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Potential for a blue shark management procedure in the Indian Ocean

Prepared for the Indian Ocean Tuna Commission

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1 Introduction

The Indian Ocean Tuna Commission (IOTC) is an intergovernmental organization established under Article XIV of the FAO constitution. It is mandated to manage sixteen tuna and tuna-like species in the Indian Ocean with its primary objective being the conservation and optimum utilization of these stocks over the long term. Scientific advice on the status of major IOTC tuna stocks is based upon the results of quantitative stock assessment models and analyses of available information. More recently, Management Strategy Evaluation (MSE) has been increasingly utilised as a means by which scientific advice can be evaluated using simulation-based methods prior to implementation. This improves the scientific rationale for for management decisions.

The IOTC Resolution 15/10 requested the IOTC Scientific Committee (SC) to develop and assess, through the MSE process, the performance of Management Procedures (MP) and Harvest Control Rules (HCRs), to achieve Target Reference Points (TRPs) and avoid the Limit Reference Points (LRPs) with a high probability, taking into account imperfect knowledge of the population dynamics, for the priority species (IOTC, 2015). In recent years, substantial progress has been achieved in the MSE initiatives for key commercial species. These efforts have led to the successful adoption of an MP for skipjack tuna, bigeye tuna, and swordfish (IOTC, 2022, 2024a,b, 2025a). Despite these advancements, similar processes have yet to be applied to pelagic sharks, primarily due to their status as bycatch species and the challenges associated with limited data availability.

Among pelagic sharks, the blue shark is the most frequently caught species in the Indian Ocean (IOTC, 2021, 2025c). It is commonly captured as bycatch in the longline fisheries but also supports targeted catch by several fleets. Notably, compared to other pelagic sharks, data availability for the blue shark is more comprehensive, and there is a longer history of reported catches. This data sufficiency has allowed the application of an integrated assessment model, Stock Synthesis (Methot & Wetzel, 2013), to assess stock status, which has been performed by the Working Party on Ecosystem and Bycatch (WPEB) since 2015 (Rice & Sharma, 2015, Rice, 2017, 2021b, 2025a,c). Stock Synthesis (SS) models for blue shark have similarly been developed by the Western Central Pacific Fisheries Commission (ISC, 2017, Neubauer et al., 2021, 2022) and the International Commission for the Conservation of Atlantic Tunas (ICCAT, 2023, Courtney et al., 2023, Gustavo-Cardoso et al., 2023).

Simulation-based testing of MP performance, as part of the MSE process, requires an operating model (OM) with which to reproduce the dynamics *in silico*. The OM is required to predict response of the resource to the management action being tested, and should therefore reflect our best understanding of the population being fished, as well as its interaction with the fisheries exploiting it. Stock assessments typically provide a good starting point for OM development, because they usually represent our best understanding of the resource. For example, Carruthers (2024) demonstrated the simulation of Atlantic blue shark dynamics in response to different MPs, using a previous SS model as the OM. The availability of mature stock assessments for blue shark in the Atlantic, Indian and Pacific oceans, to the extent that they are considered reliable, improves the feasiblity of MSE in each of these regions.

Project objectives

The IOTC, during its 28th session, requested that the SC initiate a MSE for blue shark (IOTC, 2024c). As a consequence, this objective has been incorporated into the SC's program of work, with oversight by the Working Party on Methods (WPM). However, although the recent SS assessment models of Rice (2017, 2025a,c) offer a good foundation for constructing the OM, they have also highlighted significant uncertainties, concerning both the input data and the model performance, and raised questions about the model's suitability for direct application as an OM within the MSE framework.

The objective of the current report is to provide a preliminary scoping study, aiming to identify suitable methodologies and options for the application of MSE to Indian Ocean blue shark. This includes options for a robust OM, informed by recent assessments, and preparing the groundwork for a comprehensive MSE process.

2 Management measures and objectives

It is assumed that the primary management objective for blue shark is the long term conservation of the population. Current management measures are detailed in IOTC (2025b). Consistent with its consideration as a bycatch species, these include gear restrictions designed to limit the bycatch by longlines targetting other stocks. In contrast to target species, optimum utilisation is not at present considered an objective.

