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BDMs and Stock Appraisal of *Istiophorus platypterus*: Nexus between MSY, Fisheries Management, and Export Dynamics

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AM conceptualized the study, administered the project, and wrote the manuscript. MM planned the methodology, performed data analysis, and edited various parts of the manuscript.

Key words
BDM, Stock appraisal, Fishery management, *Istiophorus platypterus, MSY, Export dynamics*

ABSTRACT

Blind commercial fisheries can not only decrease fish populations but also completely wipe out fish stocks, negatively impacting export quantities. Thus, stock assessment is imperative for safe fishing operation, particular for commercial fisheries. This study assesses the the stock status of *Istiophorus platypterus* in Pakistan for the first time by employing biomass dynamic models (BDMs). Catch and effort (CE) statistics were statistically analyzed using three BDMs: Schaefer-Surplus Production Model (S-SPM), Pella-Tomlinson-Surplus Production Model (PT-SPM), and Fox-Surplus Model (F-SPM). Three error modes, Gamma (Gam), Normal (Nor), and Log-Normal (L-Nor), were used for each of these models. Sometimes, Gam encountered a computational error (CE). S-SPM and PT-SPM estimates of maximum sustainable yield (MSY), Gam (2058 t), Nor (1735 t), and L-Nor (1644t) were higher than F-SPM, Gam (1836 t), Nor (1694 t), and L-Nor (1523 t). Higher model fitting values (R^2) were observed in F-SPM, i.e., Gam (0.678), Nor (0.821), and L-Nor (0.754). MSY estimates and catch per unit effort statistics call for adopting the Precautionary Principal and suggest reducing catch levels to safeguard this fishery resource for its long-term use. This objective can be achieved through joint directional management plans of the various bodies involving stakeholders. This study's findings will help formulate effective fisheries management policies, leading to increased biomass production and revenue generation through exports.

INTRODUCTION

The word risk is commonly used to describe various hazards the fisheries sector faces (Sethi, 2010). These risks can be of diverse nature, such as economic, management, social, etc. (Ma *et al*., 2023; Sethi, 2010). Thus, the need for fisheries management arises to encounter these risks for sustainable development of the fisheries sector (Chen *et al*., 2021). Fisheries management is a science that begins with data collection and ends with policy recommendations based on the data analysis findings (Mohsin *et al*., 2022). Data analysis directs us to identify sustainable harvest levels, without which sustainable fishing is impossible. Data analysis signposts sustainable harvest levels and, thus guidelines for fishery managers (Jacobson *et al*., 2024). These harvest levels are of two types. First, target reference points (TRPs) represent that catch quantity that maximizes economic output and makes fisheries stock biologically viable. Second, limiting reference points (LRPs) are those threshold harvest levels. If they are crossed, the sustainability of the fisheries stock is threatened (Memon *et al*., 2024; Da-Rocha *et al*., 2024). Therefore, fisheries managers strive to achieve TRPs and avoid LRPs. As their name implies, these reference points are not fixed quantities. Instead, they reflect certain levels of harvest beyond which overexploitation is expected to occur (Hoggarth *et al*., 2006).

In the field of fisheries management, scientists employ different statistical models, such as catch data analysis, virtual population analysis, age-structured stock assessment, surplus production model (SPM), stock-recruitment models, stock recruitment models, etc. (Kalhoro *et al*., 2024; Maunder *et al*., 2023). However, catch data analysis and SPMs are widely employed to manage fisheries. This frequent use is due to its ability to collect catch statistics quickly and produce reliable results compared to other stock assessment statistical techniques. Mostly, fisheries statistics are reported in terms of catch and effort. Thus, the acquisition of such type of data spanning over several years is possible and brings reliable results. Moreover, commercial statistics are considered suitable for the stock assessment analysis.

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SPMs are sometimes called depletion models (Memon *et al*., 2015; Noman *et al*., 2019). Survey statistics can also be used to access stock status. However, survey statistics are expensive and difficult to collect for several years. Therefore, commercial statists are primarily employed in stock assessment studies. Depletion of the fisheries stock denotes that there will be a decrease in the fisheries biomass abundance due to overexploitation (Maynou *et al*., 2021). SPMs can be classified into two main types, depending on whether they are classical or recent. Their classical version employed the concept of a stable fishery state and hence are termed equilibrium models. However, in recent versions, this notion has been replaced by the dynamic nature of the fishery stock and are called non-equilibrium models (Mormede *et al*., 2020; Hoggarth *et al*., 2006; Mohsin *et al*., 2021). The dynamic nature of fisheries means that stock status does not remain stable. Instead, it changes due to all biotic and abiotic conditions.

