TROPHIC DYNAMICS AND LIFE HISTORY OF ATLANTIC SKIPJACK TUNA (*KATSUWONUS PELAMIS*) CALL FOR A 'FORAGE FISH APPROACH' TO MANAGEMENT PROCEDURES

J.J Bohorquez[1], G. Galland[2], S. Miller[1]

SUMMARY

Nearly 3 million t of skipjack tuna are caught and landed annually, the most of any tuna species and the third most of any wild-caught fishery. The Atlantic is the only ocean basin without a management procedure (MP) or harvest control rule (HCR) in place for skipjack. As MPs are developed for the eastern and western Atlantic stocks, ICCAT should consider adopting management objectives, reference points, and other MP components more typical of forage fishes than the larger-bodied tunas. As a small species of tuna, skipjack has a life history and broader ecosystem impact that are characteristic of forage fishes, a conclusion that is highly relevant to MP development. This paper reviews the scientific basis for managing skipjack in this way and discusses some features of forage fish MPs for consideration by ICCAT managers and its skipjack MP development teams. We argue that MPs for Atlantic skipjack should be flexible, precautionary, and inclusive of broader ecosystem impacts and that these considerations should be made early in the development process, including when finalizing management objectives to be tested using management strategy evaluation.

RÉSUMÉ

Près de trois millions de tonnes de listao sont capturées et débarquées chaque année, soit la plus grande quantité de toutes les espèces de thonidés et la troisième plus grande quantité de toutes les pêcheries de poissons sauvages. L'Atlantique est le seul bassin océanique sans procédure de gestion (MP) ou règle de contrôle de l'exploitation (HCR) en place pour le listao. Lors de l'élaboration des MP pour les stocks de l'Atlantique Est et Ouest, l'ICCAT devrait envisager d'adopter des objectifs de gestion, des points de référence et d'autres éléments de MP plus typiques des poissons fourrage que des thonidés de plus grande taille. En tant que petite espèce de thon, le listao a un cycle de vie et un impact plus large sur l'écosystème qui sont caractéristiques des poissons fourrage, une conclusion qui est très pertinente pour le développement des MP. Ce document examine la base scientifique de la gestion du listao de cette façon et discute de certaines caractéristiques des MP de poissons fourrage à prendre en considération par les gestionnaires de l'ICCAT et ses équipes de développement des MP de listao. Nous soutenons que les MP pour le listao de l'Atlantique devraient être flexibles, prudents et inclure des impacts plus larges sur l'écosystème et que ces considérations devraient être prises en compte dès le début du processus de développement, y compris lors de la finalisation des objectifs de gestion à tester en utilisant l'évaluation de la stratégie de gestion.

RESUMEN

Cada año se capturan y desembarcan casi 3 millones de t de listado, la mayor cantidad de cualquier especie de atún y la tercera mayor cantidad de cualquier pesquería de captura en estado salvaje. El Atlántico es la única cuenca oceánica que carece de un procedimiento de ordenación (GP) o de una norma de control de capturas (HCR) para el listado. A medida que se desarrollen los MP para los stocks del Atlántico oriental y occidental, ICCAT debería considerar la adopción de objetivos de ordenación, puntos de referencia y otros componentes de los MP más típicos de los peces forrajeros que de los túnidos de mayor tamaño. Al ser una especie de pequeño túnido, el listado tiene un ciclo vital y un impacto en el ecosistema más amplio que son

[1] The Ocean Foundation – International Fisheries Conservation, 1320 19th St NW, Washington, DC 20036, USA, jbohorquez@oceanfdn.org
[2] The Pew Charitable Trusts, 2005 Market Street, Suite 1700, Philadelphia, PA 19203-7077, USA

característicos de los peces forrajeros, una conclusión que es muy relevante para el desarrollo de los MP. En este documento se revisa la base científica para que la ordenación del listado se realice de este modo y se debaten algunas características de los MP para peces forrajeros para que sean consideradas por los gestores de ICCAT y sus equipos de desarrollo de MP para el listado. Argumentamos que los MP para el listado del Atlántico deben ser flexibles, preventivos e incluir los impactos más amplios sobre el ecosistema, y que estas consideraciones deben realizarse al principio del proceso de desarrollo, incluso al finalizar los objetivos de ordenación que se pondrán a prueba mediante la evaluación de estrategias de ordenación.

