a indicates that species with a *V* score above 1.8 shows the decreasing catch trend. Figure 4.4b indicates that the CSA in PSA over-classified the fishing status (i.e., underfishing status to overfishing status) for *Mytus gulio* with a non-significant catch trend and for *Otolithoides pama* and *Pampus chinensis* with stable catch trends (shaded circle).

While comparing the V scores of the bycatch stocks of our PSA with the catch trends, our analysis indicated species with a V score above 1.8 to have a decreasing catch trend in the ASA scenario (Figure 4.4a). However, species with $V \leq 1.8$ largely presented a stable catch trend. We presumed that species with decreasing catch trends suffer from overfishing (when $V > 1.8$). Indeed, the consistency levels between the V-score-derived fishing status and fishers' perceived catch trends were found to be high in PSA under ASA. However, some inconsistent cases were observed when CSA was applied. For instance, two species with stable catch trends (*Otolithoides pama* and *Pampus chinensis*) and one bycatch with not significantly changed catch trend (*Mystus gulio*) were suggested to be at an overfishing state based on the V scores in our PSA (Figure 4.4b). However, it is reasonable to assume that species with stable catch trends or catch trends without significant changes are sustainably fished or undergoing underfishing but do not suffer from overfishing problems.

4.4 Discussion

In response to rising concerns about the impacts of target fisheries on bycatches and associated species, fishery scientists have sought to develop comprehensive risk assessment and management tools for all exploited fishery stocks. PSA is one such tool that can include a large number of exploited stocks in an assessment framework to evaluate the relative risk among species interacting with particular gear types (Patrick et al., 2009). Despite its extensive usage in fishery sciences for risk assessment, there is no standardized framework for PSA (Hordyk and Carruthers, 2018). As a result, risk assessors can tailor the PSA tool in a variety of ways (e.g., for determination of the scoring threshold and treatment of missing information) based on the assessment objectives, fishery characteristics, and data availability (Patrick et al., 2010). In general, when precise data for the attribute scoring of a species is unavailable (e.g., the t_{max} of a fish determined from otolith or scale methods), PSA may use the imprecise data (e.g., adopting t_{max} data for a species from the same genus or family) and thereby predict species vulnerability. Thus, the uncertainty in PSA outcomes cannot be avoided when low-quality data is used or when the highest score is assigned in the case of unavailable information (Fujita et al., 2014; Hobday et al., 2011). In the present study, we calculated the vulnerability for the 21 bycatch stocks of the Hilsa gillnet fishery in Bangladesh using two different scoring approaches. Finally, our PSA outcomes were tested against other assessment outcomes to verify which scoring approach is most appropriate in PSA.

Our findings of an increased V score and a greater number of moderate and high-risk species under the conservative scoring approach of PSA are consistent with the findings of Osio et al. (2015). Osio et al. (2015) applied two scoring approaches—the best guess scoring approach (e.g., using missing information for attributes derived from expert knowledge) and the conservative scoring approach—to study 151 Mediterranean demersal stocks. The authors found that the conservative scoring approach tended to over-classify the risk for many species. The conservative scoring approach generally produced more false positives (i.e., overestimation of risk) than false negatives (i.e., underestimation of risk) (Fujita et al., 2014; Zhou et al., 2016). We did not find large differences in vulnerability scores between CSA and ASA in our analysis. This result is likely because most of the species-specific information on the life history parameters for the selected bycatch species are available in the existing literature. In the case of data unavailability for 3 (out of 12) particular attributes (L_{mat}, t_{mat}, t_{max}) for some selected bycatches, the assigned scores were changed between the two scoring approaches. However, the resulting vulnerability scores in CSA showed greater inconsistency when compared with other assessment outcomes. Since the contribution of each of the attributes to the overall vulnerability score is minimal (Rosenberg et al., 2009), it is expected that increasing the number of attributes treated with CSA (for missing information) would result in larger differences in vulnerability scores, especially for data-limited bycatch stocks.

Hobday et al. (2011) developed a three-tier hierarchical ecological risk assessment framework (three-tier approach) in which PSA was used to screen out low- and moderate-risk species, with high-risk species suggested for quantitative risk assessment at a higher level. The authors determined that species with over-classified risk ranks (false-positive results) due to the assignment of conservative risk scores would eventually be screened out during higher-level assessments. However, quantitative assessment at a higher level in the authors' proposed framework entails higher data requirements, which are difficult to manage for a large number of species if many false cases occur in PSA. The data needed for higher-level assessments of a large number of species would take several years to complete and implement [49]. However, Rosenberg et al. (2009) argued that the underlying benefit of CSA in PSA is that it provides an incentive to gather more information, and new robust data can only ever decrease the risk score, not raise it.

In PSA using the alternative scoring approach, we found a greater consistency between our V-score-suggested fishing status and the fishing status determined from the exploitation rate, with only a few inconsistent cases. Lucena-Frédou et al. (2017) found a similar level of consistency between their PSA findings and exploitation status (fishing mortality relative to fishing mortality that gives the maximum sustainable yield) for finfish caught by pelagic tuna longline fleets in the South Atlantic and Western Indian Oceans. Overall, 75% of stocks with a higher risk score (*V* = 1.96–2.64) were found to be overfished or subjected to overfishing conditions. Since PSA does not provide any absolute stock estimates, the values of *V* scores and their likely association with exploitation status can vary between fisheries (Patrick et al., 2009; Osio et al., 2015). Osio et al. (2015) reported that unsustainable exploitation was mostly observed for Mediterranean demersal stocks with higher *V* scores (≥ 1.8). Patrick et al. (2010) also observed vulnerability ratings greater than 1.8 in 50 American fish populations that had previously been overfished or were presently being overfished.

Fishing mortality varies across gear types, which has a direct influence on the exploitation rate (i.e., fishing mortality relative to total mortality) (Gulland, 1971). Therefore, the inconsistent instances of *Coilia ramcarati* (ZZU), *Harpadon nehereus* (BUC), and *Rastrelliger kanagurta* (RAG) could be explained by a lack of compatibility (Parvez and Nabi, 2015; Sarker et al., 2017). The majority of the aforementioned species are obtained using other types of fishing gear, such as set bag nets and trawl nets, with different levels of fishing mortality (Rahman t al., 2009). The disparity for the Lates calcarifer, on the other hand, could be explained by the prior study's limited coverage in its sample areas (Mustafa et al., 2019). In contrast, when using PSA with the conservative scoring approach, we observed lower consistency in the *V*-score-suggested fishing status and the absolute fishing status determined by the E score from the formal assessment.

The stock status for *Otolithoides pama*, *Pampus chinensis*, and *Mystus gulio* remained stable and did not significantly change the catch trend, which suggests that these species do not suffer from overfishing problems despite being classified as overfished by their *V* scores under the conservative scoring approach. Although using qualitative catch trend analysis (i.e., the fisher's perceived stock status) to determine the stock status for fishery stocks or populations is not as robust as other quantitative indices such as catch per unit effort (Osio et al., 2015), the catch trend has been used for many years in fishery science to determine the stock status when there are no quantitative data (Early-Capistrán et al., 2018; Sáenz-Arroyo and RevolloFernández, 2016).

The PSA results are less precise than those obtained from fully quantitative stock assessments. However, when comprehensive data on stock abundance, catch levels, or other conventional fisheries indicators are lacking, PSA offers a helpful starting point for identifying the relative risk of a species due to fishing, thus prioritizing data collections, future research needs, and management activities. A higher level of agreement between PSA outcomes and the results obtained from other reliable quantitative assessments may increase stakeholders' confidence in PSA's outcomes. The PSA approach performed on 21 bycatch species from the Hilsa gillnet fishery in Bangladesh does not replace the conservative scoring method in PSA but instead provides aid for PSA users to determine which scoring approach is most reliable in PSA. Our PSA outcomes for the two different scoring approaches suggest that the conservative scoring approach could overestimate vulnerability. In contrast, the alternative scoring approach is comparatively more reliable in PSA, which could minimize false estimates of species vulnerability and thus increase the credibility of PSA's application in data-limited situations.

Acknowledgments

We are indebted to all local fisheries officials in the areas we surveyed for their assistance in conducting surveys. We are grateful to all Hilsa fishers for their support and exchanging valuable knowledge about the Hilsa fishery and bycatch by engaging in face-to-face interviews and focus group discussions. We are also thankful to Kendra Karr, Oceans Program, Environmental Defense Fund, USA, who provided us with the Excel edition of the PSA tool and the accompanying guidance notes. The Graduate School of Environment and Information Sciences, Yokohama National University, Japan, sponsored this study through the Research Promotion Program (grant No 65A0515b). This work was also partly supported by JSPS KAKENHI grant (20K06180) to Hiroyuki Matsuda.

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Chapter 5

Current Study's Limitations, Future Research Needs, and Conclusion

5.1 Limitations of the current study and future research needs

PSA performed in this work on Hilsa and bycatch species from Hilsa gillnet fishing in Bangladesh does not replace traditional stock assessments but rather helps managers in determining which species are most at risk and should be prioritized for further assessment and management, data collection, and future research. The limitations of the current study and the potential study topics are discussed in further detail in the following bullet points:

- In this study, gillnet-specific bycatch species were identified through Hilsa fisher's recognition and then confirmed with the taxonomic key. Fish identification using a taxonomic key is often used in fisheries science. However, the shortcoming of this technique is that it becomes difficult or even impossible to identify species where there is small morphological variation between species or once the external features of fish are damaged due to excessive handling or processing. Therefore, molecular identification methods of fish species, could be a more authentic approach to identify the fish at species level (Teletchea, 2009).
- Many of the bycatch species assessed in this study are also exploited by other fishing gears. For instance, Barua et al. (2014) listed 66 commercially important marine fishes from industrial trawling in Bangladesh, with 36 appearing in our recorded species list for Hilsa gillnet fishing from marine habitats. Therefore, the cumulative impact of the different co-occurring fisheries require to be addressed in future assessment when a stock is harvested simultaneously by different gear types. In this case, the incorporation of aggregated susceptibility score in PSA would be one way to obtain the reliable vulnerability score, assuming that the productivity score remains the same regardless of the gear type (Micheli et al., 2014). Another way would be weighting the aggregated productivity and susceptibility score according to the proportional catch contribution (if catch data are available) of each gear to produce better predictions regarding the risk status of a given species (Patrick et al., 2010).
- The species selectivity by gear types varies by lifecycle stage. For example, a juvenile Hilsa is more likely to be caught in a seine net than in a typical Hilsa gillnet. However, lifecycle stage did not consider in this analysis, as we used maximum body size rather than actual landed size. Further considerations could be included in future assessments, with species being divided at the very least into juveniles and adults and each being assessed independently. This may aid in identifying the most vulnerable life phases of fish, allowing

the fisheries manager to enact appropriate management actions to preserve or conserve those life stages of fish.

- We considered management strategy as one of the susceptibility attributes for our PSA. Therefore, during our assessment period, we took into account the actual fisheries regulations and their enforcement posed by gillnet fishing to Hilsa and its bycatch species while scoring the management strategy attribute. If the more robust data replaced the low quality or outdated data, or if the current management measures altered the fishery characteristics in future, the species vulnerability could change. Therefore, residual risk analysis will be periodically performed in future for species assessed as high risk by PSA to revise the vulnerability score (AFMA, 2017). Notably, climate change may affect the seasonal and temporal patterns of stock distribution and fisheries interactions, making this a critical subject for future study.

5. 2 Conclusion

Fishing focused on a particular fisheries stock contributes to the direct mortality of target stocks and may also intensify the bycatch stocks' mortality (Diamond et al., 1999). Therefore, the impact of fishing on the target stocks as well as non-target or bycatch stocks is becoming a concern globally (Hastings et al., 2017). Hilsa, a national fish of Bangladesh, constitutes the single most important fishery of Bangladesh. Million of Hilsa fishers exploit Hilsa using different gillnets throughout the year from both its marine and riverine habits (Hossain et al., 2019). A couple of recent studies suggested that Hilsa has been experiencing an overfishing problem (Miah et al., 2015; Rahman et al., 2018, 2020). The Hilsa gillnet fishery of Bangladesh is primarily artisanal in nature, and Hilsa gillnets capture several bycatch species on a regular basis along with Hilsa. These bycatch species are landed by Hilsa fishers alone with Hilsa for selling. Therefore, it is reasonable to believe that Hilsa gillnet fishing impacts not only Hilsa but also its bycatch stocks. However, neither their status regarding any biological reference point (e.g., Maximum Sustainable Yield, MSY) nor their ecological risk was assessed, with few exceptions for some species (e.g., IUCN, 2015; Mustafa et al., 2019; Rashid et al., 2007). This is primarily due to the lack of data on Hilsa-gillnet specific bycatch species lists, species-specific limited information on life-history parameters, catch statistics, fishing efforts, and so on.

