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Are the current IUCN category and CITES listing appropriate for the conservation and management of shortfin mako, *Isurus oxyrinchus*, in the North Pacific Ocean?

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ABSTRACT

In 2018, the ISC conducted a benchmark stock assessment with a future projection and concluded that the latest stock status of North Pacific shortfin mako was healthy and that its stock abundance would gradually increase within 10 years. Then in 2019, this species was categorized in the North Pacific Ocean as Vulnerable on the IUCN Red List and listed in Appendix II of CITES. The inconsistent outcomes are a controversial issue and raise a fundamental question on why different international organizations had different views on the stock's current and future declines. To clarify the reasons, this paper reviews the risk assessment conducted by the IUCN and the process of CITES listing, and then, based on the assessment results in 2018, conducts a future projection that incorporates uncertainties in the population trajectory. This projection indicates that the population level does not meet the criteria for the IUCN category of Vulnerable and listing in Appendix II. The results suggest that the IUCN's simplified methodology of assessment is inappropriate for long-lived, sexually dimorphic species, and that the mechanism of CITES listing is inappropriate from the scientific view of stock assessment because all global stocks, each with a different status, have been treated as one stock. This paper therefore concludes that the IUCN category and CITES listing are both inappropriate for the conservation and management of North Pacific shortfin mako and that such efforts should be implemented by tuna RFMOs based on stock assessment and future projection results derived from a suitable assessment model.

1. Introduction

Historical fisheries expansion into the open ocean for targeting tuna and tuna-like species with gear advancements has faced widespread declines in the numbers of many pelagic sharks over the past few decades [17,58,63]. The decline, however, is principally attributed to the fact that pelagic sharks are caught mainly by artisanal, recreational, and commercial fisheries as bycatch due to their relatively low commercial value [4,50]. As a result, stock assessments and management for pelagic sharks have often suffered from incomplete data, since pelagic shark catches are not always recorded by fisheries targeting high-value tuna and tuna-like species [3,50] in addition to the fact that international organizations had not effectively required these data until recent years. A substantial number of sharks in these bycatches are discarded dead or dying, and finning occurs frequently [9,16,37]. The underreporting of incidental catches and the lack of sufficient records at the species level for pelagic sharks degrade the quality and quantity of fishery data [10] and can result in greater uncertainties in stock assessments and a failure of stock management.

Tuna Regional Fishery Management Organizations (RFMOs) such as the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), and the Western and Central Pacific Fisheries Commission (WCPFC), have been responsible for the stock assessments and management of pelagic sharks as well as tunas and tuna-like species within the jurisdiction of each organization [49]. These tuna RFMOs conduct full stock assessments for pelagic sharks in their respective jurisdictions [31,33,60] using integrated stock assessment models such as MULTIFUN-CL [13] and Stock Synthesis (SS; [44]). Assessments of four key sharks, i.e. silky shark (*Carcharhinus falciformis*) and oceanic whitetip shark (*Carcharhinus longimanus*) in the western and central Pacific Ocean, shortfin mako (*Isurus oxyrinchus*) in the North Pacific Ocean, and blue shark (*Prionace glauca*) in the Indian Ocean and the North Pacific Ocean, were completed using these integrated models and accepted by the IOTC [33] and the WCPFC Scientific Committee [60]. A stock assessment of one key shark, shortfin mako in the North Atlantic Ocean, was completed using SS and accepted by the

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Standing Committee on Research and Statistics (SCRS) [30]. Most of the key shark species, however, suffer from large gaps in the biological and fishery data required for full stock assessments. The lack of sufficient data often makes full stock assessments impractical or incomplete. While blue shark stocks in the South Pacific Ocean and North Atlantic Ocean were assessed using the full integrated models, the stock statuses were inconclusive due to issues concerning data that caused large uncertainties in the assessments [29, 59]. The stocks of other pelagic sharks for which data was poor were assessed using a variety of methods such as the Bayesian state-space surplus production model for blue shark in the South Atlantic Ocean [29], sustainability risk assessment for bigeye thresher shark (*Alopias superciliosus*) in the western and central Pacific Ocean [25], sustainability assessment of fishing effects for porbeagle shark (*Lamna nasus*) in the North Atlantic Ocean [32], indicator-based analysis for silky shark in the eastern Pacific Ocean [40], and ecological risk assessment for pelagic sharks in the Indian Ocean [48]. These simplified methods are frequently used for most of the key shark species in the world's oceans. However, their objectives vary with the model used, and each model's ability to assess stock status as well as fisheries exploitation levels is limited. Since these assessments and analyses for pelagic sharks conducted by tuna RFMOs are occasionally considered to be insufficient and incomplete due to the large uncertainties in the assessment, other international organizations are being motivated to propose alternative ways of preventing over-exploitation.

Shortfin mako is a top predator and a large pelagic shark species that can attain approximately 3.7 m fork length (FL), and females grow larger than males [11]. The shortfin mako is a highly migratory species widely distributed throughout tropical and temperate oceans worldwide between 50ºN and 50ºS [11]. It is also a viviparous species, giving birth to live young of approximately 65–70 cm FL, and the mean litter size varies from 4 to 25 [46]. Fifty percent sexual maturity size of female shortfin mako ranges from 2.5 to 2.7 m FL [46] and longevity is 31 years estimated from bomb-radiocarbon [1]. This shark is fundamentally considered a low-productivity, high-susceptibility species [12, 38] due to its slow growth, late maturity at age and low fecundity [11], and to their incidental and occasionally targeted catch by multi-gear fisheries [31,34]. A past genetic study based on specimens collected from the Atlantic Ocean and the Pacific Ocean suggested that shortfin mako in the North Atlantic Ocean appeared to be isolated from those in the other oceans [26]. However, further analyses with substantial samples are required to elucidate the stock structure of shortfin mako from the gene level. Although tagging studies have suggested that they undergo large-scale migration [6], there is not yet enough information to completely understand their distribution and migration patterns. The stock structure of shortfin mako in the Pacific Ocean has been recognized to comprise two stocks – one in the North Pacific Ocean and the other in the South Pacific Ocean – based on genetics and tagging studies [34].