KEYWORDS:

Tuna fisheries, Forage fish, Ecosystem management, Predation, Natural mortality, Multispecies fisheries

1. Introduction

The skipjack tuna (*Katsuwonus pelamis*) is a small to medium sized tuna found in the tropics of the Atlantic, Indian, and Pacific Oceans. Globally, it is the most widely caught tuna species by biomass (2.9 million tonnes, 57.83% of global total), second highest in value at the first point of sale ($4.0 billion/year, 34.05% of global tuna landings value), and highest at the final point of sale ($16.1 billion/year, 39.52% of total tuna end value) (McKinney et al., 2020). The social value of skipjack is further amplified by the relative affordability of skipjack compared to other species of tuna, making it a vital and accessible source of protein around the world. With such high socioeconomic importance, combined with increasing global fishing pressure, sustainable management of skipjack fisheries is vital. Developing management procedures (MP) to direct management decisions based on pre-agreed, science-based indicators over the long-term is therefore a focus worldwide, including in the Atlantic as mandated by the International Commission for the Conservation of Atlantic Tunas (ICCAT) Recommendation 15-07 (ICCAT, 2015).

All of the regional fisheries management organizations dedicated to tunas (tRFMOs) have developed or are developing MPs for skipjack. The Indian Ocean Tuna Commission (IOTC) adopted a harvest control rule for skipjack in 2016 (IOTC, 2016) and will expand it to a full MP as soon as 2023. Western and Central Pacific Fisheries Commission (WCPFC) adopted an MP for skipjack in 2022 and will implement it as soon as 2024 (WCPFC, 2022). While the Inter-American Tropical Tuna Commission (IATTC) adopted an HCR for skipjack and other tropical tunas in 2016, it was not developed using management strategy evaluation (MSE), and it is only loosely specified so should not be viewed as a precedent. The Atlantic remains the only ocean basin without a full or partial MP for skipjack.

Skipjack tuna fisheries in the Atlantic are managed as separate eastern and western stocks. Significant progress towards an MP has been made for the western stock. ICCAT adopted conceptual management objectives in 2022 upon which an MP could be based and formally adopted in 2023, in accordance with ICCAT's MSE Roadmap (ICCAT, 2022a). Preliminary MSE results are already available for western skipjack in an open access online data visualization tool (Blue Matter Science, 2021). The eastern stock will be included in a multispecies MSE since the majority of skipjack fisheries in the eastern Atlantic catch yellowfin and bigeye too. The multispecies MSE is underway but not as advanced as that for western skipjack. The MSE Roadmap calls for MP adoption for eastern skipjack in 2024. Therefore, while important progress has been made, it will be important to better specify the approach and eventual characteristics of any MPs for skipjack tuna in the Atlantic over the next year.

ICCAT, alongside other RFMOs, has made notable advancements in MPs for other species in recent years. One of the most scientifically robust harvest strategies in the world was adopted in 2022 as a joint MP for eastern and western Atlantic bluefin tuna (*Thunnus thynnus*) (ICCAT, 2022b). This accomplishment closely followed an MP for North Atlantic albacore adopted in 2021 (ICCAT, 2021a), and could precede another MP for North Atlantic swordfish that will likely be adopted in 2023. Because individuals from the two Atlantic bluefin populations mix and are caught together in the North Atlantic, one MP was developed to manage both stocks, In contrast, MSEs for the two skipjack populations can proceed separately, given the apparent lack of geographic overlap of the two (Fonteneau, 2015), similar to the MSEs for North Atlantic albacore and swordfish.

MPs adopted by other RFMOs also provide important insights for developing a skipjack MP. At first glance, it may appear preferable to apply examples from other tuna MPs for skipjack, such as bluefin, albacore (*Thunnus alalunga*), and bigeye (*Thunnus obesus*). However, the ecological role of skipjack tuna, combined with lifecycle characteristics in the context of environmental indicators that typically inform MPs, have close similarities with smaller forage fishes that have also had MPs adopted in recent years. Here, we summarize these similarities and potential implications for designing an MP for skipjack that draws from past MPs for forage fish, which are typically more precautionary due to the broader ecosystem importance of the species.

2. Parallels between skipjack and forage fish

2.1 Trophic Dynamics

Forage fishes have traditionally been defined by their role in marine food webs as, "small or intermediate sized pelagic species…that are the primary food source for many marine predators, including mammals…seabirds…and larger fish" (Pikitch et al., 2014). These include many smaller species like anchovies, mackerel, krill, squid, and herring. As such, forage fishes are not limited to a defined set of species and can be applied to any species that fill the ecological role as an important point of energy transfer.

Skipjack tuna are larger than most typical forage fishes, with catch at size in the Atlantic ranging from ~30 – 60 cm and ~1 – 8 kg (Bell et al., 2022). Some prior studies generally grouped skipjack tuna as top predators alongside large sharks, tunas, and billfishes (Essington, 2003; Luckhurst, 2015). However, on a more granular level, some of these works have found that skipjack occupy a trophic position below the threshold of true top or apex predators (Luckhurst, 2015), and may be better described as mesopredators rather than apex predators (Hunsicker et al., 2012).