If utilisation is not important, the simplest and best MP would recommend a zero catch. However, we also need to consider management of the target species. For the current work, it is assumed that effort is set through management of the target species, and that the blue shark catch is an indirect consequence of this fishing effort.

If fishing effort is being set externally to the MP, this is an important consideration in MP design. In order to limit the mortality of blue shark, a Total Allowable Catch (TAC) would need to take precedent over the TAC being set for other target species. Limiting blue shark catch in this way would therefore potentially impose a restriction on targetted fishing effort, which is undesirable and likley unacceptable to participating fisheries. Instead, an MP is required that will limit the fishing mortality inflicted by the concurrent level of fishing effort, but without exerting control over the amount of effort itself.

Management procedures for bycatch species are rare, but typically take the form of a strike limit which requires a cessation of fishing when it is reached. Fishing vessels may be required to stop fishing if they record the death of a marine mammal or turtle (Moore & Curtis, 2016), or to move if benthic bycatch is excessive (Cryer & Soeffker, 2019). Neither of these management rules is suitable for blue shark, given their high mobility and attraction to the fishing gear.

In the current work size limits are considered. These are currently used by the IOTC for the management of marlin (IOTC, 2018), are consistent with current management measures for blue shark, and have the potential to limit fishing mortality without imposing a restriction on fishing effort. Potential use of a TAC is also reviewed, but as a limit rather than a target.

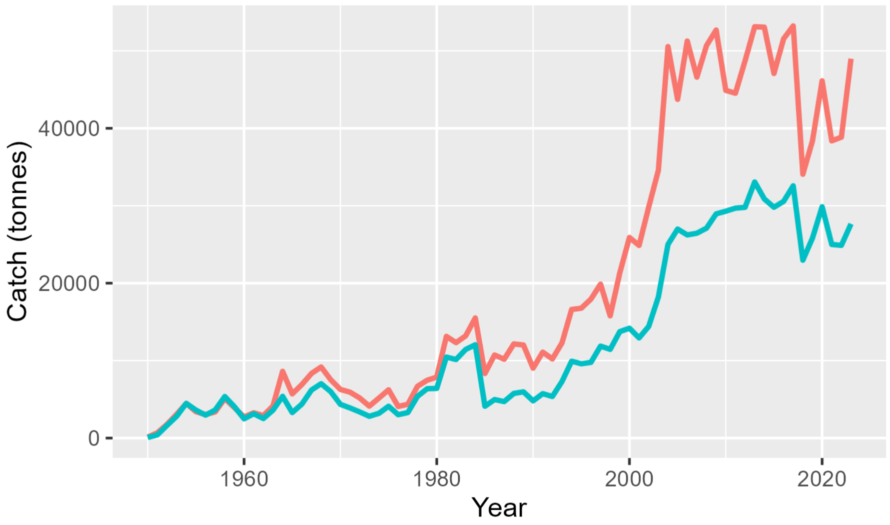

Figure 1: Catch time series for blue shark in the Indian Ocean. High and Low scenarios are shown (Coelho, 2025).

3 Stock assessments for blue shark

In this section, current stock assessments for blue shark in the Indian Ocean are reviewed, with a particular emphasis on the information content of the data, and how the models are interpreting that information.

Catch

The total catch of blue shark in the Indian Ocean is uncertain. Although the reported (nominal) catch data are thought to be the most comprehensive of any of the shark species, they are considered to be substantial underestimates of the true catch (IOTC, 2021, 2025c). This has required the nominal catch to be adjusted upwards, and a variety of methods have been proposed to achieve this (Martin, 2015, Martin & Rice, 2017, Rice, 2021a, 2025b). These attempt to predict the blue shark catch for fishing events where no catch has been reported, but the most reliable method to achieve this has not yet been agreed by the WPEB. The range of values assumed in the recent assessment by Coelho (2025) is illustrated in Figure 1.

The catch is important for the stock assessment primarily because it provides an indication of the scale of the population. If productivity and abundance are fixed, then a larger catch equates to a larger unexploited population size. The scale is important because it is used to estimate catch-based reference points, such as the maxium sustatinable yield (MSY), from rate-based reference points (F_{MSY}). Productivity assumptions, such as the natural mortality rate and steepness, are often assumed on input, but they require the population scale to be known if productivity is to be converted to catch-based management targets. Uncertainty in the catches therefore equates to uncertainty in the model estimates of MSY, and the ratio of current catch to this reference point.