The International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) completed a benchmark stock assessment of shortfin mako using SS in 2018 under request from the WCPFC, and the results from the base-case model showed that the stock was likely not in an overfished condition and overfishing was not likely to be occurring [34]. The spawner abundance (i.e. number of mature female sharks) in 2016 was estimated to be 860,200 sharks (CV = 46%), which was 59% of the unfished level. These results suggested that the stock status of shortfin mako in the North Pacific Ocean was in a healthy condition. In addition, the future projections indicated that the spawning abundance was expected to increase gradually within a 10-year period. Meanwhile, the International Union for Conservation of Nature and Natural Resources (IUCN) assessed the extinction risk of shortfin mako in 2019 and in its Red List categorized the population of shortfin mako globally and in the North Pacific Ocean as Endangered and Vulnerable, respectively [56]. In addition, in 2019 the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed the shortfin mako in Appendix II [7]. The inconsistent outcomes are a controversial issue and raise a fundamental question about why different international organizations had different views on current and future stock declines.

This paper aims to elucidate the reasons for the inconsistent views on the stock decline of shortfin mako in the North Pacific Ocean. The clarification could help stakeholders understand the current and future stock decline of shortfin mako more accurately and disseminate scientifically reliable views regarding stock status, conservation, and management. A correct understanding is key to the establishment of suitable management procedures that will maintain the stock at an appropriate level. To achieve this aim, the author (1) reviews the latest assessments conducted by the ISC and IUCN, (2) reviews the procedures and criteria of CITES listing, (3) conducts a future projection based on the assessment by the ISC incorporating the uncertainty in the population trajectory to examine whether the past and future population trajectories can meet the criteria of IUCN categories and CITES listing, and (4) discusses the appropriateness of the current IUCN categorization and CITES listing for the conservation and management of shortfin mako in the North Pacific Ocean.

First of all, it should be noted that the underlying concepts at RFMOs and IUCN/CITES are completely different. RFMOs conduct a stock assessment to evaluate the latest stock status of the species and generate a projection that shows the predicted population trends for the near future, such as whether the population will increase, decrease, or reach a predetermined reference point, and then give management recommendations for the stock management and conservation of the species. IUCN/CITES, on the other hand, conduct extinction risk assessments based on historical population trends and future projections. Proportions of the historical and future population decline from the baseline in a time window is a basis of the overall extinction risk for the species, and then decisions on the IUCN category and the CITES listing are made. The IUCN category provides an awareness of conservation for the species and the CITES listing aims to protect the species from over-exploitation through restrictions in international trade.

2. Assessment of shortfin mako in the North Pacific Ocean

To accentuate the differences in the two assessments conducted by the ISC and IUCN, the author in particular focuses on the differences in model structures and data used in the assessments.

2.1. Stock assessment conducted by the ISC

The ISC conducted its latest stock assessment of shortfin mako in the North Pacific Ocean in 2018 using SS (a length-based, age-structured, forward simulation population model) with biological and fishery data [34]. SS is designed to accommodate age structure in the population, fits to relative abundance indices (i.e. standardized catch per unit effort; CPUE), and size composition data for each fleet, to estimate hundreds of parameters using maximum likelihood estimates [44]. The ISC [34] assessment drew its main conclusions from a base-case model under the cooperation of scientists from Canada, Japan, the Republic of Korea, Mexico, Chinese Taipei, the United States, the Inter-American Tropical Tuna Commission (IATTC), and the WCPFC. Input parameter values and model structure for the base-case model were selected based on the best available information. The base-case model included annual catch data from 18 fleets between 1975 and 2016, annual abundance indices from five fleets for the same period, and annual size composition data from 11 fleets between 1994 and 2016 (See Table 1 in [34]). The details of the biological parameters such as growth curve, steepness, maturity ogives, and natural mortality, which can characterize the low productivity of shortfin mako, are described in ISC [34] and Kai [38]. After the base-case model was selected, several sensitivity analyses were conducted to evaluate the effects of changes in the parameters and model structures for the base-case model. Model diagnostics such as residual analysis, the age-structured production model, the likelihood profile, and retrospective analysis [5,42] were also applied to the base-case model. The results from the sensitivity analysis as well as the base-case model suggested that shortfin mako in the North Pacific Ocean was not in an overfished condition and overfishing was not occurring given that a maximum sustainable yield (MSY) level is used as a limit reference point.

Future projections for 10 years (2017–2026) were also conducted using the base-case output to assess the future trajectory of stock abundance [34]. Three harvest policies were assumed: (1) Status-quo F scenario: fishing intensity is maintained at the current level for 2013–2015, (2) High F scenario: relative fishing intensity increases by 20% from the current level, and (3) Low F scenario: relative fishing intensity decreases by 20% from the current level. Selectivity at the average of 2013–2015 was fixed for all fleets, and recruitment was given based on the Beverton-Holt stock recruitment relationship in the base-case model. The future projections indicated that spawning abundances were expected to increase gradually over a 10-year period.