Even mature skipjack are important prey items of other species managed by ICCAT, including sharks, large yellowfin tuna, and billfishes (Hunsicker et al., 2012). Large billfishes such as blue marlin (*Makaira nigricans*) are particularly dependent, with mature skipjack comprising up to two thirds or more of their diet in biomass for populations worldwide, including the Atlantic (Shimose et al., 2006; Vaske Jr. et al., 2011). In the Atlantic, the blue marlin continues to be overfished (Mourato et al., 2018), so consideration of the skipjack's role in pelagic food webs is relevant to ICCAT's mandate to recover overfished populations under its jurisdiction.

Skipjack (of all sizes) represent an important prey resource for many large pelagic species. As such, fluctuations in abundance of skipjack tuna could have large ramifications across pelagic ecosystems. There are many small scombrids, but the vast biomass of skipjack makes them extremely important. Notably, many species that prey on skipjack are priority ICCAT stocks, including the larger tropical tunas (Horn et al., 2013; Hunsicker et al., 2012), billfishes (Hunsicker et al., 2012), and large pelagic sharks such as blue sharks (Bornatowski et al., 2018; Hunsicker et al., 2012; Kitchell et al., 2002; Preti et al., 2012). The relationship between skipjack and these apex predators may be significant enough that some scientists have suggested that, in other parts of the world, depletion of apex predators may have increased the abundance and range of skipjack through mesopredator release (Hunsicker et al., 2012). Management measures for skipjack, including MPs, would therefore benefit from taking the broader ecological role of skipjack as an important prey of larger species into consideration.

2.2 Life history

Atlantic skipjack fully mature within 1-2 years and have a life span of about 7 years (Mourato et al., 2022; NOAA, 2022), which is comparable to several species of forage fishes (Siple et al., 2019). Skipjack have a faster rate of growth and shorter lifespan compared to larger-bodied tunas. For example, the relatively quick to mature bigeye tuna takes three years to mature and can live over 15 years (ICCAT, 2021b). Atlantic bluefin tuna may take up to 15 years to mature and can live up to 40 years.

Faster growth and shorter lifespans can result in higher year-to-year variability for skipjack compared to larger tunas, and the species is known for larger interannual differences in relative abundance (Bell et al., 2022). Similar to forage fish, climate patterns, such as Atlantic Multidecadal Oscillation have been shown to affect skipjack abundance even in the Pacific (Hou et al., 2022). A demonstrated history of occasional "runs" and troughs in some

parts of the Atlantic from shifting regional distributions (Bell et al., 2022) makes streamlining management decisions highly important – a service which MPs can provide. But this geographic variability can also challenge the MSE process and testing of MPs, and there was historical skepticism among scientists on the ability to apply MSE and MPs to forage fishes and other short-lived pelagic species (de Moor et al., 2011).

But with special adaptations to MPs, they have been successfully applied for these species around the world (de Moor et al., 2022, 2011; Siple et al., 2019). The lifecycles of Atlantic skipjack call for similar applications to maximize the potential of any future MPs.

3. Forage fish lessons for Atlantic skipjack

The MSE tool used to develop MPs was first applied for conservation of whales, long-lived, k-selected species with little variability in recruitment and year to year abundance (de Moor et al., 2011). MSEs and MPs for prey species should thus be adapted to account for the special considerations of skipjack tuna and other forage fishes, including broader ecosystem impacts and shorter lifecycles.

Before discussing those specifics, it is important to emphasize that imperfect MPs can still be highly beneficial for forage fishes and similar species. For example, de Moor et al. 2022 reviewed several challenges to MPs for forage fishes in South Africa, but still concluded that, "an MP adopted after following a best practices MSE process still provides for considerably more benefits than the conventional best assessment approach" (de Moor et al., 2022). Further, Siple et al. argued that hockey-stick rules are effective for reducing the risk and severity of collapses for forage fishes with the inclusion of "stop-loss" rules (i.e., HCRs that close the fishery below the limit reference point), even if detection of population decline is delayed. Nonetheless, in the interest of maximizing catches and minimizing risk of collapse, an MP will deliver best results when tailored to the specifics of any species as much as possible.

With the potential for significant interannual variability of forage fish biomass, MPs for these species require flexibility to respond to rapidly changing circumstances, including close attention to those factors that result in changes in growth and mortality (Siple et al., 2019). For skipjack, that could include focus on identifying and managing exceptional circumstances that may, among other actions, trigger a review of the MP ahead of schedule (de Moor et al., 2022, 2011). Measures that can maximize flexibility, such as more frequent evaluations of the MP, may also be beneficial (de Moor et al., 2022). Prior MPs for forage fishes, such as South African sardines and anchovies, have also incorporated a two-tiered system where maximum proportional decreases in TAC can shift depending on total landings in the previous year (de Moor et al., 2011). For example, the maximum decrease in TAC may be larger in a year following a boom, allowing fishers to capitalize on high abundance when available, provided that harvest rates are able to return to 'normal' the following year.