Abundance trends

When estimating the population size, because absolute abundance is not known, it is not only the catch but also changes in the catch over time, in conjunction with changes in the abundance, that provide this information to the stock assessment model. For Indian Ocean blue shark, the catch is increasing but the abundance indices are conflicting (Figure 2), with no clear change over time (either increasing or decreasing). The catch data place a lower limit on the carrying capacity because the population has not gone extinct, but without any clear relationship between the catch and abundance an upper limit cannot be estimated. Almost any population size is consistent with a constant population size over time, provided it is large enough for the catch to have no effect.

Application of a simple stock assessment model can be used to illustrate this point. As well as the recent SS models of Rice (2017, 2025a,c), surplus production models have also been applied by, for example, Coelho (2025). These are useful because they are often easier to interpret, and provide insight into the information on stock status being (or not being) povided by the data. They can include prior information on the maximum per capita growth rate (r), which is available for blue shark (e.g., Geng et al., 2021), and with appropriate data can provide robust estimates of the depletion relative to the carrying capacity K, which is also estimated. One feature of these models is that they assume that abundance is driven by the catch (i.e., an increase in the catch leads to a decrease in the abundance). For fisheries in which catch and abundance appear to be independent, at least over the range of data included, this assumption is not met. A surplus production model is therefore not able to extract information on K from these data.

This can be seen in Figure 3, which provides posterior estimates of the carrying capacity (on a log-scale) and intrinsic growth, estimated using the surplus production model described by Edwards (2020), and with an informative r prior. The prior for K is log-uniform(0, 100), and the posterior distribution for $\log(K)$ has an upper limit that is constrained only by that prior. Without a reliable esimate of K, depletion cannot be estimated. In the assessment results provided by Coelho (2025), the carrying capacity is resolved by the model, but this appears to be a consequence of the prior, which is lognormal (Winker et al., 2018) and constrains the upper limit without invoking a hard boundary.

Even for the more complicated SS models, the fundamental assumption of a catch driven fishery is retained, and there is no reason to expect that the abundance indices provide any more information to SS than they do to the simpler production models. The only difference is that, whilst production models assume that all indices are reflective of the same biomass, in an SS model the indices are weighted by the selectivity attributes of each fleet. This may help to resolve conflicts in the abundance data, but nevertheless, if the abundance has not changed, the data can only provide information on a lower bound to the carrying capacity. This is confirmed by the likelihood profiles shown in Figure 7 of Rice (2025c), which demonstrate that the abundance indices provide almost no information on an upper limit to the population size (in this case measured by the equilibrium recruitment, R_0). A similar situation exists for the stock assessment of blue shark in the South Atlantic (Figure 27 of Gustavo-Cardoso et al., 2023), with no information on an upper limit to the population size being provided by the abundance indices. This is to be expected given that the abundance indices have been increasing slightly over a period of increased catch, violating a primary assumption of the model.