2.2. Background and goals of the IUCN

The IUCN was established in 1948 as the first global environmental union. The IUCN aims to protect nature and natural resources by listing threatened species in red lists that are intended to raise awareness and help direct conservation actions for the species [41]. The goals of the IUCN's red list are to (1) provide a global index of the state of the degeneration of biodiversity and (2) identify and document those species most in need of conservation attention if global extinction rates are to be reduced [35]. The IUCN system of incorporating a set of quantitative listing criteria classifies species into several categories according to their risk of extinction and identifies those species at highest risk of extinction, for which it was urgent to assess their situation and then design and implement effective actions for conservation [41].

2.3. Risk assessment conducted by the IUCN

In 2019, the IUCN assessed the latest extinction risk for shortfin mako in the world's oceans using a Bayesian state-space tool designed to conduct trend analyses of abundance indices in IUCN Red List assessment (i.e. Just Another Red-List Assessment; JARA) [56]. JARA builds on the Bayesian state-space tool, Just Another Bayesian Biomass Assessment (JABBA), which is an open-source modeling software package that can be used for biomass dynamic stock assessment applications [61]. JABBA was developed based on a Bayesian State-Space Surplus Production Model (BSPM) framework [43,45], which can account for both process and observation errors [14]. JABBA includes multiple useful functions, such as an option of model-fitting to multiple CPUE time series simultaneously. In addition, JABBA can provide model diagnostic tools and future projections with illustrations of the outputs. A major advantage of the model is that it imputes any missing data and provides estimates of both status and parameters [8]. The model is therefore useful in several situations, such as when there is a lack of data on age composition and catch data. JABBA has already been applied in stock assessments of tunas as well as relatively data-poor sharks and billfishes globally (e.g., [51,56,62]). Of particular importance here is that JARA is not used to assess stock status like JABBA but to classify the species into several categories through extinction risk probability that results from a quantitative analysis to estimate extinction risk [41].

Since there are no data available on the absolute global population size of shortfin mako, the IUCN used the population trend data of shortfin mako in four regions: the Atlantic Ocean, the North Pacific Ocean, the South Pacific Ocean, and the Indian Ocean [56]. For North Pacific shortfin mako, the population trend was assessed using the output of SS (i.e. spawning abundance trend for 1975–2016) (see Fig. ES4 in [34]). The annual percentage of change in the spawning abundance (−0.64%) was calculated directly from the posteriors of the population time series estimated by the Bayesian state-space model. In addition, a future projection until 2045 was conducted based on the four-decade declining trends of spawning abundance to predict the population trajectory over approximately three generations (i.e. 72 years) including the assessment periods (i.e. 1975–2045). As a result, the median rate of population decline over three generations for North Pacific shortfin mako was determined to be 36.5%, which categorized it as Vulnerable in the IUCN Red List. Rigby et al. [56] assigned five categories to the shortfin mako on the basis of quantitative criteria that are designed to reflect varying degrees of threat of extinction in the wild [36], i.e. Critically Endangered (> 80% decline): extremely high risk of extinction; Endangered (50–80% decline): very high risk of extinction; Vulnerable (30–50% decline): high risk of extinction; Near Threatened (25–30% decline): close to qualifying for or likely to qualify for a threatened category in the near future; and Least Concern (0–25% decline or increase): does not qualify for the other categories.

The remaining three stocks in the other regions were also categorized using the median rates of population decline over three generations [56]. The median change was −60.0%, +35.3%, and −47.9% for the stocks in the Atlantic Ocean, the South Pacific Ocean, and the Indian Ocean, respectively. The respective statuses assigned were Endangered, Least Concern, and Vulnerable for the three stocks. Finally, the global change was determined based on weighting the regional posterior probabilities by the proportion of each ocean's area. The proportional areas were 0.29, 0.31, 0.22, and 0.18 for the stocks in the Atlantic Ocean, the North Pacific Ocean, the South Pacific Ocean, and the Indian Ocean, respectively [18]. The overall estimated median reduction was 46.6%, with the highest probability of 50–79% reduction over the three generations. The species was therefore classified as Endangered overall.

3. Overview of CITES and listing of shortfin mako shark

The author provides an overview of CITES, reviews the criteria of CITES listing for commercially exploited aquatic species, and then explains the process of CITES listing for the shortfin mako shark.

3.1. Overview of CITES and listing of pelagic sharks

CITES is an international agreement between governments. The main objective of CITES is to ensure that international trade in specimens of wild animals and plants does not threaten their survival (https://cites.org/eng/disc/what.php). The species covered by CITES are listed in three appendices based on the degree to which they are jeopardized under the globalization of trade. Trade in specimens of Appendix I species is basically prohibited. Trade in specimens of Appendix II species is permitted through a licensing system unless it is detrimental to the sustainability of wild populations. Trade in specimens of Appendix III species is controlled in at least one country or region, and those parties request other CITES parties for assistance in controlling the trade. As of Sept. 2021, conservation agreements have been concluded among 183 parties globally, and approximately 38,500 species of wild fauna and flora are protected by CITES against over-exploitation via international trade. Of those species, 14 sharks have been included in the list of Appendix II species over time since 2003 (Table 1). These sharks are fundamentally considered to be vulnerable to over-exploitation and environmental degradation due to their low productivity and high susceptibility [2,12] given their biological characteristics of slow growth, late maturity at age, and low fecundity [11] and most being caught as bycatch by industrial, artisanal, and recreational fisheries targeting tuna and tuna-like species such as bigeye tuna and swordfish [50].