Given the above circumstances, a semi-quantitative risk assessment tool—Productivity Susceptibility Analysis (PSA)—was used to reveal the relative vulnerability of Hilsa and its data-limited bycatch species from Hilsa gillnet fishing in Bangladesh (**Chapter 3**). To do this risk assessment, firstly, this study for the first time identified and reported the Hilsa gillnet-specific bycatch species from Bangladesh water areas, and among the identified species (130 species) 74 bycatch stocks were subjected to PSA alone with target stock, Hilsa. Additionally, the results of our vulnerability assessment in two different scoring approaches (conservative and alternative scoring approaches) for some selected bycatch stocks were compared to the results of other assessments for some selected bycatch species in order to determine the more reliable and recommendable PSA scoring approach (**Chapter 4**).

In conclusion, Hilsa was found to be moderately vulnerable to gillnet (see Table 3.4). The majority of the bycatch were found to be highly susceptible to fishing, with 17 bycatch species in the high-risk category (See Tables 3.4 and 3.5). The rest of the bycatch species had low (21 species) to moderate (36 species) risk ranking (see Figures 3.7 and 3.8). Our analysis also implied that the exploitation rate associated with overfishing corresponds to the vulnerability scores (V >1.8, overfishing) (see Figure 3.10). Moreover, we found that species with V score over 1.8 showed decreasing catch trend (Tables 3.4 and 3.5). Furthermore, our result revealed that around 55% (12 species out of 22) of inland bycatch and 42% (22 species out of 52) of marine bycatch experience an overfishing situation (Tables 3.4 and 3.5). However, data quality analysis indicated that the majority of bycatch species received low data quality scores, especially for productivity attributes (Tables 3.4 and 3.5). Our analysis finally suggested that the conservative scoring approach in PSA could lead toward the overestimation of species vulnerability (Figures 4.1–4.4). Therefore, alternative scoring approach is more reliable than conservative scoring approach in PSA, which may increase the confidence of fisheries stakeholders in PSA.

The sustainable use of fisheries resources is an urgent need for the Bangladesh economy as the fisheries sector supports millions of people's livelihood. Unsustainable harvesting of target stocks using less selective fishing gears such as gillnets may have an adverse impact on the target stocks and could also increase the vulnerability of dependent or other fisheries stocks that inhabit the same fishing zone or migrate to it during fishing operations. A couple of management regulations have been imposed since 2003 in Bangladesh, including the minimal legal mesh size for gillnet, minimal legal catch length of Hilsa, spatial and temporal Hilsa fishing bans, to recover the stock status and boost production of the Hilsa from Bangladesh water areas (DoF, 2019). While calculating the vulnerability score, we considered the existing fisheries regulations for Hilsa fishery and the fisher's compliance or non-compliance to existing regulations for scoring the management strategy attributes coupled with other susceptibility attributes. It is anticipated that fishing regulations focusing on the target stock may improve the stock status of the target stock and increase the viability of the other stocks (i.e., bycatch stocks). Our analysis identified that exploitation rate, which defines the fishing status (i.e., overfishing or underfishing) of fish, is associated with vulnerability scores (V). In this manner, our analysis identified 35 species, including the target species Hilsa, that are experiencing overfishing problems. Moreover, the majority of them are in a decreasing catch trend (Tables 3.4 and 3.5).

For many of the bycatch species that are fished simultaneously by other fishing gears, it is expected that vulnerability scores and stock status will increase in full assessments when all fisheries' impacts are taking into account. Species that are experiencing overfishing problems, the majority of them had low data quality score, especially for the productivity attributes, and the productivity scores for those species remain unchanged across the fisheries until new robust data replaces existing low-quality data. In contrast, the improvement in the susceptibility score through management interventions may improve the overall risk score for the assessed stocks impacted by Hilsa gillnet fishing.

Fisheries' non-compliance, or the breach of fishing laws by fishers, continues to be one of the most persistent issues impeding the sustainable use of fisheries resources on a global scale (Arias et al., 2015). In the Hilsa gillnet fishery of Bangladesh, fisher's non-compliance to regulations and violation of the laws is common (Islam et al., 2017). During our field survey, we commonly found the extensive usage of illegal gillnet (e.g., monofilament gillnet, locally known as current jal) and other Hilsa gillnets with smaller mesh size than permitted. These gillnets indiscriminately exploited the juvenile stage of the target stocks. These illegal gillnets are also becoming a threat to some of the other small-sized bycatch species (e.g., *Alilia coila*, *Gagata gagata*, *Johnius coitor*, *Panna microdon*, *Polynemus paradiseus*). Even the legal gillnet for Hilsa fishing with mesh size ≥ 4.5 cm exploited a substantial amount of undersized Hilsa (Hilsa catch < 25 cm in total length is illegal as per the existing fishing law of Bangladesh). This implies that the current mesh size regulations for Hilsa gillnet fishing are not effectively reducing the fishing mortality for the juvenile life phase of the target stock, Hilsa. Intuitively, mesh size increment will reduce the interaction between juvenile Hilsa and other bycatch species or bycatch species whose maximum length is below or close to the length of maturity of Hilsa (Hilsa becomes mature at 26 cm of its total length), and Hilsa gillnets, can thus improve their risk score by enhancing some of the susceptibility attributes scores (e.g., management strategy, vertical overlap with fishery). For bycatch species larger than Hilsa, a mesh size increase does not guarantee the protection of juveniles of the larger species. In that case, an increment in gillnets' mesh size can be taken as a precautionary management measure. After implementing this management measure, the species-specific vulnerability score can be reassessed to ascertain the effectiveness of this management measure in reducing the bycatch and Hilsa's overall stock status.

Our analysis did not calculate the gillnet type-specific (e.g., bottom, surface, and mid-water gillnets) susceptibility scores for Hilsa and its bycatch species. We calculated the susceptibility scores collectively for Hilsa and its bycatch species confronted by all gillnet types. This is because most Hilsa fishers mentioned that they sometimes simultaneously use both the surface drift gillnet or mid-water gillnet and the bottom set gillnet during their fishing operation, and they landed all the captured species together (i.e., not divide the species with gillnet types) for selling. Therefore, it is not easy to determine which species are captured by which gillnet types. However, during the focus group discussion, most of the Hilsa fishers stated that bottom set gillnets usually catch more juveniles Hilsa (since juvenile Hilsa graze in the bottom areas of its habitat) and many other bottom-dwelling species (e.g., *Netuman thallassina*, *Silonia silondia*, *Sperata aor*, among others) than the surface or mid-water gillnets. Therefore, the avoidance of the use of the bottom set gillnets may further help reduce the interaction between species, particularly juvenile Hilsa and other bottom-dwelling bycatch species, and Hilsa gillnets, thereby improve the risk or stock status of these species. Additionally, all the Hilsa fishers interviewed during the field survey mentioned that they do not release any of the bycatch species back into the water, though a substantial number of bycatch species are found alive (e.g., sharks and certain catfishes) and in good physiological condition. They do not even release the juveniles of any catfish species (e.g., *Bagarius bagarius*, *Rita rita*, *Sperata aor*, among others), which are often captured in Hilsa gillnets and found alive or other species with very low market demand and value (e.g., shark species, *Rhizoprionodon acutus*, *Scoliodon laticaudus*). Fishers' tendency to release the bycatch species safely into water can improve the overall susceptibility score for the mentioned species to a certain extent.

Violating fishing regulations is a common occurrence, but it is critical to understand why, how, and when this is happening. According to the Hilsa fishers of our study areas, poverty, insufficient incentives from the government agency during the fishing ban periods, improper distribution of incentives, high indebtedness (advance loan with high-interest rate) to middlemen, lack of alternative income opportunities, lack of awareness regarding regulations, and country's top-down policy approach in the fisheries sector are the key factors of the non-compliance of fisheries regulation in Bangladesh. Participatory management, which is based on the action and participation of resource users, should be enhanced to maintain the sustainability of the Hilsa and its bycatch stocks. Building awareness among fishers about the long-term consequences of overfishing on their livelihood and country's economy and the fisheries stocks need to be strengthened to improve compliance to the country's existing fisheries regulations. Our study concluded that the amendment of mesh size regulations for Hilsa gillnets, avoidance of the usage of the bottom set gillnets, building awareness among fishers to release undersized individuals of both target and non-target species (where possible), monitoring and surveillance of the regulatory agencies to ensure the effective enforcement of regulations are critical to reduce the susceptibility of both Hilsa and its bycatch stocks to fishing and thus to reduce the number of overfished stocks or stocks undergoing overfishing problems..

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Appendix

Appendix A

Table A.1 Study districts including the survey points details. Values inside the parenthesis indicates the number of participants in each FGD.

District	Survey Points ID	Survey Station Name	Type of Survey Station	Adjacent River/Marine area	Hilsa Fisher Intervi-ewed	FGD (No)	KII
Chandpur	CHA1	Rajrajeshwar	Inland	Meghna and Padma river	15	1(5)	1
	CHA2	Haim Char	Inland	Meghna river	15	1(5)	
Barishal	BAR1	Puraton Hizla Bazar	Inland	Meghna river	15	1(5)	2
	BAR2	Mehendiganj	Inland	Meghna river	15	1(5)	
Bhola	BHO1	Daulatkhan	Inland	Meghna river	15	1 (5)	
	BHO2	Mirza Kalur Ghat	Inland	Meghna river	15	1(5)	2
	BHO3	Joya Mazir Ghat	Inland	Tetulia river	15	1(5)	1
	BHO4	Bokshi Fish Market, Charfassion	Marine, Inland	Bay of Bengal Tetulia river	30 15	1(10) 1(5)	1
Patuakhali	PAT1	Sudhirpur	Inland	Andharmanik river	15	1(5)	1
	PAT2	Char Baliatali	Inland	Galachipa river	15	1(5)	1
	PAT3	Mohipur Fish Landing Centre	Marine	Bay of Bengal	30	1(10)	1
Barguna	BAU	Patharghata BFDC Fish Landing Centre	Marine	Bay of Bengal	30	1(10)	2
Chattogram	CHI	Fishery Ghat (New)	Marine	Bay of Bengal	30	1(10)	1
Cox's Bazar	COX	Bangladesh Fisheries Development Corporation (BFDC) Fish Landing Centre	Marine	Bay of Bengal	30	1(10)	2

FGD=Focus Group Discussion; KII= Key Informant Interview

Table A.2 Infrequently captured bycatch species of Hilsa gillnet fishery from inland (14 species) and marine habitats (41 species) of Bangladesh

	Inland bycatch (infrequently captured)		
Serial no.	**Scientific name**	**Common name**	**Family**
1	*Apocryptes bato*	Goby	Gobiidae
2	*Cirrhinus cirrhosus*	Mrigal carp	Cyprinidae
3	*Cynoglossus lingua*	Long tonguesole	Cynoglossidae
4	*Eutropiichthys vacha*	Batchwa vacha	Schilbeidae
5	*Glyptothorax cavia*	Sisorid torrent catfish	Sisoridae
6	*Johnius gangeticus*	Gangetic bola	Sciaenidae
7	*Labeo calbasu*	Orangefin labeo	Cyprinidae
8	*Macrospinosa cuja*	Cuja croaker	Sciaenidae
9	*Mystus bleekeri*	Day's mystus	Bagridae
10	*Odontamblyopus rubicundus*	Rubicundus eelgoby	Gobiidae
11	*Ophisternon bengalense*	Bengal mudeel	Synbranchidae
12	*Pseudapocryptes elongatus*	Pointed–tailed Goby	Gobiidae
13	*Sperata seenghala*	Giant river catfish	Bagridae
14	*Taenioides buchanani*	Burmese gobyeel	Gobiidae

Table A.2 (Cont…) Infrequently captured bycatch species of Hilsa gillnet fishery from inland (14 species) and marine habitats (41 species) of Bangladesh