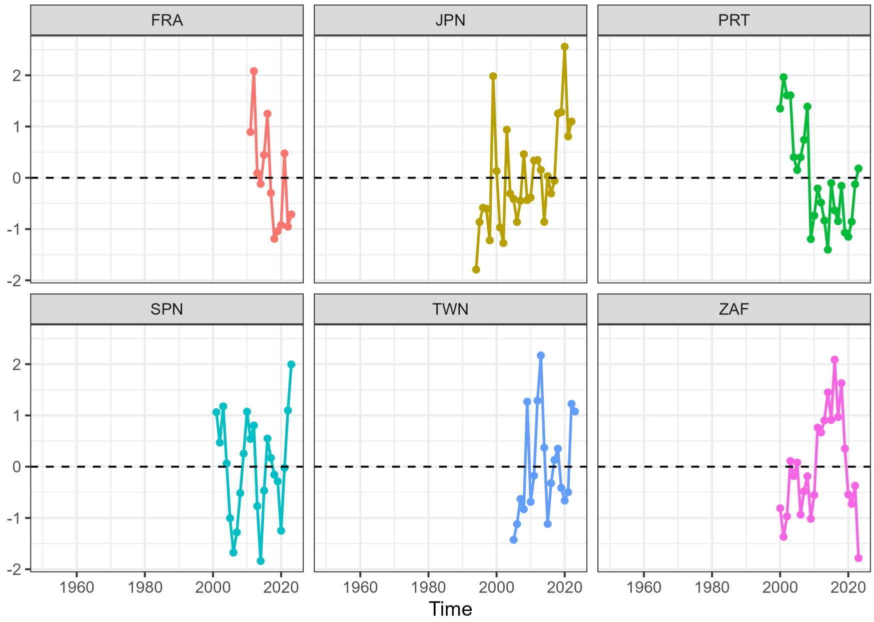

Figure 2: Catch rate abundance indices for blue shark in the Indian Ocean (renormalised; Coelho, 2025).

In the South Pacific, the abundance indices provide conflicting information on the population size, with no one index providing an estimate for R_0 (Figure 25 of Neubauer et al., 2021).

Length frequency data

In the Indian, South Atlantic and Pacific Oceans, given the lack of informative abundance indices, SS assessment models for blue shark appear to be deriving information on the population size, and therefore depletion, from the length-frequency data. This can be seen from the likelihood profiles provided by Figure 6 of Rice (2025c), Figure 27 of Gustavo-Cardoso et al. (2023) and Figure 25 of Neubauer et al. (2021). In each case, higher values for $\log(R_0)$ are not supported by the length frequencies observed in the catch.

Typically, fewer large individuals are observed in the blue shark catch data than would be expected from the effects of natural mortality alone. If fishing is limiting the number of large individuals in the population, then the population must be small enough to be limited. This provides the model with information on the population size. However, for this logic to hold, it must be assumed that large individuals would be seen if present. If they are present but not seen in the catch data, then for a fixed natural mortality the model will underestimate the population size. However, other reasons exist for why large individuals may not be observed. For sharks, an important consideration is discarding. Estimates are highly uncertain, but for blue shark, discards might be up to 80% of the catch (IOTC, 2025c). There is therefore a large unobservable component to the catch, which has the potential to put a downward bias on model estimates of the population size.

Interpretation of length frequency data by an SS model is governed by the selectivity curve. A sigmoid (increasing) selectivity curve assumes that all large individuals will be caught and observed in the length-frequency data if present. If large individuals are not observed, the model will assume a higher fishing mortality (lower population size) to explain their absence. An

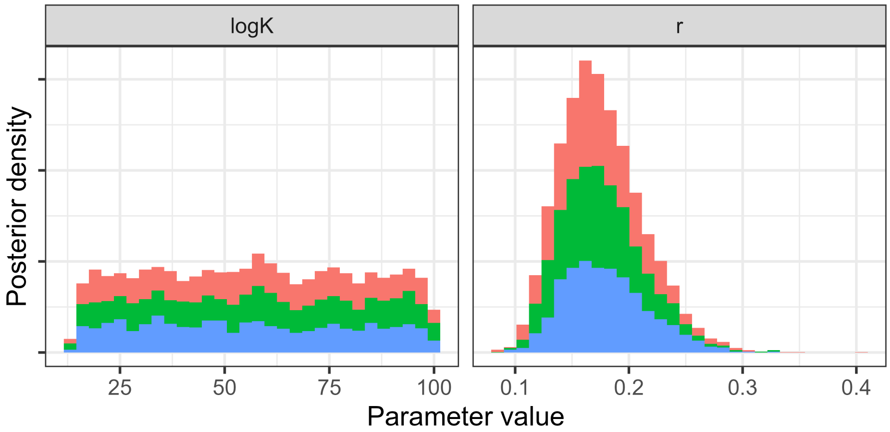

Figure 3: Posterior probability distributions for $\log(K)$ and r generated from a surplus production model fitted to the abundance data in Figure 2 and assuming the high catch scenario in Figure 1. Independent chains are indicated by different colours.