Despite measures to develop and maintain as precise and accurate an MP as possible, MPs for forage fishes must be robust to particularly high degrees of uncertainty. Overestimating abundance when abundance is low can be particularly consequential, for both forage fishes and the species that prey upon them at various life history stages, and experts have advocated for additional harvest restrictions at such points in order to mitigate the chance of collapse in the case of inaccurate stock assessments (Siple et al., 2019).

Of special importance for forage fish MPs, which skipjack tuna can benefit from, are broader ecosystem considerations for their role as an important source of prey for larger species. This supporting role can be substantial enough that previous research has argued that the economic value of forage fishes is greater as prey for other species than their value when harvested (Pikitch et al., 2012), and similar patterns may be found for skipjack. Blue marlin, which are particularly dependent on skipjack in some regions, are especially valuable due to their importance for recreational fishing economies around the world (Luckhurst, 2003; Vaske Jr. et al., 2011).

There are several approaches have been taken or advocated to incorporate ecosystem considerations for forage fishes that could be applied for skipjack. "Stop-loss" approaches have frequently been advocated for forage fishes among fisheries scientists (Pikitch et al., 2012; Pikitch, 2015; Siple et al., 2019). An example of an MP that this has been applied for is the Atlantic herring (*Clupea harengus*). Implemented in 2019, this MP incorporates many precautionary features, including management objectives that seek to achieve a SSB/SSB_{MSY} ratio of 100%, with

acceptable levels as low as 85%, alongside a 0% probability of being overfished (NEFMC, 2019). The Atlantic herring MP also allows a maximum fishing mortality of 80% of F_{MSY} so that the remaining 20% could be left for predators.

Management of skipjack tuna in the Atlantic could highly benefit from these ecosystem considerations, including precautionary measures and more direct consideration of the species' role in the tropical pelagic food web. Currently, ICCAT's conceptual management objectives for western Atlantic skipjack agreed in Resolution 22-02 call for the following:

- Greater than [__] % probability of occurring in the green quadrant of the Kobe matrix
- Less than [__] % probability of the stock falling below B_{LIM}
- Maximize overall catch levels
- Any increase or decrease in TAC between management periods should be less than [__] %

Considering the importance of skipjack to the broader pelagic ecosystem, the probability of occurring in the green quadrant should be higher than the 60% adopted in recent ICCAT MPs for bluefin and albacore. A requirement for 70% or higher probability would be better aligned with other MPs designed for forage species. Similarly, the probability of falling below B_{LIM} should be lower than the 15% adopted for bluefin in 2022, and the B_{LIM} value should potentially be higher. Other forage fishes are managed with no more than a 10% probability of breaching the limit, with some requiring even less risk. Maximum increases in TAC do not necessarily need to be overly restrictive to allow the fishery to take advantage of peak years, but only if maximum TAC decreases are also flexible and/or the fishery adopts a two-tiered approach like some prior forage fish MPs as explained above for South Africa. Furthermore, while ICCAT has already agreed to the above conceptual management objectives, additional measures, such as leaving 20% of MSY as forage for predators as was done with Atlantic herring, is best practice and should still be considered.

4. Conclusions

Traditional fisheries management, which is often hampered by tedious annual negotiations on catch and effort limits, is not ideal for a short-lived species like skipjack that has potential for higher interannual variability in regional abundance and distribution compared to other tunas. Impacts from climate change could further shift the productivity and habitable range for skipjack, and may further require well-informed but expeditious decision making under unforeseen impacts (Hou et al., 2022; Muhling et al., 2015). An MP informed by a well-executed MSE can provide a science-based decision-making framework designed to address these very challenges affecting the fishery and help ensure a healthy status for decades to come. An MP for skipjack, that maximizes catches during peaks in abundance and minimizes the chance of a crash during periods of low abundance, should draw from experiences with smaller forage fishes that have similar life histories and broader ecosystem impacts, rather than following the same approach used for large tunas.

Without specific consideration of conservative management objectives and reference points, a skipjack MP could fail to deliver sustainable management and leave other species that depend on skipjack at risk. It is also important to emphasize that these considerations are general principles and features for further research during the MSE and MP development process. More specific features of MPs vary widely across different species of forage fishes (Siple et al., 2019). Nonetheless, as general overarching principles, MPs for Atlantic skipjack should be: (i) flexible to respond to higher interannual regional variability in the stock, (ii) precautionary to account for higher uncertainty, and (iii) inclusive of broader ecosystem impacts of skipjack as an important food source for other species. These features are likely to be paramount to success of skipjack fisheries, fisheries for larger-bodied tunas and billfishes, and stability of wider tropical pelagic ecosystems, in the Atlantic and worldwide.

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