These non-equilibrium models are built several assumptions. The core assumption of these models is that fishery stocks are characterized by a constant state of flux in response to various biotic and abiotic factors. Moreover, fish harvest has an impact on the population growth and its size. Thus, there is a dynamic relationship between catch and fishery population. These models also assume that various environmental factors, such as habitat conditions, and temperature greatly impact fish productivity (Cousido-Rocha *et al*., 2022; Prager, 2002; Mueter and Megrey, 2006). Sometimes, one or more of these assumptions do not exist in reality. However, these statistical models are still valid as they can guide fishery managers to make fishing policies, especially in vague situations (Khatun *et al*., 2019). Estimates of these non-equilibrium models suggest sustainable harvest levels (McClanahan and Azali, 2020). These estimates are not precise figures. Rather, they represent a range among which sustainable fishing can continue without harming fish stock. Thus, these estimates signpost the target harvest levels (Mohsin *et al*., 2021). There are two types of these estimates, as aforementioned. The estimates that indicate desirable harvest levels are called TRPs, whereas the estimates that designate harmful harvest levels are called LRPs. Fishing at TRPs ensures maximum benefit by following maximum sustainable yield (MSY). In the case of LRPs, the economic benefit of fishing decreases, and the sustainability of the fish stock is also threatened. Thus, careful advice by considering TRPs and LRPs is crucial for successful fisheries management (Barua *et al*., 2022; Tsai *et al*., 2020). Non-equilibrium models compute estimates in the form of different fishery parameters. Among these fishery parameters, three are the most important, i.e., MSY, fish stock biomass (B), and fishing mortality (F) (Mohsin *et al*., 2021; Hoggarth *et al*., 2006).

The concept of MSY is central in fisheries management science, where the core objective is to exploit the fish population to the maximum level by considering its sustainability (Mace, 2001; Rindorf *et al*., 2017). MSY represents the harvest level at which fishing operations do not harm fish stock (Ulrich *et al*., 2017). Thus, sustainable fishing can be continued for a long time. TRPs estimated by non-equilibrium models help achieve MSY. MSY-based fisheries management has been widely used worldwide to safeguard fisheries resources (Sun *et al*., 2021). This concept has helped to formulate sustainable long-term fishery exploitation policies. Alongside MSY, calculated B indicates the state of the fishery by comparing the current B of the fish population and B that should be at MSY (Methot Jr and Wetzel, 2013; Memon *et al*., 2015). Another important parameter computed by non-equilibrium models is F which signposts fish stock status. High fishing mortality is a warning about the swiftly decreasing fish stock (Mohsin *et al*., 2017; Mace, 2001; Kokkalis *et al*., 2015). There are two types of fishing mortality, i.e., natural and fishing mortality. In this study the parameter F denotes fishing mortality. Hence, considering the results of MSY in conjunction with B and F, reliable fisheries management policies can be devised that will better manage fisheries efficiently.

Istiophorus platypterus is found in temperate and tropical waters of the world (Rosas-Alayola *et al*., 2002). Several researchers have conducted fisheries stock assessment studies in Pakistan (Memon *et al*., 2015; Mohsin *et al*., 2017). However, despite being a major Istiophoridae fish and having immense importance economic importance, *I. platypterus* stock status has not been explored before. The nexus between MSY, fisheries management, and trade is critical in ensuring the long-term sustainability of fish stocks while optimizing economic outcomes, particularly in export-driven economies. By determining MSY, fisheries managers can set catch limits that prevent overfishing, thus safeguarding the resource for future generations. Thus, this study aims to assess the stock status of *I. platypterus* in Pakistan by estimating MSY using biomass dynamic models (BDMs). The research examines the implications of these estimates for fisheries management, focusing on sustainable catch limits and precautionary approaches. Additionally, it explores the link between sustainable fisheries management and export dynamics, with the goal of providing policy recommendations to balance ecological sustainability with economic growth in the export sector.