alternative is to assume a dome-shaped selectivity curve, which predicts a lower probability of catch for larger individuals. For blue shark, assuming that large individuals are less observable is reasonable, given what is known of size-specific discards. For this reason, dome-shaped selectivities are often assumed. In the Indian Ocean, Rice (2025c) assumes that all but one of the fleets has a dome-shaped selectivity. Sensitivity runs showed that using sigmoid selectivity curves had no noticeable effect on the outcome (with a similar result being reported by Neubauer et al., 2021). However, the interpretation of this result is not clear. Typically, a dome-shaped selectivity would lead to a lower fishing mortality estimate, because a higher mortality is not required to explain the absence of larger fish. Larger fish are assumed to be unavailable. If the shape of the selectivity curve has no impact on the result, then whether larger fish are there and not seen or not there appears to make no difference. One explanation for this result is that fishing mortality is small, and the difference between these two assumptions is negligible, but it may require further exploration.

Figure 4 shows the length-frequency distributions per fishery, and Figure 5 shows these over time. There is clearly a difference in the modal catch length per fleet, and for Taiwan (TWN) there appears to have been a reduction in the number of large fish in recent years. This would indicate that cohorts entering the fishery in more recent years have a truncated size distribution. Unless there has been a change in fishing practicies, this would be consistent with an increase in fishing mortality. A similar result is not seen for the other fleets.

Reference points and current status

Given uncertainties in the input data, it is likely that F-based reference points are more robust than catch-based reference points, because the latter require an estimate of the population size. A lack of information in the abundance data and uncertain catches indicate that the population size, although estimated by the current assessment, is uncertain. Rice (2025c) further points out that MSY-based reference points have not been agreed by the IOTC for pelagic shark species, and therefore reports status of the stock relative to F_{MSY}. For all runs, the current fishing mortality is estimated to be much lower than this reference point.

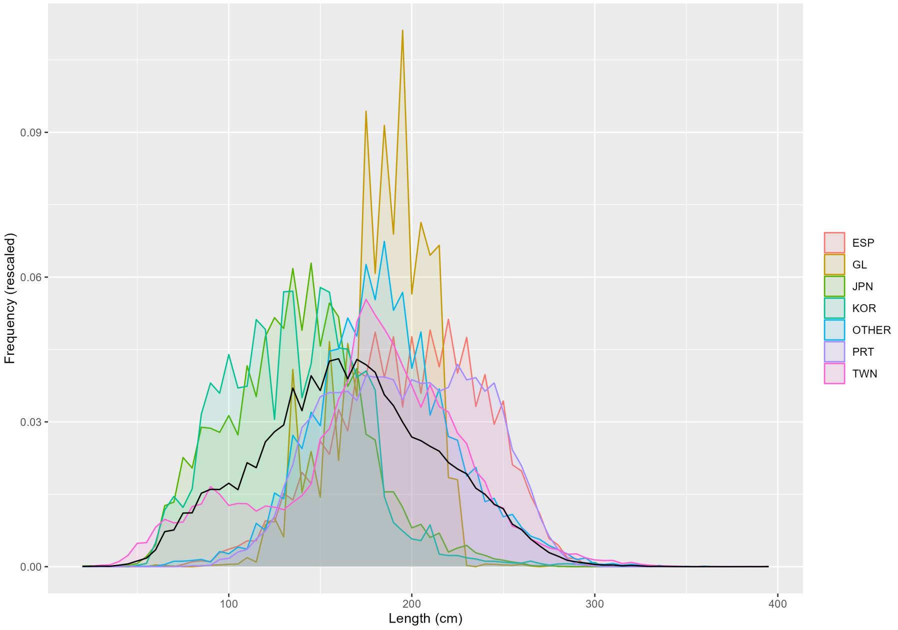

Figure 4: Length frequency data for blue shark in the Indian Ocean, aggregatted across years and renormalised to the same scale (Rice, 2025c).