Table 1
Pelagic sharks listed in CITES Appendix II.

Species		Effective year
English name	Scientific name	
Basking shark	*Cetorhinus maximus*	2003
Whale shark	*Rhincodon typus*	2003
Great white shark	*Carcharodon carcharias*	2005
Porbeagle shark	*Lamna nasus*	2014
Oceanic whitetip shark	*Carcharhinus longimanus*	2014
Scalloped hammerhead	*Sphyrna lewini*	2014
Great hammerhead shark	*Sphyrna mokarran*	2014
Smooth hammerhead shark	*Sphyrna zygaena*	2014
Bigeye thresher shark	*Alopias superciliosus*	2017
Common thresher shark	*Alopias vulpinus*	2017
Pelagic thresher shark	*Alopias pelagicus*	2017
Silky shark	*Carcharhinus falciformis*	2017
Shortfin mako	*Isurus oxyrinchus*	2019
Longfin mako	*Isurus paucus*	2019

The lucrative market and international criticism for finning drive increases in illegal, unreported or unregulated (IUU) fishing [57] that result from the strict regulations on finning (e.g., https://www.europarl.europa.eu/doceo/document/DCL-7–2010–0071_EN.pdf). According to a report on the state of the global market for shark products [15], the trade in shark fins peaked in 2003–2004 and subsequently decreased due to several factors such as increases in domestic production by Chinese fleets, new regulations in China on the expenditures of governmental officials, consumer backlash against artificial shark fin products, and increased monitoring and regulation of finning, while the trade in shark meat has been growing in the past decade due to the trend to fully utilize carcasses. To eradicate IUU fishing, Dent and Clarke [15] mentioned that reliable information on quantities and patterns of shark fin trade would facilitate efforts to monitor, control, and enforce restrictions on shark finning. However, assessing the global trade in species-specific shark products is a complex and challenging task. In this context, the most controversial issue is the effectiveness of the CITES listing of the 14 sharks in Appendix II. In other words, can a CITES listing contribute to a reduction in the international trade of shark products from listed species, illegal trade in particular, and provide a conservation benefit to the species?

3.2. Criteria of CITES listing for marine species

At its 17th meeting, the Conference of the Parties (CoP) to the Convention agreed in Resolution Conf. 9.24 (Rev. Cop17) on a set of biological and trade criteria to help determine the CITES listing (https://cites.org/sites/default/files/document/E-Res-09-24-R17.pdf). A footnote of Resolution Conf. 9.24 explains that the historical extent of decline is a more appropriate criterion for exploited marine species to be listed in Appendix II, and that "decline" could be expressed either as an overall long-term extent of decline or a recent rate of decline, and advised that these rates of decline should be considered together. If the historical extent of decline for the species is high, the recent rate of decline would be more important. As a general guideline, the footnote stated that a marked recent rate of decline would drive a population down within a 10-year period from the current population level to the X % historical extent of decline from the baseline. It is also necessary to consider the buffer zone where the population level falls Y% above the relevant extent of decline. The proportions X and Y depend on the species productivity based on its life history characteristics (see Table 1 in [19]). Since X = 20 and Y = 5–10 are given for low-productivity species such as the 14 listed sharks, the decline of 80% and 70–75%, resulting in the population being 20% and 25–30% of the level at the beginning of the time series, would meet the criteria for listing in Appendices I and II, respectively.

3.3. Process of CITES listing for the shortfin mako shark

On 1 April 2019, Mexico and 54 other countries submitted a proposal to the 18th Meeting of the CoP to CITES (https://cites.org/eng/cop/18/prop/index.php) to include the shortfin mako shark in Appendix II in accordance with Article II paragraph 2(a), and longfin mako shark, *Isurus paucus*, in Appendix II in accordance with Article II paragraph 2 (b). The latter is applied to specimens of a species that might be traded in a form that resembles specimens of a species included in Appendix II under the provisions of Article II paragraph 2(a) or in Appendix I. The main rational for the proposal was the decreasing population trend of shortfin mako worldwide, citing the stock assessment conducted by the IUCN [56]. In addition, the stock status of shortfin mako in each region was described in the proposal based on the most recent scientific information [21]: the stock in the Mediterranean Sea experienced historical declines above 96%; the stocks in the North Atlantic Ocean and the Indian Ocean were projected to decline by 60.0% and 41.6% over the next ten years, respectively; the stock in the South Atlantic Ocean is probably overfished and over-exploited; and the stock in the North Pacific Ocean is neither overfished nor over-exploited.

An FAO expert advisory panel for the assessment of proposals to amend Appendices I and II of CITES concerning commercially exploited aquatic species was held prior to the 18th Meeting of the CoP to CITES [21]. They concluded that the available data did not provide evidence that shortfin mako met CITES Appendix II listing criteria from the global perspective even when precautionary considerations were taken into account [21]. In the report, the panel noted that the ICCAT had adopted a recommendation to reduce catches in the North Atlantic Ocean, which may in turn reduce further population decline. In the Mediterranean Sea, the population has declined, but the extent of this decline is not well documented. The panel found no evidence that this population met the CITES criteria for all stocks except for the North Atlantic Ocean, whether based on the historical extent of decline or recent rates of decline. Nevertheless, on 25 August 2019, the 18th CoP to CITES decided to list the two species of mako shark in Appendix II of the convention after conducting a ballot with a vote of 102 parties in favor, 40 opposed, and 5 abstentions (https://cites.org/sites/default/files/eng/cop/18/Com_I/SR/E-CoP18-Com-I-Rec-12-R1.pdf). The decision forces restrictions on trade in specimens of these two species and products derived from them.