MATERIALS AND METHODS

CE data acquisition

This study was conducted using the desk study method. First, all of the available literature, including research papers, government reports, and official websites, was explored to develop a solid background for the research. Second, CE statistics, spanning over 11 years, i.e., 2011-2021, was collected through online published Sindh Bureau of Statistics (SBOS, 2024). This data is reported by the Marine Fisheries Department, which is the sole official department handling and declaring data related to marine fisheries in Pakistan. It is pertinent to declare that this data represents commercial catch of *I. platypterus* fishery and is suitable for the analysis to produce reliable results. This data reports the catch of *I. platypterus* fishery in tons (t). On the other hand, the effort represents both gillnetters as well as trawlers.

Data analysis tools

Depletion models were selected to evaluate scientific data in this study. These models assume that the removal of the fishery is represented by the decrease in the abundance index. There are several different types of depletion models. This study employed SPMs. These models represent that removing a particular quantity of fish from the fish stock will not affect the fish population in the long-run. Thus, sustainable fisheries can be performed for an extended period. In total, three SPMs were utilized in this study. These models are based on the names of the scientists who developed them and include Schaefer-SPM (S-SPM), Pella-Tomlinson-SPM (PT-SPM), and Fox-SPM (F-SPM). The objective of employing multiple SPMs in the same study was to compare and draw reliable results. That's why several published studies employ them frequently.

S-SPM is the first classical model among the models presented by Schaefer (1954). It uses the concept of fish stock growth (r) to estimate fish stock status. Following is the mathematical expression of the Schaefer model:

$$\frac{dB}{dt} = rB(B_{\infty} - B)$$

In this expression, t, B_{∞}, B denote time, carrying capacity and fish stock biomass, in that order. PT-SPM is a refined version of the S-SPM incorporating the fish stock growth concept proposed by Gompetz (Pella and Tomlinson, 1969). This model can be expressed as follows:

$$\frac{dB}{dt} = rB(B_{\infty}^{n-1} - B^{n-1})$$

It is important to note that due to peculiar assumptions and statistical design, sometimes this model does not fit the data. This frequency of being miss-fit to the data is higher than S-SPM and F-SPM. F-SPM is considered more authentic for fisheries stock assessment as this model implies that fisheries populations cannot be wiped out (Fox, 1970). However, in contrast, many fisheries populations have been reported to be depleted during the course of time (Musick and Bonfil, 2004).

CEDA package

CEDA, a user-friendly computer package, is specifically designed to access fisheries stock using CPUE. It creates visualizations that help to efficiently manage fisheries stock health and control fishing efforts effectively. CE data in various formats can be used for the analysis by CEDA. It employs 95% confidence limit in data analysis. The capability of doing exploratory analysis and representing output estimates in graphs makes it easy for researchers to draw directional and meaningful results. A sensitive analysis of CEDA for various IP values makes it possible to understand the actual state of fisheries stock exploitation. Various parameters estimated by CEDA include MSY, B, F, r (growth rate), R^2 (fitting goodness of data), and K (carrying capacity). These parameters were estimated using three different error modes of CEDA, viz. Gamma (Gam), Normal (Nor), and Log-Normal (L-Nor). Each error assumption is based on different suppositions, thus testing the data comprehensively and creating different data fitting, making it possible to compare and find the best fit. For data analysis through CEDA, the CE data input file was uploaded, and fisheries parameters were estimated for each IP. The data output was either extracted to make tables or copied to make graphs using Excel 2013.

ASPIC package

ASPIC is a world-renowned fisheries management software. It integrates biological and environmental covariates into fisheries stock assessment and produces important fishery parameters. This software requires manual input of individual IP files and the setting of several trials during the estimation process. In this study, the number of trails was set at 500. Trail means number of checks the software should do to estimate parameters. Furthermore, this computer package employs two IP file specifications, viz., FIT (bootstrapping focus) and BOT (management focus). The operational time of BOT is longer as compared to FIT. Key fishery parameters produced by this software include MSY, CV (coefficient of variation), Q (catchability coefficient), K, R^2, FMSY and BMSY. ASPIC figures and tables were made by extracting data from output files.

Different SPMs were employed in this study. Certain criteria were used to compare SPMs in terms of their reliable output. Only those output results were considered, which had reasonable CV values (lower than 0.5), acceptable MSY estimates (logically consistent with catch trends) and satisfactory R^2 estimates (0.5 or higher than 0.5).