	Marine bycatch (infrequently captured)		
Serial no.	**Scientific name**	**Common name**	**Family**
1	*Aetomylaeus nichofii*	Banded eagle ray	Myliobatidae
2	*Arius gagora*	Gagora catfish	Ariidae
3	*Auxis rochei*	Bullet tuna	Scombridae
4	*Batrachocephalus mino*	Beardless sea catfish	Ariidae
5	*Chirocentrus nudus*	Whitefin wolf–herring	Chirocentridae
6	*Cynoglossus arel*	Largescale tonguesole	Cynoglossidae
7	*Cypselurus comatus*	Four–winged flying fish	Exocoetidae
8	*Dasyatis bennettii*	Bennett's stingray	Dasyatidae
9	*Dussumieria acuta*	Dwarf round–herring	Dussumieriidae
10	*Ephippus orbis*	Orbfish	Ephippidae
11	*Epinephelus lanceolatus*	Giant grouper	Serranidae
12	*Eusphyra blochii*	Winghead shark	Sphyrnidae
13	*Himantura bleekeri*	Bleeker's whipray	Dasyatidae
14	*Himantura uarnak*	Honeycomb stingray	Dasyatidae
15	*Ilisha elongata*	Elongate ilisha	Pristigasteridae
16	*Istiophorus platypterus*	Indian sailfish	Istiophoridae
17	*Johnius carutta*	Karut croaker	Sciaenidae
18	*Katsuwonus pelamis*	Skipjack tuna	Scombridae
19	*Lagocephalus lunaris*	Green pufferfish	Tetraodontidae
20	*Leiognathus equulus*	Common ponyfish	Leiognathidae
21	*Lutjanus johnii*	John's snapper	Lutjanidae
22	*Mene maculata*	Moonfish	Menidae
23	*Mugil cephalus*	Flathead grey mullet	Mugilidae
24	*Nemapteryx nenga*	Thickspined catfish	Ariidae
25	*Nematalosa nasus*	Long–finned gizzard shad	Clupeidae
26	*Netuma bilineata*	Bronze catfish	Ariidae
27	*Opisthopterus tardoore*	Long–finned herring	Pristigasteridae
28	*Otolithoides biauritus*	Bronze croaker	**Sciaenidae**
29	*Priacanthus tayenus*	Purple spotted bigeye	Priacanthidae
30	*Psettodes erumei*	Indian halibut	Psettodidae
31	*Rhinobatos granulatus*	Granulated guitarfish	Rhinobatidae
32	*Rhynchobatus djiddensis*	Giant guitarfish	Rhinidae
33	*Saurida tumbil*	Greater lizardfish	Synodontidae
34	*Selar boops*	Oxeye scad	Carangidae
35	*Setipinna breviceps*	Shorthead hairfin anchovy	Engraulidae
36	*Sphyraena forsteri*	Bigeye barracuda	Sphyraenidae
37	*Takifugu oblongus*	Oblong blow fish	Tetraodontidae
38	*Tenualosa toli*	Toli shad	Clupeidae
39	*Terapon jarbua*	Cresent perch	Terapontidae
40	*Thryssa purava*	Oblique–jaw thryssa	Engraulidae
41	*Triacanthus biaculeatus*	Short–nosed tripod fish	Triacanthidae

Table A.3 Market demand, average supply price, selectivity of the species to Hilsa fishing gillnets and the catch trend data of Hilsa and bycatch species of Hilsa gillnet fishing of Bangladesh (FGD = Focus Group Discussion; DO= Direct observation; CTS = Catch trend score; VS = Vulnerability score).

Scientific Name	Market demand	Data Source	Average supply price (in USD, 1 USD= 85 BDT)	Data Source	Selectivity to Hilsa gillnets	Ref.	Catch trend (n=50, total number of fishers) Increasing (1)	Stable (2)	Decreasing (3)	Data Source	CTS*	VS
Hilsa and Marine Bycatch Species												
Tenualosa ilisha	High	FGD	6.24	FGD, DO	High	1; 2; FGD	18	8	24	FGD	0	1.95
Acanthopagrus latus	Moderate	FGD	2.65	FGD, DO	High	2; 3, FGD	12	9	29	FGD	0	1.86
Anodontostoma chacunda	Low	FGD	1.77	FGD, DO	High	2; 3, FGD	12	21	17	FGD	1	1.53
Arius arius	Moderate	FGD	1.89	FGD, DO	High	2; 3, FGD	6	8	36	FGD	-1	2.19
Auxis thazard	Low	FGD	1.24	FGD, DO	High	2; 3, FGD	29	18	3	FGD	1	1.41
Carangoides malabaricus	High	FGD	3.29	FGD, DO	High	2; 3, FGD	8	26	16	FGD	1	1.36
Chelon subviridis	High	FGD	2.56	FGD, DO	Moderate	2; 3, FGD	12	26	12	FGD	1	1.69
Chirocentrus dorab	Moderate	FGD	1.81	FGD, DO	Moderate	2; 3, FGD	13	23	14	FGD	1	1.62
Coilia dussumieri	Low	FGD	1.44	FGD, DO	Low	2; 3, FGD	21	21	8	FGD	1	1.32
Coilia ramcarati	Low	FGD	1.44	FGD, DO	Low	2; 3, FGD	18	20	12	FGD	1	1.54
Conger cinereus	High	FGD	4.19	FGD, DO	Moderate	2; 3, FGD	7	8	35	FGD	-1	1.83
Decapterus russelli	Moderate	FGD	2.58	FGD, DO	High	2; 3, FGD	15	27	8	FGD	1	1.22
Dendrophysa russelii	High	FGD	2.55	FGD, DO	High	2; 3, FGD	10	29	11	FGD	1	1.74
Drepane punctata	Moderate	FGD	2.79	FGD, DO	High	2; 3, FGD	9	14	27	FGD	0	1.81
Eleutheronema tetradactylum	High	FGD	5.52	FGD, DO	High	2; 3, FGD	4	3	43	FGD	-1	2.08
Euthynnus affinis	Low	FGD	1.54	FGD, DO	High	2; 3, FGD	19	21	10	FGD	1	1.39
Harpadon nehereus	High	FGD	1.30	FGD, DO	Low	2; 3, FGD	21	18	11	FGD	1	1.52
Hilsa kelee	Moderate	FGD	2.14	FGD, DO	High	2; 3, FGD	13	22	15	FGD	1	1.59
Ilisha filigera	Moderate	FGD	1.87	FGD, DO	High	2; 3, FGD	19	18	13	FGD	1	1.73
Ilisha melastoma	Low	FGD	1.81	FGD, DO	High	2; 3, FGD	15	27	8	FGD	1	1.61
Lates calcarifer	High	FGD	5.71	FGD, DO	High	2; 3, FGD	10	4	36	FGD	-1	1.93
Leptomelanosoma indicum	High	FGD	5.52	FGD, DO	High	2; 3, FGD	5	6	39	FGD	-1	2.13
Lepturacanthus savala	High	FGD	1.53	FGD, DO	Low	2; 3, FGD	17	18	15	FGD	1	1.59
Lobotes surinamensis	High	FGD	3.43	FGD, DO	Moderate	2; 3, FGD	23	18	9	FGD	1	1.44
Megalaspis cordyla	Moderate	FGD	0.99	FGD, DO	High	2; 3, FGD	27	17	6	FGD	1	1.51
Nemapteryx caelata	Moderate	FGD	1.87	FGD, DO	High	2; 3, FGD	6	2	42	FGD	-1	2.08
Nemipterus japonicus	Moderate	FGD	2.21	FGD, DO	High	2; 3, FGD	8	39	3	FGD	1	1.08

Table A.3 (Cont…) Market demand, average supply price, selectivity of the species to Hilsa fishing gillnets and the catch trend data of Hilsa and bycatch species of Hilsa gillnet fishing of Bangladesh (FGD = Focus Group Discussion; DO= Direct observation; CTS = Catch trend score; VS = Vulnerability score).

Hilsa and Marine Bycatch Species												
Scientific Name	Market demand	Data Source	Average supply price (in USD, 1 USD= 85 BDT)	Data Source	Selectivity to Hilsa gillnets	Ref.	Catch trend (n=50, total number of fishers)			Data Source	CTS*	VS
							Increasing (1)	Stable (2)	Decreasing (3)			
Netuma thalassinus	Moderate	FGD	1.89	FGD, DO	High	2; 3, FGD	3	6	41	FGD	-1	2.32
Otolithes ruber	Moderate	FGD	3.07	FGD, DO	High	2; 3, FGD	9	4	37	FGD	-1	1.81
Pampus argenteus	High	FGD	7.57	FGD, DO	Moderate	2; 3, FGD	21	18	11	FGD	1	1.72
Pampus chinensis	High	FGD	7.13	FGD, DO	Moderate	2; 3, FGD	26	16	8	FGD	1	1.76
Panna microdon	High	FGD	2.51	FGD, DO	Moderate	2; 3, FGD	12	10	28	FGD	0	1.85
Parastromateus niger	High	FGD	3.94	FGD, DO	High	2; 3, FGD	11	7	32	FGD	-1	1.85
Pennahia anea	Moderate	FGD	1.41	FGD, DO	Moderate	2; 3, FGD	10	28	12	FGD	1	1.53
Pennahia argentata	Moderate	FGD	2.41	FGD, DO	High	2; 3, FGD	6	34	10	FGD	1	1.46
Platycephalus indicus	Moderate	FGD	3.03	FGD, DO	Moderate	2; 3, FGD	15	27	8	FGD	1	1.58
Polynemus paradiseus	High	FGD	3.54	FGD, DO	Moderate	2; 3, FGD	4	5	41	FGD	-1	2.06
Pomadasys argenteus	Moderate	FGD	2.29	FGD, DO	High	2; 3, FGD	13	6	31	FGD	-1	1.89
Protonibea diacanthus	High	FGD	4.82	FGD, DO	High	2; 3, FGD	2	1	47	FGD	-1	2.36
Pterotolithus maculatus	High	FGD	4.09	FGD, DO	High	2; 3, FGD	3	4	43	FGD	-1	1.86
Rastrelliger kanagurta	High	FGD	2.38	FGD, DO	High	2; 3, FGD	18	25	7	FGD	1	1.55
Rhizoprionodon acutus	Low	FGD	0.90	FGD, DO	High	2; 3, FGD	7	4	39	FGD	-1	1.83
Sardinella fimbriata	Moderate	FGD	1.05	FGD, DO	High	2; 3, FGD	29	19	2	FGD	1	1.56
Sardinella melanura	Moderate	FGD	1.08	FGD, DO	High	2; 3, FGD	32	14	4	FGD	2	1.49
Sciades sona	Moderate	FGD	2.60	FGD, DO	High	2; 3, FGD	2	5	43	FGD	-1	2.36
Scoliodon laticaudus	Low	FGD	0.84	FGD, DO	High	2; 3, FGD	7	3	40	FGD	-1	1.99
Scomberoides commersonnianus	High	FGD	3.67	FGD, DO	High	2; 3, FGD	4	5	41	FGD	-1	2.33
Scomberomorus commerson	High	FGD	2.77	FGD, DO	High	2; 3, FGD	14	32	4	FGD	1	1.72
Scomberomorus guttatus	High	FGD	3.17	FGD, DO	High	2; 3, FGD	12	27	11	FGD	1	1.59
Sillaginopsis panijus	High	FGD	3.11	FGD, DO	High	2; 3, FGD	8	8	34	FGD	-1	1.90
Strongylura leiura	Moderate	FGD	1.43	FGD, DO	Low	2; 3, FGD	15	25	10	FGD	1	1.80
Thryssa mystax	Moderate	FGD	1.56	FGD, DO	Low	2; 3, FGD	28	15	7	FGD	1	1.42
Trichiurus lepturus	High	FGD	1.53	FGD, DO	Moderate	2; 3, FGD	8	10	32	FGD	-1	2.00

Table A.3 (Cont…) Market demand, average supply price, selectivity of the species to Hilsa fishing gillnets and the catch trend data of Hilsa and bycatch species of Hilsa gillnet fishing of Bangladesh (FGD = Focus Group Discussion; DO= Direct observation; CTS = Catch trend score; VS = Vulnerability score).

Inland bycatch species												
Scientific Name	**Market demand**	**Data Source**	**Average supply price (in USD, 1 USD= 85 BDT)**	**Data Source**	**Selectivity of Hilsa gillnets**	**Data Source**	**Catch trend (n=50, total number of fishers)**			**Data Source**	**CTS***	**VS**
							Increasing (1)	**Stable** (2)	**Decreasing** (3)			
Ailia coila	High	FGD	3.46	FGD, DO	Low	1; 4; 5; FGD	9	15	26	FGD		1.86
Anguilla bengalensis	High	FGD	4.76	FGD, DO	Moderate	1; 4; 5; FGD	0	0	50	FGD	0	2.16
Bagarius bagarius	High	FGD	7.50	FGD, DO	High	1; 4; 5; FGD	3	0	47	FGD	-1	1.97
Chitala chitala	High	FGD	6.03	FGD, DO	Moderate	1; 4; 5; FGD	7	0	43	FGD	-1	2.07
Clupisoma garua	High	FGD	4.20	FGD, DO	High	1; 4; 5; FGD	9	5	36	FGD	-1	1.80
Gagata gagata	High	FGD	3.43	FGD, DO	High	1; 4; 5; FGD	14	10	26	FGD	-1	1.91
Gibelion catla	High	FGD	5.85	FGD, DO	High	1; 4; 5; FGD	13	20	17	FGD	0	1.67
Glossogobius giuris	Moderate	FGD	2.79	FGD, DO	Low	1; 4; 5; FGD	19	21	10	FGD	1	1.34
Gudusia chapra	Moderate	FGD	1.33	FGD, DO	Low	1; 4; 5; FGD	10	26	14	FGD	1	1.12
Johnius coitor	High	FGD	2.50	FGD, DO	High	1; 4; 5; FGD	6	18	26	FGD	1	1.85
Labeo rohita	High	FGD	5.68	FGD, DO	High	1; 4; 5; FGD	12	23	15	FGD	0	1.67
Mystus gulio	High	FGD	3.49	FGD, DO	High	1; 4; 5; FGD	9	15	26	FGD	1	1.77
Otolithoides pama	High	FGD	3.01	FGD, DO	High	1; 4; 5; FGD	25	17	8	FGD	0	1.80
Pangasius pangasius	High	FGD	6.34	FGD, DO	High	1; 4; 5; FGD	10	6	34	FGD	1	2.22
Plotosus canius	High	FGD	4.51	FGD, DO	High	1; 4; 5; FGD	4	3	43	FGD	-1	2.13
Rhinomugil corsula	High	FGD	2.48	FGD, DO	Moderate	1; 4; 5; FGD	21	22	7	FGD	1	1.54
Rita rita	High	FGD	7.99	FGD, DO	High	1; 4; 5; FGD	2	0	48	FGD	-1	1.91
Setipinna phasa	Moderate	FGD	1.73	FGD, DO	Low	1; 4; 5; FGD	14	24	12	FGD	1	1.76
Setipinna taty	Low	FGD	1.54	FGD, DO	Low	1; 4; 5; FGD	19	22	9	FGD	1	1.72
Silonia silondia	High	FGD	3.87	FGD, DO	High	1; 4; 5; FGD	7	2	41	FGD	-1	2.19
Sperata aor	High	FGD	6.91	FGD, DO	High	1; 4; 5; FGD	7	4	39	FGD	-1	2.14
Wallago attu	High	FGD	5.51	FGD, DO	High	1; 4; 5; FGD	5	7	38	FGD	-1	2.08

*Catch Trend Score (2 = increasing; 1 = stable; 0 = not significant; -1= decreasin

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Table A.4 Definition of productivity and susceptibility attributes.