4. Future projection of shortfin mako in the North Pacific Ocean

With the recently developed statistical method [47], the author conducted a future projection based on the most recent assessment by the ISC [34] to examine whether the current and future population (i.e. spawner abundance) trajectory of shortfin mako in the North Pacific Ocean could meet the criteria of CITES listing as well as the current IUCN Red List category. The author focused only on the stock in the North Pacific Ocean because a benchmark stock assessment with future projection had already been conducted using SS with sufficient scientific information, and the current and future stock status was considered to be healthy in contradiction to the status in the CITES listing and IUCN categorization of Vulnerable for this stock.

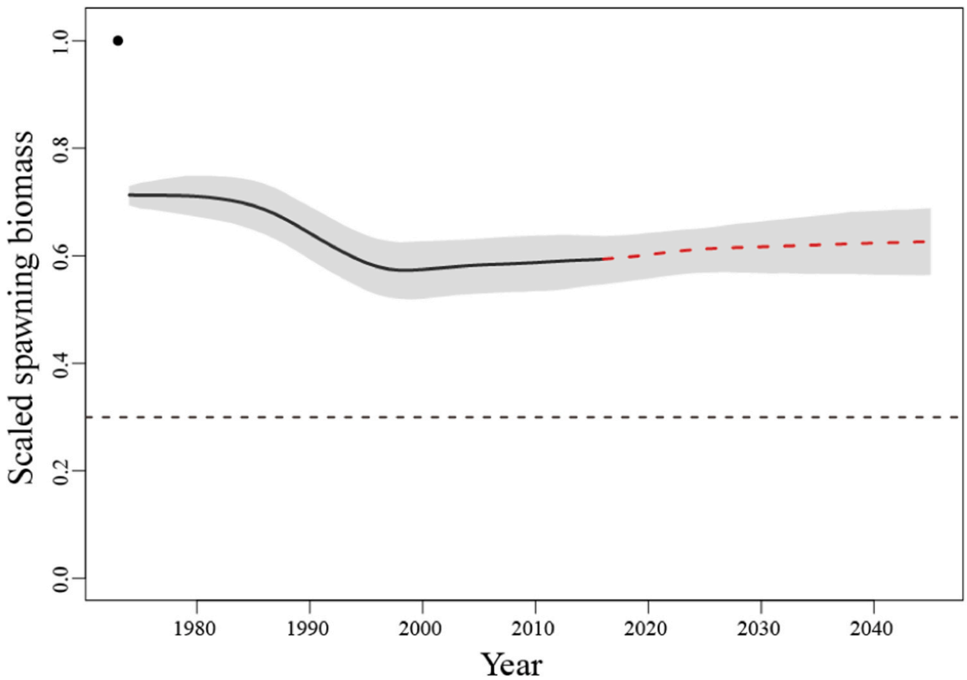

Fig. 1. The observed (solid black line) and predicted (dashed red line) spawner abundance trajectory of shortfin mako in the North Pacific Ocean scaled by unfished spawner abundance (black filled circle) over three generations (72 years) with credible intervals (gray areas) derived from the NUTS chains. Horizontal broken line denotes the criteria (i.e. declines to 30% of historic levels) of the CITES listing in Appendix II.

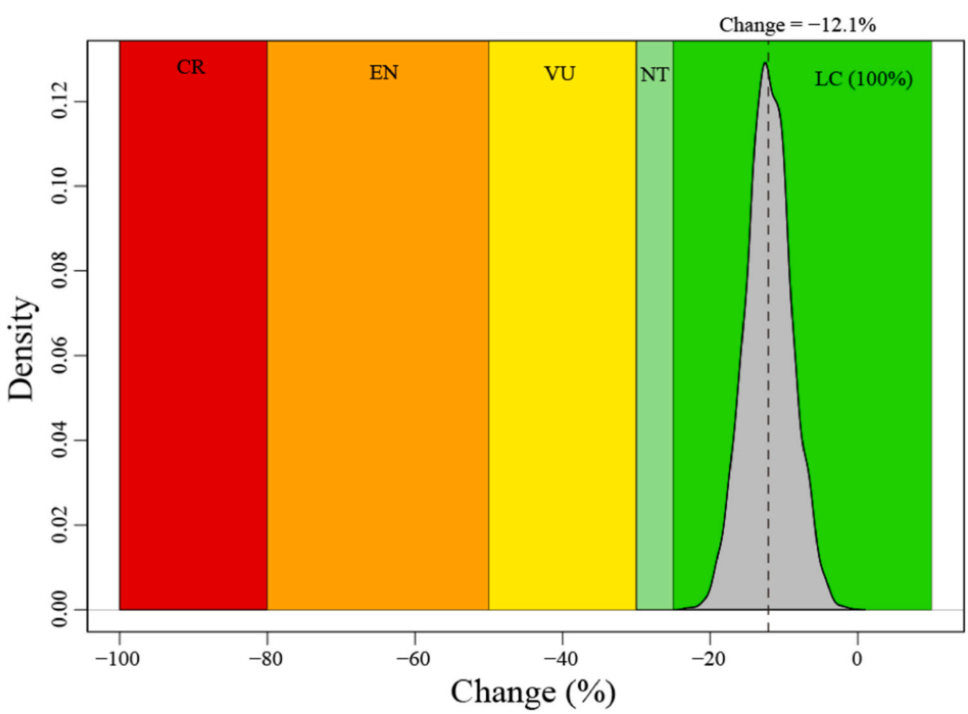

Fig. 2. The median decline of shortfin mako in the North Pacific Ocean over three generations (dashed vertical line) and the range (gray area) predicted from the NUTS chains and corresponding rates of population decline falling within an IUCN Red List category (CR: Critically Endangered; EN: Endangered; VU: Vulnerable; NT: Near Threatened; LC: Least Concern).