RESULTS

CE statistics showed considerable fluctuations during the study period (2011-2021). In 2011, the reported catch was 1489 t which after several variations increased to 1999 t in 2021. The average catch quantity remained 2143 t/year, with a maximum catch of 3314 in 2017. On the other hand, effort showed a relatively smooth increase starting from 8173 in 2011 to 10298 in 2021. The average effort remained at 9481/year. The highest effort, 10298, was observed in 2021 (Fig. 1). CPUE estimates showed ebb and flow during the study period. In 2011, the calculated CPUE was 0.182 which increased to 0.206 in 2015. The top three CPUE estimates were observed in 2016 (0.327), 2017 (0.328), and 2018 (0.281). The estimated values of CPUE remained the same during the years 2019 (0.177) and 2020 (0.177). The calculated value of CPUE was 0.194 for the year 2021 (Fig. 2).

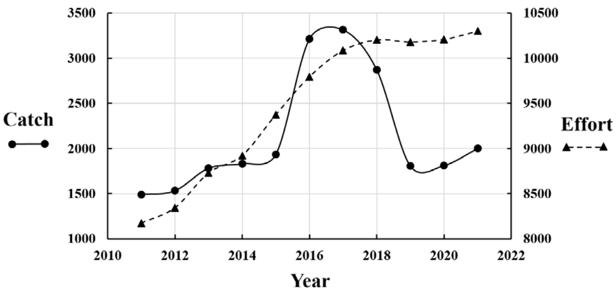


Fig. 1. Catch (t) and effort (gillnetters and trawlers) statistics of *I. platypterus* fishery.

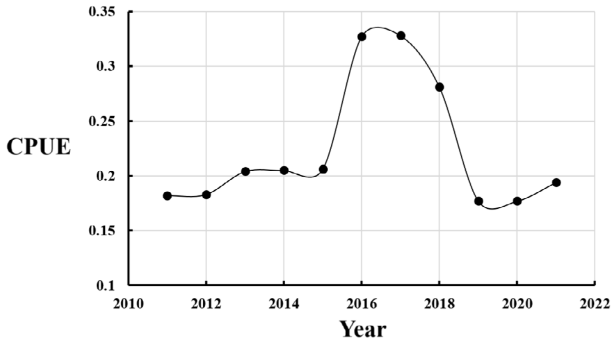


Fig. 2. Estimated CPUE of *I. platypterus* fishery.

Table I presents sensitivity analysis estimates of CEDA, IP = 0.5-1. In all the SPMs employed in this study, Gam error sometimes produced computational error or minimization failure. Mostly F-SPM estimates remained lower as compared to S-SPM and PT-SPM calculations. It was also observed that S-SPM and PT-SPM produced same MSY estimates. However, their CV estimates differed from each other. As a general trend, it was noticed that for lower IP values higher MSY and higher IP values lower MSY estimates were produced. For instance, in F-SPM, the L-Nor error assumption estimated MSY 1523 t against an IP of 0.5. Meanwhile, for IP = 1, the estimated value of MSY remained 982 t. Different parameters and their estimations by CEDA for IP = 0.5 using all three SPMs are given in Table II. For S-SPM and PT-SPM, the estimated value of MSY remained 2058 t, 1735 t, and 1644 t for Gam, Nor and L-Nor error assumptions, respectively.

Table I. Sensitivity analysis outputs of CEDA for *Istiophorus platypterus* fishery (IP = 0.5-1).

IP	Model								
	S-SPM			PT-SPM			F-SPM		
	Gam	Nor	L-Nor	Gam	Nor	L-Nor	Gam	Nor	L-Nor
MSY									
0.5	2058	1735	1644	2058	1735	1644	1836	1694	1523
0.6	CE	1864	1727	CE	1864	1727	CE	1532	1604
0.7	CE	1545	1576	CE	1545	1576	CE	1387	1351
0.8	CE	1439	1408	CE	1439	1408	CE	1254	1176
0.9	CE	1321	1130	1628	1321	1130	1348	1297	1048
1	1879	1389	1145	1879	1389	1145	847	1021	982
CV									
0.5	0.618	0.115	0.362	0.498	0.267	0.154	0.546	0.387	0.265
0.6	CE	0.317	0.293	CE	0.396	0.285	CE	0.154	0.248
0.7	CE	0.096	0.354	CE	0.025	0.174	CE	0.215	0.177
0.8	CE	0.413	0.143	CE	0.392	0.297	CE	0.354	0.387
0.9	0.127	0.364	0.354	0.354	0.354	0.494	0.049	0.451	0.559
1	0.646	0.420	0.418	0.465	0.618	0.543	0.375	0.587	0.548

CE, computational error.