Productivity attributes	Definition
Maximum age	Maximum age is a direct indication of the natural mortality rate (M), where low levels of M are negatively correlated with high maximum ages.
Maximum size	Maximum size is correlated with productivity, with large fish tending to have lower levels of productivity, although this relationship tends to degrade at higher taxonomic levels.
Von Bertalanffy growth coefficient	The von Bertalanffy growth coefficient measures how rapidly a fish reaches its maximum size, where long–lived, low productivity stocks tend to have low values of *K*.
Estimated natural mortality	Natural mortality rate directly reflects population productivity; stocks with high rates of natural mortality will require high levels of production in order to maintain population levels.
Measured fecundity	Fecundity (i.e., the number of eggs produced by a female for a given spawning event or period) is measured here at the age of first maturity.
Breeding strategy	The breeding strategy of a stock provides an indication of the level of mortality that may be expected for the offspring in the first stages of life.
Age at first maturity	Age at maturity tends to be positively related with maximum age; long–lived, lower productivity stocks will have higher ages at maturity than short–lived stocks.
Mean trophic level	The position of a stock within the larger fish community can be used to infer stock productivity; lower–trophic–level stocks generally are more productive than higher–trophic–level stocks.
Size at first maturity	Length at which the individuals attain sexual maturity for the first time. Maturity size tends to be positively associated with maximum size. Smaller species tend to reach maturity at larger sizes relative to their maximum body sizes, while larger species tend to mature at relatively smaller sizes.
Breeding cycle	Breeding cycle directly reflects the stocks productivity; species with protracted annual breeding season tends to be more productive than the species with bi/triennial breeding cycle.
Size at first maturity/Maximum size	A ratio that describes the relative investment into somatic and reproductive growth.

Table A.4 (Cont…) Definition of productivity and susceptibility attributes.

Susceptibility attributes	Definition
Areal overlap	The extent of geographic overlap between the known distribution of a stock and the distribution of the fishery.
Vertical overlap	The position of the stock within the water column (i.e., whether is demersal or pelagic) in relation to the fishing gear.
Seasonal migrations	Seasonal migrations (i.e. spawning or feeding migrations) either to or from the fishery area could affect the overlap between the stock and the fishery.
Schooling, aggregation and other behavioral responses	Behavioral responses of both individual fish and the stock in response to fishing.
Morphological characteristics affecting capture	The ability of the fishing gear to capture fish based on their morphological characteristics (e.g., body shape, spiny versus soft rayed fins, etc.).
Management strategy	The susceptibility of a stock to overfishing may largely depend on the effectiveness of fishery management procedures used to control catch.
Survival after capture and release	Fish survival after capture and release varies by species, region, and gear type or even market conditions, and thus can affect the susceptibility of the stock.
Value of the fish	The assumption that highly valued fish stocks are more susceptible to overfishing or to becoming overfished by recreational or commercial fishermen owing to increased effort.
Market demand for fish	The assumption that highly demanded fish stocks are more susceptible to overfishing or to becoming overfished by recreational or commercial fishermen owing to increased effort.
Fishing rate relative to natural mortality	As a conservative rule of thumb, it is recommended that M should be the upper limit of F so as to conserve the reproductive potential of a stock.

Table A.5a Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.4 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), k= Von Bertalanffy growth coefficient (year^{-1}), M=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	t_{max} value	t_{max} score	DQ	Ref.	L_{max} value	L_{max} score	DQ	Ref.	k Value	k score	DQ	Ref.
HIL	6.00	2	1	1, 2	60.0	2	1	32, 33	0.8	3	2	66
YWF	6.00	2	4	3	50.0	2	2	34	0.23	1	4	67
CHG	3.45	3	4	4	17.0	3	2	35	0.87	3	4	68
AUI	6.00	2	4	5	60.0	2	4	36	0.33	2	3	51
FRI	5.00	2	4	6	54.0	2	1	37	1.2	3	4	69
NGS	3.00	3	4	7	36.5	3	2	38	0.78	2	2	38
LZI	4.54	2	4	8	40.0	2	4	39	1	3	4	8
DOB	4.00	2	4	9	100.0	1	2	9, 40	0.73	2	4	70
ECD	2.00	3	1	10	20.0	3	2	35	1.3	3	2	10
ZZU	6.12	2	4	4	25.0	3	1	41	0.49	2	2	71
COI	42.86	1	4	11	140.0	1	4	39	0.7	2	4	72
RUS	2.40	3	4	12	45.0	2	2	42	1.24	3	4	73
ENU	3.16	3	4	4	25.0	3	2	43	0.95	3	4	74.
SPS	15.79	1	4	4	50.0	2	4	44.	0.19	1	4	75
FOT	20.00	1	4	4	90.0	1	4	40	0.15	1	4	76
KAW	3.80	3	4	4	60.0	2	1	37	0.79	3	4	77
BUC	2.31	3	4	4	40.0	2	1	45	1.3	3	2	78
HIX	3.19	3	4	4	35.0	3	2	43	0.94	3	4	79
PIF	4.00	2	4	13	47.0	2	1	46	0.8	3	2	46
PIE	3.75	3	4	4	27.9	3	4	47	0.8	3	3	46
GIP	6.00	2	2	14	152.0	1	4	48	0.5	2	2	14
OYD	16.67	1	4	4	113.0	1	2	45	0.18	1	4	4
SVH	3.30	3	4	15	104.0	1	1	49	0.8	3	2	49
LOB	4.35	2	4	4	110.0	1	4	50	0.69	2	4	80
HAS	4.00	2	4	16	40.0	2	2	35	0.58	2	2	81
ZZN	9.09	1	4	4	45.0	2	4	39	0.33	2	3	51
NNJ	8.00	2	4	17	32.0	3	4	40	0.94	3	2	82
AUX	9.09	1	4	4	95.0	1	1	51	0.33	2	2	51
LKR	6.00	2	4	18	48.4	2	4	52	0.67	2	4	52
SIP	7.00	2	4	19	52.0	2	1	53	0.39	2	2	53
CPO	4.84	2	4	4	50.0	2	1	53	0.62	2	2	53
NAM	6.38	2	4	4	20.0	3	1	45	0.47	2	4	4
POB	6.00	2	4	20	54.0	2	1	53	0.94	3	2	53
NHK	4.29	2	4	4	30.0	3	4	54	0.7	2	4	83
CRV	3.49	3	4	4	44.2	2	4	55	0.86	3	2	55
FLI	6.00	2	4	21	100.0	1	1	41	0.5	2	4	21
ONU	6.12	2	4	4	21.7	3	1	56	0.49	2	2	84
GRL	7.89	2	4	4	55.0	2	2	40	0.38	2	2	85
OTI	13.00	1	4	22	120.0	1	2	35	0.29	1	4	68
USM	9.38	1	4	4	45.0	2	2	35	0.32	1	4	39
RAG	4.00	2	4	23	26.0	3	1	57	0.9	3	2	57
RHA	8.00	2	4	24	178.0	1	4	58	0.32	1	4	86
FRS	3.50	3	4	25	16.0	3	2	35	1.32	3	4	25
SDM	4.10	2	4	26	23.0	3	4	59	0.7	2	4	74.
ZZV	6.00	2	4	27	112.0	1	2	43	0.36	2	4	87
SLA	6.00	2	4	24	75.0	2	2	60	0.3	1	2	88
OBM	11.00	1	4	28	120.0	1	4	61	0.25	1	4	89
COM	15.30	1	4	29	194.0	1	4	62	0.21	1	4	29
GUT	5.00	2	4	4	82.0	2	2	35	0.6	2	2	90
SIJ	7.50	2	4	4	38.2	2	1	63	0.4	2	4	39
SYQ	15.79	1	4	4	120.0	1	2	42	0.19	1	4	39
EYY	4.00	2	4	30	24.8	3	4	64	1	3	4	91
LHT	15.00	1	4	31.	234.0	1	4	65	0.29	1	4	92

Table A.5a (Cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.4 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), k= Von Bertalanffy growth coefficient (year^{-1}), M=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	*M* value	*M* score	DQ	Ref.	MF value	MF score	DQ	Ref.	BS score	DQ	Ref.
HIL	0.99	2	2	93	108500	3	1	96	3	1	34
YWF	0.57	1	4	67	1362137	3	4	97	3	1	127
CHG	1.88	3	4	94	297457	3	4	98	3	3	128
AUI	0.64	1	4	40	66	1	2	40	1	1	40
FRI	1.65	3	4	69	78803	3	4	99	3	1	129
NGS	1.42	3	4	94	36800	2	4	100	3	1	130
LZI	0.8	2	4	8	32010	2	1	101	3	1	39
DOB	2.16	3	4	70	60268	2	4	70	3	4	131
ECD	1.3	3	4	95	1200	1	4	102	3	1	132
ZZU	1.19	2	2	71	3129	1	1	103	3	1	103
COI	0.2	1	4	94	3000000	3	4	104	3	1	133
RUS	2.1	3	4	73	29986	2	4	105	3	1	134
ENU	1.79	3	4	94	52290	2	4	40	3	3	135
SPS	0.54	1	4	75	149251	3	4	106	3	1	135
FOT	0.38	1	4	94	1005219	3	1	107	3	1	136
KAW	0.93	2	4	77	201542	3	4	99	3	1	129
BUC	1.86	3	2	78	89600	3	4	108	3	1	137
HIX	1.78	3	4	79	108500	3	3	96	3	1	128
PIF	1.35	3	2	46	32756	2	4	47	3	1	110
PIE	1.55	3	4	94	32756	2	4	47	3	1	110
GIP	0.956	2	2	14	4448496	3	4	109	3	1	39; 40
OYD	0.4	1	4	94	1005219	3	3	107	3	3	136
SVH	1.08	2	2	49	9178	1	4	110	3	3	138
LOB	0.97	2	4	94	66843	3	4	111	3	1	139
HAS	1.17	2	2	81	91854	3	4	112	3	1	130
ZZN	0.76	2	4	94	66	1	4	113	3	1	140
NNJ	1.81	3	2	82	14212	2	4	114	3	1	40
AUX	0.62	1	2	51	66	1	4	113	1	1	140
LKR	1.19	2	4	94	44621	2	4	115	3	1	132
SIP	0.73	1	2	53	26109	2	1	116	3	1	132
CPO	0.99	2	2	53	26109	2	3	116	3	1	132
NAM	1.2	2	4	94	44621	2	4	115	3	3	40
POB	1.28	3	2	53	412920	3	1	117	3	1	141
NHK	1.35	3	4	83	44621	2	4	115	3	1	40
CRV	1.44	3	2	55	44621	2	4	115	3	3	142
FLI	0.77	2	4	21	55536	2	4	118	3	1	132
ONU	1.21	2	2	84	4985	1	1	119	3	1	132
GRL	0.79	2	2	85	10550	1	4	120	3	3	40
OTI	0.54	1	4	94	9506	1	1	40	3	4	35
USM	0.75	2	4	94	28159	2	3	110	3	1	135
RAG	1.71	3	2	57	42517	2	1	121	3	1	40
RHA	0.61	1	4	86	4	3	1	39, 40	1	1	143
FRS	1.75	3	4	25	11066	2	4	25	3	1	132
SDM	1.1	2	4	74	12786	2	4	25	3	1	132
ZZV	0.63	1	4	94	66	1	4	113	1	1	132
SLA	0.57	1	2	88	10	1	1	122	1	1	132
OBM	0.4	1	4	89	259488	3	4	28	3	1	130
COM	0.99	2	2	90	320000	3	4	123	3	1	40
GUT	0.99	2	2	90	385000	3	4	124	3	1	40
SIJ	0.91	2	4	94	173745	3	1	63	3	1	63
SYQ	0.41	1	4	94	1328	1	4	125	3	1	132
EYY	1.03	2	4	91	1920	1	4	126	3	1	144
LHT	0.51	1	4	92	9178	1	4	110	3	1	138