4.1. Specification of the future projection

Since the SS projection conducted by the ISC in 2018 was a deterministic version without considering uncertainty in the population trajectory, the author introduced the uncertainty in the population trajectory using SS projection based on Markov Chain Monte Carlo (MCMC) simulation. SS uses the Metropolis-Hastings algorithm for MCMC sampling. The algorithm is supplied with an approximate multivariate normal distribution calculated from the Hessian matrix [22]. The author used the same fishery data, biological parameters, and model configurations of the base-case model as those used in the 2018 stock assessment [34]. The projection was conducted under the conditions of a pre-specified constant *F* scenario ($F_{2013\text{-}2015}$) with selectivity in the projection period set equal to the estimated values from 2013 to 2015, and forecast recruitment was given from the spawner-recruit curve. The projection period was set for 29 years until 2045 (i.e. 2017–2045) to be consistent with that of JARA conducted by the IUCN [56]. The SS version was updated from 3.24 U to 3.30 to use the R package "adnuts" [47,53] that allows for easy implementation of the no-U-turn sampler (NUTS; [27]) – a Bayesian algorithm recently added to SS – and parallel computation. These newly added functions reduced run times and improved sampling from posterior distributions compared with existing Bayesian algorithms in SS. The author adopted the same procedure shown in Appendix B of Monnahan et al. [47] (see Appendix A1 in this paper).

4.2. Results of the future projection

Model diagnostics verified that the Bayesian inferences were available for this analysis (see Appendix A2 in this paper). The median of the predicted spawner abundance trajectory increased slightly until 2045 and never fell below the criteria (i.e. declines to 30% or less of historic levels) for CITES listing in Appendix II (Fig. 1). These results suggest that shortfin makos in the North Pacific Ocean do not meet the CITES criteria for Appendix II. In addition, the median decline of the population trajectory over three generations was 12.1% with a small uncertainty, enabling it to be categorized as Least Concern in the IUCN Red List (Fig. 2).

5. Discussion

The author comprehensively reviewed the assessments of North Pacific shortfin mako conducted by the ISC and IUCN to clarify the differences in the approaches. JARA applied by the IUCN is a useful and versatile tool in extinction risk assessments for data-poor pelagic sharks. However, the tool is not suitable for data-rich pelagic sharks such as North Pacific shortfin mako, because the stock assessment had already been completed using SS [34], based on sufficient information regarding size composition as well as size-/age-specific biological parameters. The major issue concerning the future projection based on JARA is that the IUCN used only the mean annual trends in the population over the assessment period estimated from SS and did not consider size/age structures of the population over recent decades in their assessment. Biological characteristics such as large size at maturity, which resulted in limited gear selectivity for immature females, could have a large impact on population dynamics in the future projection. The future projection based on JARA, however, was not able to fully consider the age structure of the stock or the slight increases in annual abundance trends since 1994. These problems resulted in a misguided future stock trajectory of the North Pacific shortfin mako.

The author also comprehensively reviewed the process of CITES listing for aquatic living resources to point out the issue concerning the mechanism of CITES listing for highly migratory species such as shortfin mako and blue shark, as there are multiple stocks of these species with a variety of stock statuses globally. Nevertheless, all stocks in the world's oceans have been accorded a single status because the stocks are of one species. This is a critical issue in the CITES listing for highly migratory species. The author, however, understands that the listing of all stocks in global waters or similar looking species is reasonable from the standpoint of trade regulation because it is difficult, if not impossible, to identify the stock or species in the trade, which is an impediment to trade regulation.

Another issue of concern with the CITES listing is the effectiveness of import and export controls. Friedman et al. [23] evaluated the changes in elasmobranch fisheries in eight Southeast Asian countries before and after the listing of sharks and rays in CITES Appendix II and demonstrated mostly a positive influence of CITES in five of the eight countries. Kuo and Vincent [39] assessed changes in the international trade of seahorses under CITES regulations. Their finding revealed that the import prices of seahorses rose with declines in declared trade volume, providing incentives for illegal catches, and a major seahorse importer, Hong Kong, was found to have expanded its sources to include a number of new African and South American countries [39]. These results demonstrated some positive effects and limitations of CITES regulations in their efforts to conserve marine species that are suffering from over-exploitation. In addition, CITES has no system for directly evaluating the population status of listed species after their regulations have been implemented, albeit the CITES requirement for non-detrimental findings is intended to encourage range states to evaluate whether stocks are at risk of further decline.