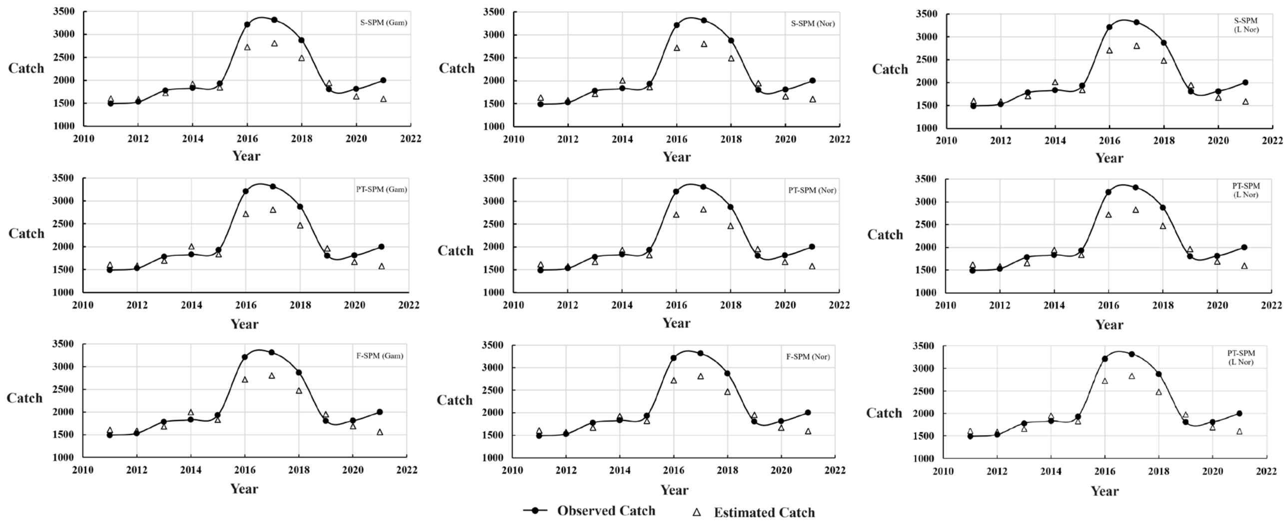


Fig. 3. Reported and calculated catch of *I. platypterus* fishery.

Table II. Sensitivity analysis outputs of CEDA for various *Istiophorus platypterus* fishery parameters (IP = 0.5).

Model	R^2	r	MSY	CV	B	K
S-SPM						
Gam	0.546	0.894	2058	0.618	1426	9513
Nor	0.754	0.901	1735	0.115	1410	9752
L-Nor	0.615	0.916	1644	0.362	1396	9647
Gam	0.546	0.894	2058	0.498	1426	9513
PT-SPM						
Nor	0.754	0.901	1735	0.267	1410	9752
L-Nor	0.615	0.916	1644	0.154	1396	9647
Gam	0.678	0.691	1836	0.546	1366	8204
F-SPM						
Nor	0.821	0.794	1694	0.387	1381	8285
L-Nor	0.754	0.514	1523	0.265	1394	6978

R^2, coefficient of determination; r, intrinsic population growth rate; MSY, Maximum sustainable yield; CV, coefficient of variation; B, final biomass; K, carrying capacity.

MSY estimates for F-SPM remained 1836 t, 1694 t, and 1523 t, in that order. It was observed that F-SPM produced higher estimates of R^2 than S-SPM and PT-SPM. For example, in F-SPM, the estimates of Gam, Nor, and L. Nor remained 0.678, 0.821, and 0.754, respectively. On the other hand, values of this parameter in S-SPM and PT-SPM remained 0.546, 0.754, and 0.615, correspondingly. Figure 3 depicts a comparison between observed and estimated catch statistics by CEDA. This figure comprises nine graphs, one for each error assumption in each model. These graphs have tiny variances depending on the error assumption and model suppositions.