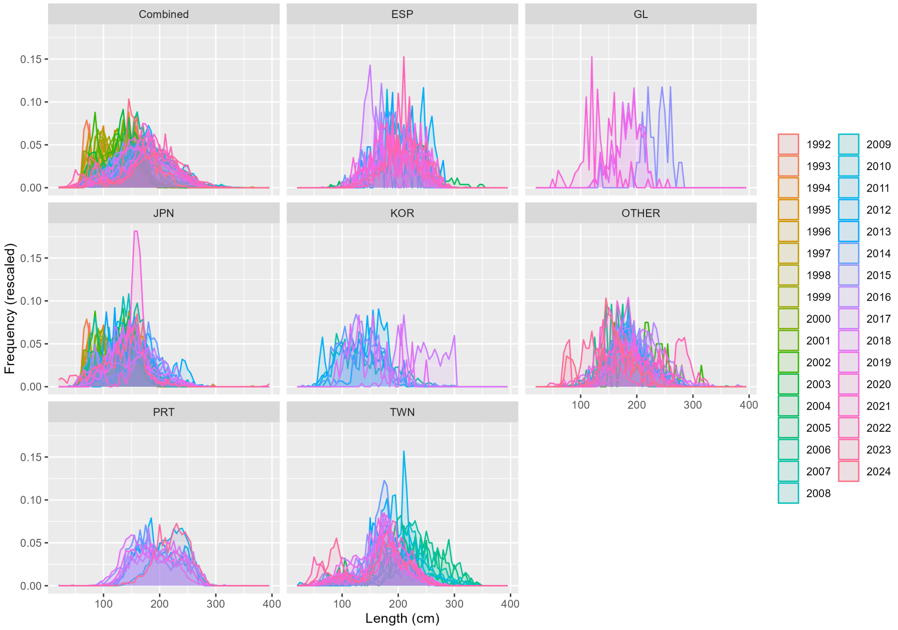

Figure 5: Length frequency data for blue shark in the Indian Ocean, per year, renormalised to the same scale (Rice, 2025c).

Operating model

The purpose of an OM is reproduce the likely response of a population to the management measures being tested. Although the current SS assessment model contains significant uncertainties, these relate mostly to the data inputs. The model is still able to reproduce the data as presented to it, suggesting it to be an adequate representation of the system. It is therefore likely feasible to use the assessment model as an OM, or set of OMs, with each conditioned with alternative input data assumptions.

4 Management procedures

Management procedures describe a relationship between resource status and management action that has been tested through simulation. Management action typically takes the form of a recommended TAC, but in the current setting, size based recommendations will also be considered. Information on the resource status can be obtained by the MP from trends in a relevant metric, such as the catch rate, or through application of a stock assessment model.

A key characteristic of an MP is whether it provides a recommended management action directly, or whether it provides a recommended fishing mortality that is then converted to a management measure via another estimated quantity. For example, an MP may recommend a fishing mortality that is converted to a TAC using an estimate of the exploitable biomass. Both direct and indirect approaches have their own merits. An F-based MP is considered more desireable because it is the fishing mortality that ultimately determines a populations trajectory. The major weakness is that conversion of a recommended F to a recommended catch is dependent on a well conditioned stock assessment model to be operational. Direct control rules have lower data requirements, because they are not dependent on an intermediate estimated parameter. A catch-based control rule, for example, does not require an estimate of the absolute population size (e.g., IOTC, 2024a). A second defining characteristic of an MP is whether it adjusts the current management action, or whether management is set relative to a global target reference point, such as the maximum sustainable yield (MSY or F_{MSY}). The latter approach can make use of a reference point defined during development of the MP, or a reference point defined internally by the MP as part of its implementation (i.e., using a stock assessment model).

These different types of MP are represented within the IOTC. The MP for bigeye tuna, currently the most complex of those being implemented, applies a stock assessment model to estimate the current fishing mortality and a fishing mortality based reference point (F_{MSY}). These are used to set a desired F, which is then multiplied by the estimated exploitable biomass to generate a TAC. The MP is therefore F-based and dependent on a global, internally estimated, target reference point (F_{MSY}). For skipjack, a catch-based MP is used. Similar to bigeye, a global reference point determines the target output (in this case stochastic MSY), but this reference point was defined during MP development rather than being estimated with each implementation. Lastly, for swordfish, the current TAC is adjusted up or down depending on recent trends in the abundance. It is catch-based, but the target catch reference point is not defined. The recommended TAC is adjusted locally depending on percieved changes in abundance.