Tuna RFMOs have been providing qualitative and quantitative information from their respective regions on the stock status of pelagic sharks as well as basic fishery statistics. Before they were added to the CITES lists, however, it was difficult to conduct full stock assessments for most of these sharks in each ocean due to the lack of reliable biological and fishery data. There were some exceptions, though, as the ICCAT [28] conducted full stock assessments for porbeagle shark in the Atlantic Ocean in 2009 using BSPM [43] and the age-structured production model (ASPM) [52], and the WCPFC conducted full stock assessments for the oceanic whitetip shark and silky shark in the western Pacific Ocean in 2012 and 2013 using SS [54,55]. These stock assessment results were used in proposals for amendments to Appendices I and II as evidence of population decline. The CITES listings for pelagic sharks, however, were mainly determined based on fragmentary information such as annual abundance indices and annual catch statistics from different areas of the range. The FAO pointed out that a number of the abundance indices were of varying reliability as indices for the species, and some of the references in relation to population decline presented in the CITES proposal were incomplete, outdated, and/or mis-cited [20]. Regarding the proposals in 2016 to include the sharks now in Appendix II, the FAO expert panel concluded that available scientific information on the status of the sharks proposed for listing did not meet Appendix II criteria. The CoP to CITES at its 17th meeting in 2016, however, decided to list these sharks in Appendix II through the agreement of more than two thirds of all parties. These facts in the past and the latest CITES listing of shortfin mako and longfin mako in 2019 clearly indicate that the CITES listings of pelagic sharks strongly depended on political rather than scientific considerations. Regarding this issue, Friedman et al. [24] suggested that the assessment period should be extended (the current period is only less than 150 days) to give CITES parties the opportunity to refute evidence and to help them make more informed, effective decisions.

Although CITES parties may utilize information on fisheries statistics such as a recent species-specific catch in consideration of non-detrimental findings in support of CITES export permits, full cooperation with tuna RFMOs is indispensable to assessments of the stock status of pelagic sharks after CITES listing. The foremost issue in stock assessments after CITES listing concerns deterioration in the quality and quantity of fishery data as well as biological parameters. Export controls are certain to reduce the total landings of pelagic sharks due to discards or live release that may result in underestimations of the catch. In addition, the CITES listing is certain to restrict the sharing of biological samples among CITES parties and hinder collaborative studies on pelagic sharks. A paucity of data reduces the accuracy of stock assessments and makes it difficult to implement effective management. The ICCAT, for example, conducted a benchmark stock assessment for porbeagle shark in 2020 after the species was added to Appendix II of the CITES listing in 2014 and a non-retention measure was adopted by the ICCAT in 2015. The stock assessment model was restricted to a data-limited approach given that the reporting of dead discards continues to be very limited and some landings might remain unreported [32].

The future projection of SS for North Pacific shortfin mako in the present study revealed that the stock should be in the IUCN's Least Concern category and did not meet the criteria for CITES Appendix II listing, whether based on the historical extent of decline or on recent rates of decline (i.e. a decline of 70% or more). These results suggested that the methodology of the assessment conducted by the IUCN was inappropriate for long-lived, sexually dimorphic species, and the approach of the CITES listing was inappropriate for this highly migratory species with different stock statuses in the world's oceans. Meanwhile, the FAO expert panel determined that the ISC assessment provided much more reliable results with its use of a more robust approach that accounted for trends in the proportion of the shortfin mako population [21]. The present study therefore concludes that the current and future stock conditions (i.e. the extent of population declines) of North Pacific shortfin mako assessed by the ISC is more robust and reliable than the results of risk assessments conducted by the IUCN and CITES. This conclusion implies that the conservation management of North Pacific shortfin mako should be implemented by the tuna RFMO covering this region based on the results of stock assessment and future projection derived from a suitable assessment model with the best available data and not based on the results of risk assessment provided by the IUCN and CITES.

The author finally advocates three fundamental points: (1) risk assessment by the IUCN based on an inaccurate method to estimate the proportion of population decline should be improved in order to prevent incorrect CITES listing of the species, (2) the results of risk assessments by IUCN/CITES should not directly influence fishery management by RFMOs, because these risk assessments may not provide information on the current and future stock status in relation to the benchmarks and these organizations have no responsibility for the fishery management of the stocks, and (3) the fact that CITES listing is largely driven by politics should be corrected, because there is no clear evidence or effective review system that trade regulation may or may not be helpful for the conservation of a particular stock, and it is also clear that CITES listing may degrade the quality and quantity of data used in the stock assessments.

6. Conclusions

The author focused on the issue of the IUCN category and CITES listing for North Pacific shortfin mako alone. Shortfin mako sharks in other regions except for the North Atlantic stock might have the same issues where stock status might not meet the criteria of CITES listing and might differ from the category that the IUCN assigned for each region. However, the task of verification for these stocks is very difficult due to large uncertainties in the status of stocks in the Indian Ocean, the South Pacific Ocean, and the South Atlantic Ocean. Although improving the accuracy of stock assessments is an urgent issue, the deterioration of assessment data as a result of CITES listing complicates these efforts. It is therefore strongly advised that the same mistake should not be made for other, non-listed cosmopolitan pelagic sharks.

CRediT authorship contribution statement

Mikihiko Kai: Conceptualization, Methodology, Software, Writing – review & editing.

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Appendix A

Technical details concerning the future projection.

A.1 Procedure of the future projection

There were four steps in this procedure:

(I) The slowest mixing parameters were examined using the most popular MCMC algorithm within SS, which is a modified random walk Metropolis (RWM) algorithm. This algorithm was applied to the base-case model with three parallel chains of 100,000 iterations and saving every 100th sample after discarding the initial 25,000 iterations for each chain. The results from all three chains were combined, and convergence of the MCMC samples to posterior distribution was checked using Gelman-Rubin's potential scale reduction factor (Rhat) – which should be less than 1.1 – and effective sample size (ESS; effective number of independent draws from the posterior distribution of the estimates of interest). Geometric issues with the posterior were also visually assessed by plotting pairwise posterior correlations for the slowest mixing parameter.