Table A.5a (Cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.4 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), k= Von Bertalanffy growth coefficient (year^{-1}), M=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	t_{mat} value	t_{mat} score	DQ	Ref.	MTL value	MTL score	DQ	Ref.	L_{mat} value	L_{mat} score	DQ	Ref.
HIL	1.00	2	2	145	2.90	3	3	39	26	2	2	211
YWF	2.75	1	4	4	3.8	1	3	39	24.4	2	4	67
CHG	1.12	2	4	4	2.80	3	3	39	11.2	3	4	4
AUI	2.41	1	4	4	3.50	2	3	39	34.1	2	4	4
FRI	2.50	1	4	146	4.40	1	3	39	33.6	2	4	99
NGS	0.70	3	4	4	3.90	2	3	39	16.1	3	4	100
LZI	0.85	3	4	4	2.70	3	3	39	23.82	2	4	4
DOB	1.00	2	4	70	4.40	1	3	39	44	1	4	70
ECD	0.75	3	4	4	3.30	3	3	39	13.1	3	4	102
ZZU	1.86	2	4	4	3.40	3	3	39	15.7	3	4	4
COI	10.00	1	4	4	4.30	1	3	39	72.1	1	4	4
RUS	1.00	2	4	147	3.70	2	3	39	12	3	4	110
ENU	0.96	3	4	4	3.50	2	3	39	15.7	3	4	4
SPS	4.29	1	4	4	3.30	3	3	39	29.01	2	4	4
FOT	2.77	1	4	4	4.10	1	3	39	31.5	2	4	76
KAW	1.20	2	4	4	4.50	1	3	39	37.7	2	4	152
BUC	0.68	3	4	4	4.20	1	3	39	24.5	2	4	153
HIX	1.00	2	4	148	2.90	3	3	39	15	3	4	154
PIF	1.00	2	4	110	3.50	2	3	39	27.5	2	4	4
PIE	1.00	2	4	110	3.50	2	3	39	14.9	3	4	47
GIP	2.00	2	2	40	3.80	2	3	39	77.5	1	4	4
OYD	4.00	1	4	110	3.90	2	3	39	59.63	1	4	4
SVH	0.55	3	4	4	4.30	1	3	39	38	2	4	15
LOB	1.00	2	4	149	4.00	1	3	39	58.2	1	4	4
HAS	1.30	2	4	4	3.90	2	3	39	22	2	4	40
ZZN	2.50	1	4	4	4.00	1	3	39	26.4	2	4	4
NNJ	0.84	3	4	4	4.10	1	3	39	18.3	3	4	114
AUX	2.30	1	4	4	3.5	1	3	39	52	1	4	113
LKR	1.55	2	4	4	3.60	2	3	39	28	2	4	18
SIP	1.82	2	4	4	3.30	3	3	39	27.5	2	4	155
CPO	1.30	2	4	4	3.60	2	3	39	29	2	4	4
NAM	2.01	1	4	4	3.60	2	3	39	12.9	3	4	4
POB	0.90	3	4	4	2.90	3	3	39	31	2	4	35
NHK	1.08	2	4	4	4.00	1	3	39	16.65	3	4	83
CRV	1.00	2	4	150	4.10	1	3	39	26	2	4	4
FLI	1.47	2	4	4	3.60	2	3	39	53.5	1	4	4
ONU	1.91	2	4	4	3.90	2	3	39	13.9	3	4	4
GRL	2.12	1	4	4	3.50	2	3	39	31.6	2	4	4
OTI	4.05	1	4	4	3.50	2	3	39	85	1	4	110
USM	1.21	2	4	4	3.70	2	3	39	15	3	4	40
RAG	1.72	2	4	4	3.20	3	3	39	21.5	2	2	121
RHA	2.00	2	4	40	4.30	1	3	39	61	1	4	4
FRS	1.16	2	4	4	2.70	3	3	39	13.27	3	4	25
SDM	1.00	2	4	110	2.70	3	3	39	14.43	3	4	59
ZZV	2.01	1	4	4	4.00	1	3	39	59.2	1	4	4
SLA	2.07	1	4	4	3.80	2	3	39	35.79	2	4	156
OBM	4.00	1	4	28	4.40	1	3	39	63.5	1	4	157
COM	2.10	1	4	29	4.50	1	3	39	70.1	1	4	62
GUT	1.80	2	4	151	4.30	1	3	39	40	1	1	37
SIJ	2.13	1	4	4	3.30	3	3	39	22.9	2	4	4
SYQ	3.77	1	4	4	3.90	2	3	39	62.9	1	4	4
EYY	0.69	3	4	4	3.60	2	3	39	13	3	4	158
LHT	0.75	3	4	4	4.40	1	3	39	46.3	1	4	4

Table A.5a (Cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.4 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), k= Von Bertalanffy growth coefficient (year^{-1}), M=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	BC score	DQ	Ref.	t_{mat}/t_{max} value	AFM/MA score	DQ	Ref.	L_{mat}/L_{max} value	L_{mat}/L_{max} score	DQ	Ref.
HIL	3	1	159	0.17	3	2	1, 145, 148	0.43	3	2	32, 33, 211
YWF	2	4	67	0.46	1	4	3, 4	0.49	3	4	34, 67
CHG	2	2	40	0.32	1	4	4	0.66	1	4	4, 35
AUI	2	4	40	0.40	1	4	4; 5	0.57	2	4	4, 36
FRI	2	4	99	0.50	1	4	6, 146	0.62	1	4	37, 99
NGS	3	2	100	0.23	3	4	4, 7	0.44	3	4	38, 100
LZI	2	2	101	0.19	3	4	4, 8	0.60	1	4	4, 39
DOB	3	2	70	0.25	2	4	9, 70	0.44	3	4	9, 40, 70
ECD	3	4	102	0.38	1	4	4, 10	0.66	1	4	35, 102
ZZU	3	2	103	0.30	1	4	4, 11	0.63	1	4	4, 41
COI	1	4	133	0.23	3	4	4	0.52	3	4	4, 39
RUS	3	4	110	0.42	1	4	12, 147	0.27	3	4	42, 110
ENU	3	4	160	0.30	1	4	4	0.63	1	4	4, 43
SPS	2	4	106	0.27	2	4	4	0.58	2	4	4, 44.
FOT	3	1	107	0.14	3	4	4	0.35	3	4	40, 76
KAW	3	4	99, 152	0.32	1	4	4	0.63	1	4	37, 152
BUC	3	4	35	0.29	2	4	4	0.61	1	4	45, 153
HIX	2	4	154	0.31	1	4	4, 148	0.43	3	4	43, 154
PIF	3	4	47	0.25	2	4	13, 110	0.59	2	4	4, 46
PIE	3	4	47	0.27	2	4	4, 110	0.53	2	4	47
GIP	3	2	40	0.33	1	2	14, 40	0.51	3	4	4, 48
OYD	3	3	107	0.24	3	4	4, 110	0.53	2	4	4, 45
SVH	2	4	161	0.17	3	4	4, 15	0.37	3	4	15, 49
LOB	3	4	139	0.23	3	4	4, 149	0.53	2	4	4, 50
HAS	2	2	40	0.33	1	4	4, 16	0.55	2	4	35, 40
ZZN	2	2	113; 40	0.28	2	4	4	0.59	2	4	4, 39
NNJ	3	4	114	0.11	3	4	4, 17	0.57	2	4	40, 114
AUX	3	2	113; 40	0.25	2	4	4	0.55	2	4	51, 113
LKR	2	4	115	0.26	2	4	4, 18	0.58	2	4	18, 52
SIP	3	4	155	0.26	2	4	4, 19	0.53	2	4	53, 155
CPO	2	4	162	0.27	2	4	4	0.58	2	4	4, 53
NAM	2	4	163	0.31	1	4	4	0.65	1	4	4, 45
POB	2	1	117	0.15	3	4	4, 20	0.57	2	4	35, 53
NHK	2	4	163	0.25	2	4	4	0.56	2	4	54, 83
CRV	3	4	142	0.29	2	4	4, 150	0.59	2	4	4, 55
FLI	2	4	164	0.25	3	4	4, 21	0.54	2	4	4, 41
ONU	2	1	119	0.31	1	4	4	0.64	1	4	4, 56
GRL	3	4	165	0.27	2	4	4	0.57	2	4	4, 40
OTI	2	4	166	0.31	1	4	4, 22	0.71	1	4	35, 110
USM	2	2	40	0.13	3	4	4	0.33	3	4	35, 40
RAG	3	1	121	0.43	1	4	4, 23	0.83	1	2	57, 121
RHA	3	4	86	0.25	2	4	24, 40	0.34	3	4	4, 58
FRS	2	4	25	0.33	1	4	4, 25	0.83	1	4	25, 35
SDM	2	4	25	0.24	3	4	26, 110	0.63	1	4	59
ZZV	2	4	110	0.34	1	4	4, 27	0.53	2	4	4, 43
SLA	2	4	122	0.35	1	4	4, 24	0.48	3	4	60, 156
OBM	2	4	28	0.36	1	4	28	0.53	2	4	61, 157
COM	3	4	62	0.14	3	4	29	0.36	3	4	62
GUT	3	2	90	0.36	1	4	4, 151	0.49	3	2	35, 37
SIJ	2	2	63	0.28	2	4	4	0.60	1	4	4, 63
SYQ	2	4	35	0.24	3	4	4	0.52	2	4	4, 42
EYY	3	4	126	0.17	3	4	4, 30	0.52	2	4	64, 158
LHT	2	4	167	0.05	3	4	4, 31.	0.20	3	4	4, 65

Table A.5b Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for inland bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.5 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), k= Von Bertalanffy growth coefficient (year^{-1}), M=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	t_{max} value	t_{max} score	DQ	Ref.	L_{max} value	L_{max} score	DQ	Ref.	k Value	k score	DQ	Ref.
AIC	9.38	1	4	4	30.0	3	1	169	0.32	1	4	39
AAG	37.50	1	4	4	118.0	1	1	45	0.09	1	4	4
BGG	150.00	1	4	4	165.0	1	4	172	0.02	1	4	4
NCC	14.29	1	4	4	120.0	1	2	148	0.21	1	4	39
LUG	3.80	3	4	4	60.0	2	1	148	0.79	2	2	177
GGA	25.00	1	4	4	19.3	3	2	34	0.12	1	4	39
CTT	5.26	2	4	4	97.6	1	1	173	0.57	2	2	173
GOU	4.30	2	2	168	30.0	3	2	148	0.7	2	2	168
CGH	2.31	3	4	4	21.0	3	1	174	1.3	3	2	178
JOC	3.45	3	4	4	19.0	3	1	45	0.87	3	3	179
LRH	10.00	1	3	169	90.0	1	2	148	0.92	3	2	180
BMG	4.00	2	2	14	29.2	3	1	175	0.75	2	2	14
OTD	3.50	3	2	14	31.0	3	1	14	0.8	3	2	14
PGP	13.64	1	4	4	150.0	1	2	43	0.11	1	4	4
PUN	30.00	1	4	4	150.0	1	1	169	0.1	1	4	39
RIC	7.00	2	4	170	35.0	3	1	45	1	3	2	181
RRT	50.00	1	4	4	45.0	2	2	148	0.06	1	4	39
ESP	7.00	2	4	171	19.0	3	1	176	0.24	1	4	182
ESY	9.09	1	4	4	15.3	3	2	34	0.33	2	4	68
LND	14.29	1	4	4	80.0	2	1	45	0.21	1	4	39
LWC	15.79	1	4	4	94.0	1	2	45	0.19	1	4	4
WAA	10.00	1	4	4	186.0	1	2	169	0.05	1	4	183

Spp. code	t_{mat} value	t_{mat} score	DQ	Ref.	MTL value	MTL score	DQ	Ref.	L_{mat} value	L_{mat} score	DQ	Ref.
AIC	2.77	1	4	4	3.90	2	3	39	18.5	3	4	4
AAG	7.80	1	4	204	3.80	2	3	39	61.95	1	4	4
BGG	34.13	1	4	4	3.70	2	3	39	83.3	1	4	4
NCC	3.40	1	4	4	3.70	2	3	39	62.9	1	4	4
LUG	1.00	2	4	169	3.70	2	3	39	34.1	2	4	4
GGA	7.90	1	4	4	3.40	3	3	39	12.5	3	4	4
CTT	1.29	2	4	4	2.80	3	3	39	52.38	1	4	4
GOU	1.30	2	4	4	3.70	2	3	39	18.5	3	4	4
CGH	0.45	3	4	4	3.10	3	3	39	9.78	3	2	206
JOC	0.96	3	4	4	3.40	3	3	39	11.4	3	4	191
LRH	2.00	2	2	169	2.20	3	3	39	50	1	4	87
BMG	1.19	2	4	4	4.00	1	3	39	18.04	3	4	4
OTD	1.10	2	4	4	3.90	2	3	39	19.02	2	4	4
PGP	4.00	1	3	205	3.40	3	3	39	54	1	3	207
PUN	6.93	1	4	4	3.90	2	3	39	76.6	1	4	4
RIC	0.34	3	4	4	2.40	3	3	39	10.42	3	4	181
RRT	13.82	1	4	4	3.70	2	3	39	26.43	2	4	4
ESP	3.96	1	4	4	3.30	3	3	39	12.3	3	4	4
ESY	3.01	1	4	4	3.60	2	3	39	10.2	3	4	4
LND	3.62	1	4	4	3.50	2	3	39	43.95	1	4	4
LWC	4.00	1	4	169	3.60	2	3	39	50.7	1	4	4
WAA	13.43	1	4	4	3.70	2	3	39	92.62	1	4	4

Table A.5b (Cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for inland bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification number (see the Table 3.5 for species details) (t_{max} = Maximum age (year), L_{max} = Maximum size (cm), *k*= Von Bertalanffy growth coefficient (year^{-1}), *M*=Estimated natural mortality ((year^{-1}), MF=Measured fecundity (number of egg), BS= Breeding strategy, t_{mat} = Age at first maturity (year), MTL= Mean trophic level, L_{mat} =Size at first maturity (cm), BS=Breeding cycle, t_{mat}/t_{max} = Age at first maturity/Maximum age, L_{mat}/L_{max} = Size at first maturity/Maximum size).