For blue shark, the choice of a suitable MP needs to consider our ability to estimate the population size and target reference points. As discussed in Section 3, a simple surplus production model is not able to resolve the carrying capacity, and estimates of either depletion or population biomass are therefore unreliable. This immediately negates the possibility of using this type of model in either an F-based or catch-based MP. An initial question concerning MP development, is what models may be available for extracting information on stock status from the length-frequency data, or whether (relative) status can be inferred from a summary metric.

Population metric

For an MP, an indicator of population status is required for input. This indicator can be derived from a stock assessment model, or directly from the data. The catch rate indices currently available appear to provide little information on stock status, which suggests that they are likely to be unsuitable for an MP. It is not possible at present to discern whether these indices are truely uninformative (i.e., they do not track abundance), or whether they are simply not able to inform the stock assessment models that have been applied. In case it is the latter, the catch rate abundance data should not be ignored, but nor can they be used to parameterise a surplus production model.

If our current perception of stock status is being derived primarily from the length-frequency data, as suggested by a review of the current SS model (Section 3), then a suitable model would need to make use of these data. Examples might be a simple length-based assessment model (e.g., Hordyk et al., 2015, Rudd & Thorson, 2017), or catch-curves (e.g., Thorson & Prager, 2011). These would be required to extract an estimate of F that could be used in a MP. Summary metrics of the length-frequency data, such as the median size, are also appealing (Froese, 2004). Although they are unlikely to provide an estimate of F (Cope & Punt, 2009), they may be useful for monitoring changes over time.

Management recommendation

As discussed in Section 2, reliance of an MP on a TAC output may cause conflict with the TAC recommendations for target species. Limiting the blue shark catch may limit the ability of vessels to catch their target species quota. This would provide an incentive to discard, or to use fishing gear that minimises the shark bycatch. Both of these are desireable, given that post-discard suvivorship is thought to be high (Sabarros et al., 2025). But to ensure that this is feasible, it requires good data on the discard rate and a subjective evaluation of whether discards could be increased should the blue shark TAC threaten to limit catch of a target species. At present this is difficult given limitations in the discard data.

A second management recommendation might be the imposition of size limits. Assuming that catch is being determined by the effort targetting other species, the fishing mortality inflicted on blue shark could be influenced through size limits on the retained catch. As well as limiting the total catch (assuming a constant fishing effort), adjustments to the size-dependent fishing mortality will influence the productivity of the population. In particular, the mortality inflicted on juvenile sharks is thought to have a large impact on the growth rate of shark populations (Cortés, 2002). Limiting juvenile mortality through a minimum size limit could be a useful tool for protecting population productivity (da Silva & Gallucci, 2007, Tsai et al., 2014).

Restrictive size limits could therefore limit the total catch, by limiting the size classes available, and increase the chance that catches are sustainable, by increasing productivity of the stock. An MP could make use of these features by adjusting the size limit in response to information on the stock status, or it could assume them to be constant and recommend a TAC. If the latter, the TAC would need to be high enough to not restrict fishing on relevant target species (i.e., bigeye tuna and swordfish). At present, the level at which this might occur is difficult to assess. We are limited to a simple inference that because current blue shark catches are not restricted, they are not restrictive of current target catches.

5 Conclusions

The current work has reviewed our understanding of blue shark in the Indian Ocean and possibilities for an MP. Based on these considerations, the following types of MP may be applicable:

1. An MP that outputs a minimum size limit recommendation, but does not limit the catches. If a simple model can be used to etimate the overal fishing mortality from the available length-frequency data, then an adjusted F could be recommended through comparison to a global reference point. An indirect approach would then use a population model to back-calculate a size limit to ensure this is likely to be acheived. A direct approach would recommend a change in the current size limit, and require MSE to determine the magnitude of the change. This latter approach could also make use of relative changes in any size-based summary statistic.

2. An MP that outputs a TAC in conjunction with a fixed minimum size limit. Given uncertainty in the current catches, MSY is assumed unknown. However, MSE can be used to explore size limits that minimise the potential for stock depletion, mitigating this uncertainty. The TAC would be considered by this MP as an upper limit, rather than a target and MSE could be used to explore the limit above which catches will start to impact the stock. Similar to the preceeding MP, size-based metrics could be used to adjust this ceiling downwards if necessary.

The feasbility of each of these approaches will need to be reviewed prior the commencement of any MSE exercise.

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