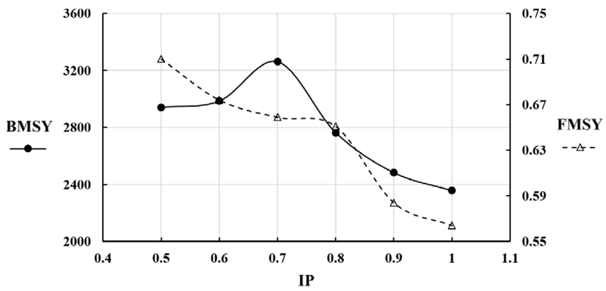
Table III. Sensitivity analysis outputs of ASPIC for *Istiophorus platypterus* fishery (IP = 0.5 -1).

IP	Q	K	CV	MSY	BMSY	FMSY	R^2
S-M							
0.5	4.4E-05	4982	0.265	1423	2941	0.710	0.874
0.6	4.4E-05	4567	0.174	1511	2986	0.674	0.812
0.7	5.2E-05	4822	0.061	1375	3961	0.659	0.812
0.8	5.2E-05	4021	0.348	1315	2764	0.651	0.812
0.9	5.2E-05	3516	0.487	1248	2483	0.584	0.817
1.0	5.2E-05	3495	0.364	1127	2357	0.564	0.812
F-M							
0.5	5.1E-05	4661	0.264	1572	3165	0.341	0.859
0.6	5.1E-05	4167	0.139	1497	2941	0.248	0.859
0.7	5.3E-05	4526	0.248	1487	2867	0.341	0.864
0.8	5.3E-05	4087	0.365	1324	2638	0.341	0.864
0.9	5.3E-05	3768	0.291	1291	2443	0.221	0.864
1.0	5.3E-05	3741	0.455	1102	2138	0.209	0.864

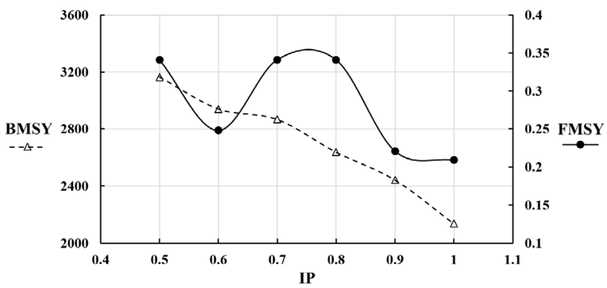
The results of sensitivity analysis performed with ASPIC are given in Table III. Several trends were observed with respect to the estimation of different parameters such as MSY, B_{MSY}, and F_{MSY}. For S-M, generally, B_{MSY} decreased with the with the increase in IP value. The same trend was exhibited by F_{MSY} estimates. MSY estimates decreased with the increase in IP values. For IP = 0.5, the estimated value of MSY, B_{MSY} and F_{MSY} remained 1423 t, 2941 t, and 0.710, correspondingly. However, for IP = 1, the estimated values of these parameters were calculated as 1127 t, 2357 t, and 0.564. ASPIC estimates of various parameters for IP = 0.5 are given in Table IV. S-SPM calculation of MSY, 1423 t, is lower than F-SPM, 1572 t. The value of CV remained at 0.265 and 0.264 for both of these models, in that order. S-SPM showed a higher value of R^2, 0.874, as compared to F-SPM, 0.859.

Table IV. Sensitivity analysis outputs of ASPIC *Istiophorus platypterus* fishery (IP = 0.5).

Model	IP	q	R^2	CV	FMSY	MSY	BMSY	K
S-SPM	0.5	4.4E-05	0.874	0.265	0.710	1423	2941	4982
F-SPM	0.5	5.1E-05	0.859	0.264	0.341	1572	3165	4661



A



B

Fig. 4. S-SPM estimates (A) and F-SPM estimates (B) of BMSY and FMSY trends for *I. platypterus* fishery.