(II) Several poorly informed parameters at their maximum likelihood estimates (MLE), for selectivity parameters in particular, were fixed to mitigate issues of slower mixing parameters (i.e. effectively constraining the geometry of the posterior). After all parameters were mixing at a reasonable rate (i.e. there were no parameters with extremely low ESS), NUTS chains were run for 500 iterations without thinning (i.e. due to the low autocorrelation of NUTS) and with a warmup of 10%.

(III) NUTS chains based on an updated mass matrix calculated as the empirical covariance of posterior samples were re-run from a previous NUTS run. Samples from 2000 iterations were collected without thinning after 100 initial iterations were discarded, and the target acceptance rate was increased from 0.8 to 0.95 to improve sampling efficacy.

(IV) The predicted spawning stock abundance of shortfin mako (i.e. 5700 posterior samples) was examined to determine whether it met the criterion of CITES listing and whether the rates of population decline fell within the IUCN Red List category.

A.2 Results of model diagnostics

Model diagnostics showed that all estimated parameters satisfied the convergence criterion (a maximum value of Rhat < 1.004) and had a sufficient effective sample size (a minimum value of ESS > 2000). Diagnostic plots for the four slowest mixing parameters estimated from 1900 iterations of three NUTS chains indicated that all parameters were mixing at a reasonable rate (Fig. A1).

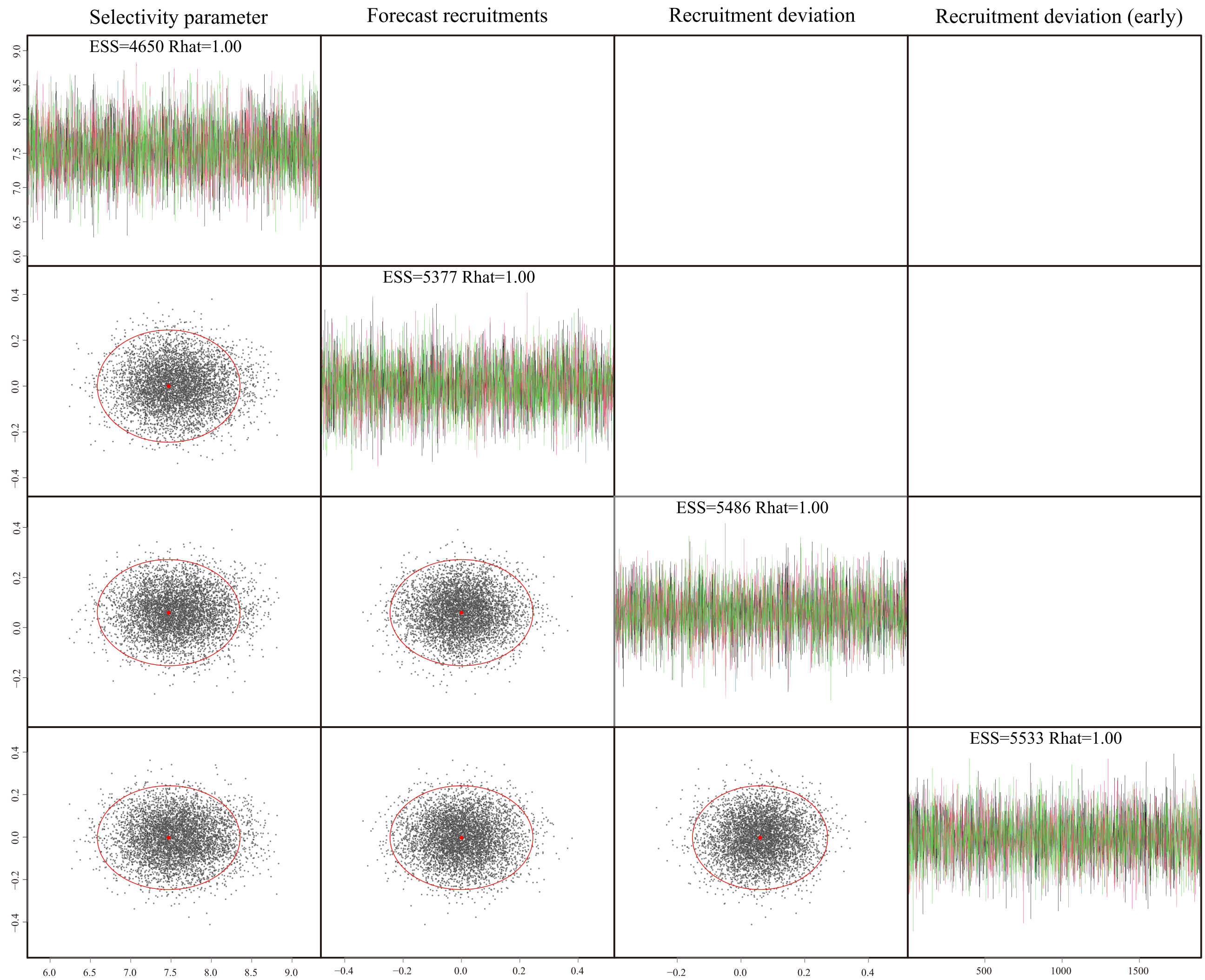

Fig. A1. Diagnostic plots for the four slowest mixing parameters. The diagonals show traces of the three NUTS chains. The scatterplots show pairwise posterior samples (black dots) and bivariate 95% confidence regions (ellipses and single dots) from the inverted Hessian, which is used as the mass matrix, a key tuning parameter. ESS: effective sample size; Rhat: Gelman-Rubin's potential scale reduction factor.

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