Spp. code	*M* value	*M* score	DQ	Ref.	MF value	MF score	DQ	Ref.	BS score	DQ	Ref.
AIC	0.84	2	4	94	600	1	1	169	3	1	202
AAG	0.25	1	4	94	330000	3	1	185	1	1	45, 169
BGG	0.09	1	4	94	1057633	3	4	186	1	4	135
NCC	0.43	1	4	94	8238	1	1	187	1	1	169, 187
LUG	1.53	3	2	177	6159	1	1	188	3	1	132
GGA	0.5	1	4	94	100	1	4	169	3	4	45
CTT	0.9	2	2	173	1564875	3	1	169	3	1	148, 169
GOU	1.55	3	2	168	14987	2	1	189	3	1	203
CGH	1.37	3	2	184	10800	2	1	190	3	1	39
JOC	1.76	3	3	179	5687	1	4	191	3	1	135
LRH	1.22	3	2	180	260972	3	1	45	3	1	39
BMG	1.59	3	2	14	11436	2	1	192	3	3	132
OTD	1.507	3	2	14	2387	1	3	193	3	4	169
PGP	0.27	1	4	94	73000	3	4	194	3	4	148
PUN	0.25	1	4	94	2122	1	1	195	3	3	132
RIC	1.73	3	2	181	9506	1	1	196	3	1	132
RRT	0.2	1	4	94	37307	2	1	197	3	4	132
ESP	0.79	2	4	94	805	1	4	198	3	1	128
ESY	1.03	2	4	94	805	1	4	198	3	1	128
LND	0.49	1	4	94	4800	1	1	199	3	1	132
LWC	0.44	1	4	94	12560	2	4	200	1	4	135
WAA	0.15	1	4	94	66070	3	4	201	1	3	169

Spp. code	BC score	DQ	Ref.	t_{mat}/t_{max} value	t_{mat}/t_{max} score	DQ	Ref.	L_{mat}/L_{max} value	L_{mat}/L_{max} score	DQ	Ref.
AIC	2	2	169	0.30	2	4	4	0.62	1	4	4, 169
AAG	1	1	148	0.21	3	4	4, 204	0.53	2	4	4, 45
BGG	2	2	169	0.23	3	4	4	0.50	3	4	4, 172
NCC	2	1	187	0.24	3	4	4	0.52	2	4	4, 148
LUG	2	1	188	0.26	2	4	4, 169	0.57	2	4	4, 148
GGA	2	4	148	0.32	1	4	4	0.65	1	4	4, 34
CTT	2	2	169	0.25	3	4	4	0.54	2	4	4, 173
GOU	3	2	148	0.30	1	4	4, 168	0.62	1	4	4, 148
CGH	2	1	208	0.20	3	4	4	0.47	3	2	174, 206
JOC	2	3	14	0.28	2	4	4	0.60	1	4	45, 191
LRH	2	1	148	0.20	3	4	169	0.56	2	4	87, 148
BMG	3	1	192	0.30	2	4	4, 14	0.62	1	4	4, 175
OTD	2	1	14	0.31	1	4	4, 14	0.61	1	4	4, 14
PGP	2	1	207	0.29	2	4	4, 205	0.36	3	4	43, 207
PUN	2	2	195	0.23	3	4	4	0.51	3	4	4, 169
RIC	2	1	196	0.05	3	4	4, 170	0.30	3	4	45, 181
RRT	2	1	197	0.28	2	4	4	0.59	2	4	4, 148
ESP	3	4	128	0.57	1	4	4, 171	0.65	1	4	4, 176
ESY	3	4	128	0.33	1	4	4	0.67	1	4	4, 34
LND	2	2	209	0.25	2	4	4	0.55	2	4	4, 45
LWC	2	2	210	0.25	2	4	4, 169	0.54	2	4	4, 45
WAA	2	1	34	1.34	1	4	4	0.50	3	4	4, 169

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Table A.6a Susceptibility attributes with scores (e.g., AO, VO etc.), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification (see the Table 3.4 for species details) (AO= Areal overlap, VO= Vertical overlap, SM= Seasonal migrations, SABR= Schooling, aggregation, and other behavioral responses, MCAC= Morphological characteristics affecting capture, MSt= Management strategy, SCR= Survival after capture and release, MVF= Value of the fishery, MDF= Market demand of the fishery, F/*M*= Fishing rate relative to natural mortality). Apart from the data on the Hilsa fishery and its bycatch stocks collected through literature review and Focus Group Discussions (FGDs) has also been considered for attribute scoring.

Spp. code	AO	DQ	Ref.	VO	DQ	Ref.	SM	DQ	Ref.	SABR	DQ	Ref.	MCAC	DQ	Ref.
HIL	3	2	1; FGD	3	4	2; FGD	3	1	3; 4; FGD	3	1	3; 4; FGD	3	4	17; 5
YWF	3	3	2; FGD	3	4	2; FGD	2	3	5; 6, FGD	2	4	17; FGD	3	4	6; 5
CHG	3	3	1; FGD	3	4	2; FGD	2	3	5; 6, FGD	3	1	18; FGD	3	4	6; 5
AUI	3	3	2; FGD	3	4	2; FGD	3	2	7; 5; 6, FGD	3	2	8; 19; FGD	3	4	6; 5
FRI	2	3	2; FGD	2	4	2; FGD	1	2	7; 5; FGD	3	3	8; FGD	3	4	6; 5
NGS	2	3	2; FGD	2	4	2; FGD	2	3	8; FGD	2	4	5	3	4	6; 5
LZI	3	1	1; FGD	3	4	2; FGD	2	2	9; FGD	3	4	20; FGD	2	4	6; 5
DOB	3	3	2; FGD	3	4	2; FGD	2	3	5; 7; FGD	2	4	21; FGD	2	4	6; 5
ECD	3	1	1; FGD	3	4	2; FGD	3	2	10; 7; FGD	3	1	5; FGD	1	4	6; 5
ZZU	3	1	1; FGD	3	4	2; FGD	3	2	10; 7; FGD	3	1	5; FGD	1	4	6; 5
COI	2	3	2; FGD	2	4	2; FGD	2	4	5; FGD	2	4	5; FGD	2	4	6; 5
RUS	2	3	2; FGD	2	4	2; FGD	1	4	11; 12; FGD	2	4	11; FGD	3	4	6; 5
ENU	3	3	2; FGD	3	4	2; FGD	3	3	7; FGD	2	4	6; FGD	3	4	6; 5
SPS	3	3	2; FGD	3	4	2; FGD	2	3	7; FGD	2	4	5; FGD	3	4	6; 5
FOT	3	3	2; FGD	3	4	2; FGD	3	2	5; 13; FGD	2	2	5; FGD	3	4	6; 5
KAW	2	3	2; FGD	2	4	2; FGD	1	3	7; FGD	3	1	5; FGD	3	4	6; 5
BUC	3	3	2; FGD	3	4	2; FGD	2	2	10; 6; FGD	3	1	5; FGD	1	4	6; 5
HIX	3	1	1; FGD	3	4	2; FGD	2	2	10; 6; 7; FGD	3	3	8; FGD	3	4	6; 5
PIF	3	1	1; FGD	3	4	2; FGD	3	2	10; 7; FGD	3	1	5; FGD	3	4	6; 5
PIE	3	1	1; FGD	3	4	2; FGD	3	2	10; 7; FGD	3	1	5; FGD	3	4	6; 5
GIP	3	3	2; FGD	3	4	2; FGD	2	2	10; 7; FGD	3	3	22; FGD	3	4	6; 5
OYD	3	3	2; FGD	3	4	2; FGD	3	4	5; 13; FGD	2	4	5; FGD	3	4	6; 5
SVH	3	3	2; FGD	3	4	2; FGD	2	3	14; 5; FGD	3	2	8; 23; FGD	1	4	6; 5
LOB	2	3	2; FGD	2	4	2; FGD	1	2	7; FGD	2	4	24; 25	2	4	6; 5
HAS	2	3	2; FGD	2	4	2; FGD	2	4	5; FGD	3	1	5; FGD	3	4	6; 5
ZZN	3	3	2; FGD	3	4	2; FGD	3	2	7; FGD	3	3	8; 19; FGD	3	4	6; 5
NNJ	1	3	2; FGD	1	4	2; FGD	1	4	5; 15; FGD	3	1	5; FGD	3	4	6; 5
AUX	3	3	2; FGD	3	4	2; FGD	3	2	7; FGD	3	2	8; 19; FGD	3	4	6; 5
LKR	3	3	2; FGD	3	4	2; FGD	3	2	10; 7; FGD	2	4	5; 6; FGD	3	4	6; 5
SIP	3	3	2; FGD	3	4	2; FGD	2	2	10; 5; FGD	3	1	8; 5; FGD	2	4	6; 5
CPO	3	3	2; FGD	3	4	2; FGD	2	2	10; 5; FGD	2	1	8; 5; FGD	2	4	6; 5
NAM	3	3	2; FGD	3	4	2; FGD	2	3	10; 5; FGD	3	3	5; 26; FGD	2	4	6; 5
POB	3	3	2; FGD	3	4	2; FGD	2	3	10; 12; 7; FGD	3	1	8; 5; FGD	3	4	6; 5
NHK	3	3	2; FGD	3	4	2; FGD	2	3	8	3	1	5; 26; FGD	2	4	6; 5
CRV	3	3	2; FGD	3	4	2; FGD	1	4	7; FGD	3	2	5; FGD	3	4	6; 5
FLI	3	3	1; FGD	1	4	2; FGD	3	2	10; 7; FGD	2	4	5; FGD	2	4	6; 5
ONU	3	3	1; FGD	3	4	2; FGD	3	3	10; FGD	3	2	27; FGD	2	4	6; 5
GRL	3	3	2; FGD	3	4	2; FGD	2	3	12; 5; FGD	2	1	5; FGD	3	4	6; 5
OTI	3	3	2; FGD	3	4	2; FGD	2	4	16; 5; FGD	2	2	5; FGD	3	4	6; 5
USM	3	3	2; FGD	3	4	2; FGD	2	4	8; 5; FGD	2	4	5; FGD	3	4	6; 5
RAG	2	3	2; FGD	2	4	2; FGD	1	3	5; 7; FGD	3	1	28; 5; FGD	3	4	6; 5
RHA	3	3	2; FGD	3	4	2; FGD	2	3	7; FGD	3	2	29; FGD	3	4	6; 5
FRS	3	3	2; FGD	3	4	2; FGD	2	4	5; 6; FGD	3	1	5; 30; FGD	3	4	6; 5
SDM	3	3	2; FGD	3	4	2; FGD	2	4	5; 6; FGD	3	1	5; FGD	3	4	6; 5
ZZV	3	3	2; FGD	3	4	2; FGD	3	3	10; 7; FGD	3	3	8; 19; FGD	3	4	6; 5
SLA	3	3	2; FGD	3	4	2; FGD	2	3	7; FGD	3	2	29; FGD	3	4	6; 5
OBM	3	3	2; FGD	3	4	2; FGD	2	3	7; FGD	3	3	31; FGD	3	4	6; 5
COM	2	3	2; FGD	2	4	2; FGD	1	4	5; 7; FGD	3	1	5; FGD	3	4	6; 5
GUT	2	3	2; FGD	2	4	2; FGD	1	4	5; 7; FGD	3	1	5; 6; FGD	3	4	6; 5
SIJ	3	1	1; FGD	3	4	2; FGD	3	3	5; 7; FGD	2	4	6; FGD	3	4	6; 5
SYQ	3	3	2; FGD	3	4	2; FGD	2	3	10; 5; 7; FGD	2	4	32; 33; FGD	1	4	6; 5
EYY	3	3	2; FGD	3	4	2; FGD	2	4	10; 7; FGD	3	2	34; FGD	1	4	6; 5
LHT	3	3	2; FGD	3	4	2; FGD	2	3	10; 7; FGD	3	4	8; 23; FGD	2	4	6; 5

Table A.6a (Cont…) Susceptibility attributes with scores (e.g., AO, VO etc.), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for Hilsa and its marine bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification (see the Table 3.4 for species details)) (AO= Areal overlap, VO= Vertical overlap, SM= Seasonal migrations, SABR= Schooling, aggregation, and other behavioral responses, MCAC= Morphological characteristics affecting capture, MSt= Management strategy, SCR= Survival after capture and release, MVF= Value of the fishery, MDF= Market demand of the fishery, F/M= Fishing rate relative to natural mortality). Apart from the data on the Hilsa fishery and its bycatch stocks collected through literature review and Focus Group Discussions (FGDs) has also been considered for attribute scoring.