Figure 4 portray CEDA estimates of IP, 0.5-1, for S-SPM and F-SPM, respectively. For S-SPM, the values of BMSY and FMSY, IP = 0.5, remained at 2941 and 0.71, in that order. Whereas the values of these parameters for IP = 1 were calculated as 2357 and 0.564, respectively. For F-SPM, the values of BMSY and FMSY, IP = 0.5, were estimated as 3165 and 0.341, respectively. The calculated values of these parameters for IP = 1 remained at 2138 and 0.209, respectively. F/FMSY and B/BMSY trends during the study period are given in Table V. In general, F/FMSY has increased during the study period from 0.746 in 2011 to 1.672 in 2021. On the other hand, B/BMSY has decreased from 1.894 in 2011 to 0.231 in 2021. The same trend for both the parameters, i.e. F/FMSY and B/BMSY, was observed for F-SPM.

Table V. ASPIC estimations of F/FMSY and B/BMSY for *Istiophorus platypterus* fishery.

Year	Model			
	S-SPM		F-SPM	
	F/FMSY	B/BMSY	F/FMSY	B/BMSY
2011	0.746	1.894	0.847	2.247
2012	1.038	1.954	0.984	2.005
2013	0.896	1.562	1.243	1.951
2014	1.145	1.164	1.294	1.845
2015	1.371	0.948	0.971	1.326
2016	1.364	0.874	1.362	1.546
2017	1.648	0.836	1.349	1.104
2018	0.956	0.794	1.467	0.849
2019	1.364	0.711	1.516	0.632
2020	1.458	0.514	1.451	0.578
2021	1.672	0.231	1.587	0.548

DISCUSSION

Overfishing is a global issue, and many fisheries resources have been victimized by it (FAO, 2007). This is a crucial level of fishing that, if not controlled well or in time, can lead to the extinction of the fisheries resources (Colloca *et al*., 2017). Thus, comprehensive fisheries management should start as soon as possible to conserve fisheries resources effectively. The fisheries management process is complicated and involves many steps, such as, data gathering, data analysis, result interpretation, policy recommendation, and implementation of policies (Rice and Rochet, 2005). There are generally more incentives at the start of the fisheries. This motivates new fishermen to join fishing (Clark, 1973). However, the increased number of fishermen creates pressure on fisheries and catch starts to decline. Thus, a stage of overexploitation commences (Brochier *et al*., 2018; Ding *et al*., 2017).

It is reported that one-fourth of the world's fisheries resources are under the pressure of overexploitation (FAO, 2007). If overexploitation is not managed well it can lead to the extinction of fisheries resources. Along this fishing cycle, the economic benefit of the fishermen also changes. At the start of the fisheries, it is maximum whereas at the stage of the overexploitation, the fishermen can get only marginal benefit (Rosenberg, 2003; Grafton *et al*., 2007).

Overexploited stocks can be restored. However, this is a time taking process. Generally, fishermen do not support the rebuilding of fisheries' stock. To motivate fishermen for this idea, transition costs can be arranged properly, which is, however a complicated task (Murawski, 2010; Ye *et al*., 2013).

Unfortunately, most of the studies conducted on fisheries stock status in Pakistan declare overexploitation (Memon *et al*., 2024; Mohsin *et al*., 2021). Even though controlling overexploitation has been the core objective of fisheries management policies in Pakistan, however, this target has not been achieved fully until now (Schmidt, 2014). According to various research findings, fisheries in Pakistan are consistently a victim of the open access regime (Mohsin *et al*., 2017). An open access regime means fish catch beyond sustainable level due to ineffective management. Several private organizations, along with public bodies, are striving to achieve this goal. There is a considerable improvement in the situation, but still, there is considerable room for improvement. According to one study, the number of trawlers is much more than the recommended one, contributing heavily to the overexploitation (Schmidt, 2014).

Several fishery parameters can be used to access the fish stock status. Some of them are very simple, non-statistical parameters such as CPUE (Sant'Ana *et al*., 2017). A declining trend in CPUE is an indication of overharvesting of the fishery stock. On the other hand, if CPUE does not change even if fishing effort increases, it can indicate the stable state of the fishery stock. In this study, CPUE has decreased during the study period from 2017-2019, which represents overexploitation of *I. platypterus* fishery resources. The state of the fishery can be statistically evaluated more precisely with the estimated MSY values (Mace, 2001; Martell and Froese, 2013). If MSY estimates exceed catch figures, then more fish catch is acceptable. However, they are lower than catch statistics. At that point, overexploitation is ongoing, which should be controlled. According to these criteria, MSY has also been estimated to have been a signpost for the overexploitation of this fishery resource, particularly during 2016-2018. If we compare the CPUE of 2011 and 2012 to 2019 and 2020, we can probably see the same CPUE. This superficially indicates that the fisheries resource is perhaps in a stable state.