Spp. code	MSt	DQ	Ref.	SCR	DQ	Ref.	MVF	DQ	Ref.	MDF	DQ	Ref.	F/*M*	DQ	Ref.
HIL	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	3	2	38; 39; 40; 41; 42; 43
YWF	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
CHG	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	1	1	FGD			
AUI	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
FRI	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD			
NGS	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
LZI	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
DOB	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
ECD	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD			
ZZU	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD	3	2	44
COI	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
RUS	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
ENU	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
SPS	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
FOT	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
KAW	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	1	1	FGD			
BUC	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	3	1	FGD	3	2	45
HIX	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
PIF	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD	2	2	46
PIE	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	1	1	FGD			
GIP	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	2	2	47
OYD	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
SVH	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD	2	2	48
LOB	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
HAS	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	2	1	FGD	2	2	49
ZZN	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
NNJ	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD	2	2	50
AUX	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD	3	2	51
LKR	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
SIP	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	1	2	52
CPO	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	2	2	52
NAM	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
POB	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	3	2	52
NHK	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	2	1	FGD			
CRV	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD	1	2	53
FLI	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
ONU	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD	3	2	54
GRL	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD	3	2	55
OTI	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
USM	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
RAG	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD	3	2	56
RHA	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD			
FRS	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	2	1	FGD			
SDM	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD			
ZZV	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
SLA	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	1	1	FGD	3	2	57
OBM	2	1	35; 36; FGD	3	1	37; FGD	3	1	FGD	3	1	FGD			
COM	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
GUT	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD	2	2	58
SIJ	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			
SYQ	2	1	35; 36; FGD	3	1	37; FGD	1	1	FGD	2	1	FGD			
EYY	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	2	1	FGD			
LHT	2	1	35; 36; FGD	3	1	37; FGD	2	1	FGD	3	1	FGD			

Table A.6b Susceptibility attributes with scores (e.g., AO, VO etc.), data quality (DQ) and references (Ref.) used in the productivity susceptibility analysis (PSA) for inland bycatch species from Hilsa gillnet fishing. In the following table FAO 3–alpha code used as the species identification (see the Table 3.5 for species details) (AO= Areal Overlap, VO= Vertical overlap, SM= Seasonal migrations, SABR= Schooling, aggregation, and other behavioral responses, MCAC= Morphological characteristics affecting capture, MSt= Management strategy, SCR= Survival after capture and release, MVF= Value of the fishery, MDF= Market demand of the fishery, F/*M*= Fishing rate relative to natural mortality). Apart from the data on the Hilsa fishery and its bycatch stocks collected through literature review and informations gathered from Focus Group Discussion (FGD) has also been considered for attribute scoring.

Spp. code	AO	DQ	Ref.	VO	DQ	Ref.	SM	DQ	Ref.	SABR	DQ	Ref.	MCAC	DQ	Ref.
AIC	2	1	1; FGD	3	4	FGD	3	2	10; FGD	3	1	17; FGD	1	4	61; 17; 63
AAG	2	1	1; FGD	3	4	FGD	3	1	10; 7; FGD	2	4	8; FGD	2	4	61; 17; 63
BGG	1	1	1; FGD	3	4	FGD	2	2	8; 10; 7; FGD	2	4	8; FGD	3	4	61; 17; 63
NCC	1	1	1; FGD	3	4	FGD	2	2	10; FGD	2	4	60; FGD	2	4	61; 17; 63
LUG	1	1	1; FGD	3	4	FGD	3	3	10; 7; FGD	3	1	61; FGD	3	4	61; 17; 63
GGA	1	1	1; FGD	3	4	FGD	3	4	8; 10; FGD	2	4	17; FGD	3	4	61; 17; 63
CTT	1	1	1; FGD	3	4	FGD	2	1	10; 7; FGD	2	1	62; FGD	3	4	61; 17; 63
GOU	2	1	1; FGD	3	4	FGD	2	3	10; 7; FGD	2	4	61; FGD	1	4	61; 17; 63
CGH	2	1	1; FGD	3	4	FGD	2	3	10; 7; FGD	3	1	61; FGD	1	4	61; 17; 63
JOC	3	1	1; FGD	3	4	FGD	3	3	10; 7; FGD	3	4	17; FGD	3	4	61; 17; 63
LRH	1	1	1; FGD	3	4	FGD	2	1	10; 7; FGD	2	1	62; FGD	3	4	61; 17; 63
BMG	3	1	1; FGD	3	4	FGD	2	2	10; 7; FGD	3	1	63; FGD	3	4	61; 17; 63
OTD	3	1	1; FGD	3	4	FGD	3	3	10; 7; FGD	3	4	61; 17	3	4	61; 17; 63
PGP	3	1	1; FGD	3	4	FGD	3	3	8; 10; 7; FGD	3	2	64; FGD	3	4	61; 17; 63
PUN	3	1	1; FGD	3	4	FGD	2	2	10; 7; FGD	2	4	65; FGD	3	4	61; 17; 63
RIC	3	1	1; FGD	3	4	FGD	2	2	10; 7; FGD	3	4	20; FGD	2	4	61; 17; 63
RRT	1	1	1; FGD	3	4	FGD	2	2	8; 10; 7; FGD	2	4	63; FGD	3	4	61; 17; 63
ESP	3	1	1; FGD	3	4	FGD	3	3	10; 7; FGD	3	1	8; 61; FGD	1	4	61; 17; 63
ESY	3	1	1; FGD	3	4	FGD	3	3	10; 7; FGD	3	1	8; 61; FGD	1	4	61; 17; 63
LND	2	1	1; FGD	3	4	FGD	2	3	10; 7; FGD	3	1	66; 1; FGD	3	4	61; 17; 63
LWC	1	1	1; FGD	3	4	FGD	2	2	10; 7; FGD	2	4	63	3	4	61; 17; 63
WAA	1	1	1; FGD	3	4	FGD	2	2	10; 59; FGD	2	4	67	3	4	61; 17; 63

Spp. code	MSt	DQ	Ref.	SCR	DQ	Ref.	MVF	DQ	Ref.	MDF	DQ	Ref.	F/*M*	DQ	Ref.
AIC	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD			
AAG	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
BGG	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
NCC	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
LUG	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD	2	2	68
GGA	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD			
CTT	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
GOU	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	2	1	FGD			
CGH	2	1	35; 36; FGD	3	1	FGD	1	1	FGD	2	1	FGD			
JOC	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD			
LRH	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
BMG	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD	2	2	46
OTD	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD	1	2	46
PGP	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
PUN	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
RIC	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	3	1	FGD	2	2	69
RRT	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
ESP	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	2	1	FGD			
ESY	2	1	35; 36; FGD	3	1	FGD	2	1	FGD	1	1	FGD			
LND	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
LWC	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			
WAA	2	1	35; 36; FGD	3	1	FGD	3	1	FGD	3	1	FGD			

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Appendix B

Table B.1 Exploitation rate (*E*) of and catch trend of the selected bycatch of Hilsa gillnet fishery of Bangladesh. Species listed in bold text are from inland habitat (river) and the rest of the species are reported from marine habitat.

Species name	*E*	Ref.	Fisher's perception (n=50) of catch trend			Split analysis	Catch trend
			Increasing	Stable	Decreasing		
Clupisoma garua	0.34	1	9	5	36	-1	D
Coilia ramcarati	0.87	2	18	20	12	1	S
Harpadon nehereus	0.58	3	21	18	11	1	S
Ilisha filigera	0.40	4	19	18	13	1	S
Lates calcarifer	0.37	5	10	4	36	-1	D
Lepturacanthus savala	0.43	9	17	18	15	1	S
Megalaspis cordyla	0.33	10	27	17	6	1	S
Mystus gulio	0.47	5	9	15	26	1	S
Nemipterus japonicus	0.41	6	8	39	3	1	S
Netuma thalassina	0.62	7	3	6	41	-1	D
Otolithoides pama	0.27	5	25	17	8	0	NS
Pampus argenteus	0.23	8	21	18	11	1	S
Pampus chinensis	0.36	8	26	16	8	1	S
Parastromateus niger	0.56	8	11	7	32	-1	D
Pennahia argentata	0.29	11	6	34	10	1	S
Polynemus paradiseus	0.72	12	4	5	41	-1	D
Pomadasys argenteus	0.51	13	13	6	31	-1	D
Rastrelliger kanagurta	0.65	14	18	25	7	1	S
Rhinomugil corsula	0.42	15	21	22	7	1	S
Scoliodon laticaudus	0.57	16	7	3	40	-1	D
Scomberomorus guttatus	0.45	17	12	27	11	1	S

D = Decreasing, NS = Not significant, S = Stable

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Table B.2 Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{max} score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.2). Attributes values have mainly complied from existing literature (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses is being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on corresponding attribute value calculated from empirical relationship equations (described in the main text).

Species name	t_{max} value	t_{max} score	Ref.	L_{max} value	L_{max} score	Ref.	*k* value	*k* score	Ref.	*M* value	*M* score	Ref.
Clupisoma garua	3.8	***3(1)***	1	60	2	12	0.79	2	27	1.53	3	27
Coilia ramcarati	6.12	***2(1)***	1	25	3	13	0.49	2	28	1.19	2	28
Harpadon nehereus	2.31	***3(1)***	1	40	2	14	1.3	3	29	1.86	3	29
Ilisha filigera	4	2	2	47	2	15	0.8	3	15	1.35	3	15
Lates calcarifer	6	2	3	152	1	16	0.5	2	3	0.956	2	3
Lepturacanthus savala	3.3	3	4	104	1	17	0.8	3	17	1.08	2	17
Megalaspis cordyla	4	2	5	40	2	18	0.58	2	30	1.17	2	30
Mystus gulio	4	2	3	29.2	3	19	0.75	2	3	1.59	3	3
Nemipterus japonicus	8	2	6	32	3	20	0.94	3	31	1.81	3	31
Netuma thalassinus	9.09	***1(1)***	1	95	1	21	0.33	2	21	0.62	1	21
Otolithoides pama	3.5	3	3	31	3	3	0.8	3	3	1.507	3	3
Pampus argenteus	7	2	7	52	2	22	0.39	2	22	0.73	1	22
Pampus chinensis	4.84	***2(1)***	1	50	2	22	0.62	2	22	0.99	2	22
Parastromateus niger	6	2	8	54	2	22	0.94	3	22	1.28	3	22
Pennahia argentata	3.49	***3(1)***	1	44.2	2	23	0.86	3	23	1.44	3	23
Polynemus paradiseus	6.12	***2(1)***	1	21.7	3	24	0.49	2	32	1.21	2	32
Pomadasys argenteus	7.89	***2(1)***	1	55	2	20	0.38	2	33	0.79	2	33
Rastrelliger kanagurta	4	2	9	26	3	25	0.9	3	25	1.71	3	25
Rhinomugil corsula	7	2	10	35	3	14	1	3	34	1.73	3	34
Scoliodon laticaudus	6	2	11	75	2	26	0.3	1	35	0.57	1	35
Scomberomorus guttatus	5	***2(1)***	1	82	2	18	0.6	2	36	0.99	2	36

Table B.2 (cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{ma} score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.2). Attributes values have mainly complied from existing literature (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses is being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on corresponding attribute value calculated from empirical relationship equations (described in the main text).