However, it must be noted that CPUE has declined considerably after 2018. On the other hand, effort has increased between 2017-2021. Therefore, following the Precautionary Principle, the recommended MSY should be lower than the catch, which is considered superficially optimal (Hoggarth *et al*., 2006). In this study, sensitivity analysis was performed with CEDA and ASPIC computer packages by using different IP values ranging from 0.5 to 1. IP values essentially represent the state of the fishery. For example, if the fishery is in a virgin state or no fishing has occurred, the IP value would be 0. Conversely, when the fishery stock is fully exploited, the IP value would be 1. All the other values between 0 and 1 represent moderate to high fishing activities depending upon the IP values (Mohsin *et al*., 2017). More effective management measures are needed to control overexploitation (Noman *et al*., 2019; Memon *et al*., 2024).

One key point is to focus on integrated fisheries management practice by involving all the related departments. Some researchers have found a lack of proper coordination between various fisheries regulatory bodies. Moreover, fisheries management is a comprehensive process prone to various risks. Since all the risks are interrelated with varying degrees, therefore, to get fruitful results, other significant risk factors should also be controlled (Mohsin *et al*., 2022). Such as, to control overexploitation effectively, it is also important to develop a sound licensing system and punishment system. In addition, training for the fishermen with the particular aim of developing sustainable fisheries is crucial. Fishery officers can play their vital role in this process. Thus, by combining all of these efforts, overexploitation can be effectively controlled.

To control overexploitation of fisheries in Pakistan, measures should include enforcing sustainable catch limits, establishing marine protected areas (MPAs), reducing bycatch, and improving monitoring to combat illegal fishing. Involving local communities in management, raising awareness about sustainable practices, and offering economic incentives for sustainable fishing can also help protect marine resources and ensure long-term sustainability.

The nexus between MSY, fisheries management, and trade is critical in ensuring the long-term sustainability of fish stocks while optimizing economic outcomes, particularly in export-driven economies. This study highlights the importance of MSY estimates as a tool for responsible fisheries management. By determining MSY, fisheries managers can set catch limits that prevent overfishing, thus safeguarding the resource for future generations. This has direct implications for trade, as sustainable fisheries practices ensure a stable supply of fish for export markets, avoiding stock depletion that could disrupt export quantities and revenue. Furthermore, adopting the precautionary approach, as suggested by the study's findings, emphasizes the need for integrated management strategies that balance biological sustainability with economic goals, ensuring both a healthy fishery and consistent trade opportunities.

This study has several limitations. First, CE data may not fully reflect fishery fluctuations. Second, the models assume constant parameters, overlooking dynamic environmental and economic factors. Third, computational errors with the Gam error mode affected some results, and sensitivity analysis showed variations in MSY estimates across models. Fourth, the study advocates the Precautionary Principle but lacks detailed management recommendations and does not consider external factors like environmental changes. Finally, the findings may not apply universally due to regional ecological and management differences.

This study highlights the importance of accurate stock assessments for sustainable fisheries management, advocating for reduced catch levels to avoid overfishing. The research supports the Precautionary Principle and provides guidelines for estimating MSY. It offers valuable insights for policymakers to develop effective management strategies, boosting export revenues while ensuring sustainability. By improving stock assessment methodologies, the study enhances the reliability of fishery evaluations and contributes to better fisheries management practices, both locally and globally. Future studies could explore the application of advanced modeling techniques, such as ecosystem-based models, to assess the broader ecological impacts of fishing on *I. platypterus* populations. Long-term monitoring programs should be implemented to track stock trends and refine model predictions. Additionally, research could focus on the socioeconomic impacts of sustainable fisheries management, particularly in relation to local communities and export dynamics. Finally, studies could investigate the effects of climate change on fishery stocks to better adapt management strategies to changing environmental conditions.

DECLARATIONS

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Generative AI and AI-assisted technology statement

The authors have declared that no generative AI or AI-assisted technologies were used to create this manuscript.

Conflict of interest statement

The authors have declared no conflict of interest.

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