Species name	MF value	MF score	Ref.	BS score	Ref.	t_{mat} value	t_{mat} score	Ref.	MTL value	MTL score	Ref.
Clupisoma garua	6159	1	37	3	57	1	2	63	3.7	2	59
Coilia ramcarati	3129	1	38	3	38	1.86	***2(1)***	1	3.4	3	59
Harpadon nehereus	89600	3	39	3	58	0.68	***3(1)***	1	4.2	1	59
Ilisha filigera	32756	2	40	3	42	1	2	42	3.5	2	59
Lates calcarifer	4448496	3	41	3	20, 59	2	2	20	3.8	2	59
Lepturacanthus savala	9178	1	42	3	60	0.55	***3(1)***	1	4.3	1	59
Megalaspis cordyla	91854	3	43	3	61	1.3	***2(1)***	1	3.9	2	59
Mystus gulio	11436	2	44	3	57	1.19	***2(1)***	1	4	1	59
Nemipterus japonicus	14212	2	45	3	20	0.84	***3(1)***	1	4.1	1	59
Netuma thalassinus	66	1	46	1	62	2.3	***1(1)***	1	3.5	1	59
Otolithoides pama	2387	1	47	3	63	1.1	***2(1)***	1	3.9	2	59
Pampus argenteus	26109	2	47	3	57	1.82	***2(1)***	1	3.3	3	59
Pampus chinensis	26109	2	48	3	57	1.3	***2(1)***	1	3.6	2	59
Parastromateus niger	412920	3	49	3	64	0.9	***3(1)***	1	2.9	3	59
Pennahia argentata	44621	2	50	3	65	1	2	66	4.1	1	59
Polynemus paradiseus	4985	1	51	3	57	1.91	***2(1)***	1	3.9	2	59
Pomadasys argenteus	10550	1	52	3	20	2.12	***1(1)***	1	3.5	2	59
Rastrelliger kanagurta	42517	2	53	3	20	1.72	***2(1)***	1	3.2	3	59
Rhinomugil corsula	9506	1	54	3	57	0.34	***3(1)***	1	2.4	3	59
Scoliodon laticaudus	10	1	55	1	57	2.07	***1(1)***	1	3.8	2	59
Scomberomorus guttatus	385000	3	56	3	20	1.8	2	67	4.3	1	59

Table B.2 (cont…) Productivity attributes with values (e.g., t_{max} value), scores (e.g., t_{ma} score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.2). Attributes values have mainly complied from existing literature (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses is being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on corresponding attribute value calculated from empirical relationship equations (described in the main text).

Species name	L_{mat} value	L_{mat} score	Ref.	BC score	Ref.	t_{mat}/t_{max} value	t_{mat}/t_{max} score	Ref.	L_{mat}/L_{max} value	L_{mat}/L_{max} score	Ref.
Clupisoma garua	34.1	***2(1)***	1	2	37	0.26	2	1, 63	0.57	2	1, 12
Coilia ramcarati	15.7	***3(1)***	1	3	38	0.3	***1(1)***	1	0.63	1	1, 13
Harpadon nehereus	24.5	2	68	3	18	0.29	***2 (1)***	1	0.61	1	45, 68
Ilisha filigera	27.5	***2(1)***	1	3	40	0.25	2	2, 42	0.59	2	1, 15
Lates calcarifer	77.5	***1(1)***	1	3	20	0.33	1	3, 20	0.51	3	1, 16
Lepturacanthus savala	38	2	4	2	71	0.17	3	1, 4	0.37	3	15, 17
Megalaspis cordyla	22	2	20	2	20	0.33	1	1, 5	0.55	2	18, 20
Mystus gulio	18.04	***3(1)***	1	3	44	0.3	2	1, 3	0.62	1	1, 19
Nemipterus japonicus	18.3	3	45	3	45	0.11	3	1, 6	0.57	2	20, 45
Netuma thalassinus	52	1	46	3	20, 46	0.25	***2(1)***	1	0.55	2	21, 46
Otolithoides pama	19.02	***2(1)***	1	2	3	0.31	1	1, 3	0.61	1	1, 3
Pampus argenteus	27.5	2	69	3	69	0.26	2	1, 7	0.53	2	22, 69
Pampus chinensis	29	***2(1)***	1	2	72	0.27	***2(1)***	1	0.58	2	1, 22
Parastromateus niger	31	2	18	2	49	0.15	3	1, 8	0.57	2	18, 22
Pennahia argentata	26	***2(1)***	1	3	65	0.29	2	1, 66	0.59	2	1, 23
Polynemus paradiseus	13.9	***3(1)***	1	2	51	0.31	***1(1)***	1	0.64	1	1, 24
Pomadasys argenteus	31.6	***2(1)***	1	3	73	0.27	***2(1)***	1	0.57	2	1, 20
Rastrelliger kanagurta	21.5	2	53	3	53	0.43	1	1, 9	0.83	1	25, 53
Rhinomugil corsula	10.42	3	34	2	54	0.05	3	1, 10	0.3	3	14, 34
Scoliodon laticaudus	35.79	2	70	2	55	0.35	1	1, 11	0.48	3	26, 70
Scomberomorus guttatus	40	1	71	3	36	0.36	1	1, 67	0.49	3	18, 71

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Table B.3 Susceptibility attributes with scores (e.g., AO score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.3). Attributes values have mainly complied from existing literature, focus group discussion (FGD) and direct field observation (DO) (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses is being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on expert opinion from key informant interview (KII).

Species Name	AO	Ref.	VO	Ref.	SM	Ref.
Clupisoma garua	1	IUCN, 2015; FGD	***3 (3)***	**FGD, KII**	3	Hossain et al., 2012; Riede, 2004
Coilia ramcarati	3	IUCN, 2015; FGD	3	Roy et al., 2019; FGD	3	Hossain et al., 2012; Riede, 2004
Harpadon nehereus	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Hossain et al., 2012; Quddus and Shafi, 1983
Ilisha filigera	3	IUCN, 2015; FGD	3	Roy et al., 2019; FGD	3	Hossain et al., 2012; Riede, 2004
Lates calcarifer	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Hossain et al., 2012; Riede, 2004
Lepturacanthus savala	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Nakamura and Parin, 1993; Rahman et al., 2009
Megalaspis cordyla	2	Roy et al., 2019; FGD	2	Roy et al., 2019; FGD	2	Rahman et al., 2009
Mystus gulio	3	IUCN, 2015; FGD	***3 (3)***	FGD, KII	2	Hossain et al., 2012; Riede, 2004
Nemipterus japonicus	1	Roy et al., 2019; FGD	1	Roy et al., 2019; FGD	1	Rahman et al., 2009; Russell, 2001
Netuma thalassinus	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	3	Riede, 2004
Otolithoides pama	3	IUCN, 2015; FGD	***3 (3)***	**FGD, KII**	3	Hossain et al., 2012; Riede, 2004
Pampus argenteus	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Hossain et al., 2012; Rahman et al., 2009
Pampus chinensis	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Hossain et al., 2012; Rahman et al., 2009
Parastromateus niger	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Hossain et al., 2012; Pauly et al., 1996; Riede, 2004
Pennahia argentata	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	1	Riede, 2004
Polynemus paradiseus	3	IUCN, 2015; FGD	3	Roy et al., 2019; FGD	3	Hossain et al., 2012
Pomadasys argenteus	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Pauly et al., 1996; Rahman et al., 2009
Rastrelliger kanagurta	2	Roy et al., 2019; FGD	2	Roy et al., 2019; FGD	1	Rahman et al., 2009; Riede, 2004
Rhinomugil corsula	3	IUCN, 2015; FGD	***3 (3)***	**FGD, KII**	2	Hossain et al., 2012; Riede, 2004
Scoliodon laticaudus	3	Roy et al., 2019; FGD	3	Roy et al., 2019; FGD	2	Riede, 2004
Scomberomorus guttatus	2	Roy et al., 2019; FGD	2	Roy et al., 2019; FGD	1	Rahman et al., 2009; Riede, 2004

Table B.3 (cont…) Susceptibility attributes with scores (e.g., AO score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.3). Attributes values have mainly complied from existing literature, focus group discussion (FGD) and direct field observation (DO) (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses was being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on expert opinion from key informant interview (KII).

Species name	**SABR**	**Ref.**	**MCAC**	**Ref.**	**MSt**	**Ref.**
Clupisoma garua	3	Shafi and Quddus, 1982	3	Shafi and Quddus, 1982; Rahman, 2005; Siddiqui et al., 2007	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Coilia ramcarati	3	Rahman et al., 2009	1	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Harpadon nehereus	3	Rahman et al., 2009	1	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Ilisha filigera	3	Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Lates calcarifer	3	Mukai et al., 2007	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Lepturacanthus savala	3	Froese and Pauly, 2019; James, 1967	1	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Megalaspis cordyla	3	Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Mystus gulio	3	Siddiqui et al., 2007	3	Shafi and Quddus, 1982; Rahman, 2005; Siddiqui et al., 2007	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Nemipterus japonicus	3	Rahman et al.,2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Netuma thalassinus	3	Froese and Pauly, 2019; Breder and Rosen, 1966	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Otolithoides pama	3	Shafi and Quddus, 1982; Rahman, 2005	3	Shafi and Quddus, 1982; Rahman, 2005; Siddiqui et al., 2007	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Pampus argenteus	3	Froese and Pauly, 2019; Rahman et al., 2009	2	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Pampus chinensis	2	Froese and Pauly, 2019; Rahman et al., 2009	2	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Parastromateus niger	3	Froese and Pauly, 2019; Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Pennahia argentata	3	Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Polynemus paradiseus	3	Kagwade, 1970	2	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Pomadasys argenteus	2	Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Rastrelliger kanagurta	3	Noble, 1962; Rahman et al., 2009	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Rhinomugil corsula	3	Harrison and Senou, 1997	2	Shafi and Quddus, 1982; Rahman, 2005; Siddiqui et al., 2007	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Scoliodon laticaudus	3	Compagno, 1984	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD
Scomberomorus guttatus	3	Rahman et al., 2009; Quddus and Shafi, 1983	3	Quddus and Shafi, 1983; Rahman et al., 2009	2	Islam et al., 2017; Murshed–e–Jahan et al., 2014; FGD

Table B.3 (cont...) Susceptibility attributes with scores (e.g., AO score) and corresponding references used in the productivity susceptibility analysis (PSA) for the selected bycatch of Hilsa gillnet fishery of Bangladesh. Each of the attribute's names in full form is provided in the main text (Table 4.3). Attributes values have mainly complied from existing literature, focus group discussion (FGD) and direct field observation (DO) (normal text). In absence of information for particular attributes (bold italic text), we have assigned scores in both the conservative and alternative scoring methods. Score inside the parentheses was being assigned considering conservative scoring approach, whereas value outside the parentheses is assigned based on expert opinion from key informant interview (KII).

Species name	SCR	Ref.	MVF	Ref.	MDF	Ref.	F/M	Ref.
Clupisoma garua	***3 (3)***	FGD, KII	3	DO	3	FGD, DO	2	Ahmed et al., 2003
Coilia ramcarati	3	IOTC, 2017; FGD	1	DO	1	FGD, DO	3	Parvez and Nabi, 2015
Harpadon nehereus	3	IOTC, 2017; FGD	1	DO	3	FGD, DO	3	Sarker et al., 2017
Ilisha filigera	3	IOTC, 2017; FGD	2	DO	2	FGD, DO	2	Rashid et al., 2007
Lates calcarifer	3	IOTC, 2017; FGD	3	DO	3	FGD, DO	2	Mustafa et al., 2019
Lepturacanthus savala	3	IOTC, 2017; FGD	2	DO	3	FGD, DO	2	Mustafa et al., 2000
Megalaspis cordyla	3	IOTC, 2017; FGD	1	DO	2	FGD, DO	2	Zafar et al., 2000a
Mystus gulio	***3 (3)***	FGD, KII	2	DO	3	FGD, DO	2	Mustafa et al., 2019
Nemipterus japonicus	3	IOTC, 2017; FGD	2	DO	2	FGD, DO	2	Mustafa, 1994
Netuma thalassinus	3	IOTC, 2017; FGD	2	DO	2	FGD, DO	3	Sultana et al., 2019
Otolithoides pama	3	FGD, KII	2	DO	3	FGD, DO	1	Mustafa et al., 2019
Pampus argenteus	3	IOTC, 2017; FGD	3	DO	3	FGD, DO	1	Karim et al., 2018
Pampus chinensis	3	IOTC, 2017; FGD	3	DO	3	FGD, DO	2	Karim et al., 2018
Parastromateus niger	3	IOTC, 2017; FGD	3	DO	3	FGD, DO	3	Karim et al., 2018
Pennahia argentata	3	IOTC, 2017; FGD	2	DO	2	FGD, DO	1	Zafar et al., 2000b
Polynemus paradiseus	3	IOTC, 2017; FGD	3	DO	3	FGD, DO	3	Rashed–Un–Nabi et al., 2007
Pomadasys argenteus	3	IOTC, 2017; FGD	2	DO	3	FGD, DO	3	Mustafa and Azadi, 1995
Rastrelliger kanagurta	3	IOTC, 2017; FGD	2	DO	3	FGD, DO	3	Mustafa and Shahadat, 2003
Rhinomugil corsula	***3 (3)***	FGD, KII	2	DO	3	FGD, DO	2	Ara et al., 2019
Scoliodon laticaudus	3	IOTC, 2017; FGD	1	DO	1	FGD, DO	3	Karim et al., 2017
Scomberomorus guttatus	3	IOTC, 2017; FGD	2	DO	3	FGD, DO	2	Rashid et al., 2010

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