Resource Use and Management of Bigeye Tuna in the Indian Ocean: Quota Scheme in Thailand

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ABSTRACT

Bigeye tuna (*Thunnus obesus*) is economically vital in the Indian Ocean, targeted extensively for commercial fishing. Research using a blend of quantitative and qualitative Indian Ocean Tuna Commission (IOTC) data from 1950 to 2021 uncovered insights. Around 35 countries participated in Indian Ocean bigeye tuna fishing, annually yielding 21 to 162,220 t over the study period. Yet, since 1999, catches dwindled, dipping below 100,000 t from 2014 to 2021. The highest quantity of bigeye tuna captured in the Indian Ocean during this period was by longliners under the flag of Taiwan, Province of China, accounting for 24.08% of the total catch. Thailand's catch, by contrast, accounted for 14,676 t (0.30%) and came from purse seines and longlines. The Western Indian Ocean was the primary fishing ground for bigeye tuna, followed by the Eastern Indian Ocean. However, the stock of bigeye tuna is currently overfished and subject to overfishing, with 2021 catches amounting to 95,400 t, representing a 5% increase from 2020. To address this issue, an allocation based on the catch during 2012–2016 was recommended for Contracting Parties and Cooperating Non-Contracting Parties. A conceptual model has been created to ensure bigeye tuna sustainability through four processes: apply management regulations, recommend total allocation catch (TAC) for 2024–2025, control actual catch, and revisit/readjust TAC if needed. The model promotes long-term sustainability. To ensure compliance with IOTC Conservation and Management Measures for bigeye tuna, Thailand must align national law with the IOTC Resolution, notably Royal Ordinance on Fisheries B.E. 2558 (2015) and its B.E. 2560 (2017) amendment. This legal synchronization is crucial, especially for quota transfers and chartering.

Keywords: Bigeye tuna, Indian Ocean, Quota scheme, Thailand

INTRODUCTION

Thunnus obesus, commonly known as bigeye tuna, is an economically crucial species that is typically sold fresh or frozen. While tuna provides sustenance and livelihoods for many people, it is more than just a food source (WWF, 2021). Bigeye tuna is a large pelagic fish found from epi- to mesopelagic layers. This species can be found in all tropical and subtropical oceans, and is widely distributed across all marine waters between 45°N and 40°S except the Mediterranean (Froese and Pauly, 2019). Compared to other tropical tunas, the bigeye tuna has tolerance to low dissolved oxygen and prefers water temperatures that are relatively low (between 11 and 15 °C); hence, they inhabit deeper parts of the water column during the day and move upward to the surface in the nighttime (Holland *et al*., 1990; Brill, 1994). The migratory behavior of bigeye tuna is more likely to be influenced by the vertical migration patterns of their prey species rather than changes in dissolved oxygen levels alone. Additionally, this migratory behavior may also serve the purpose

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of regulating their body temperature (Thygesen *et al*., 2016). Currently, this species has been placed on the "red list" of vulnerable species by the IUCN. Additionally, there is growing evidence that the stocks of bigeye tuna worldwide have been heavily exploited and that their rate of harvest is either near or beyond maximum sustainable yield levels (IUCN, 2016; IOTC, 2022a).

In the Indian Ocean, the main fishing ground for this tuna is the western portion (Nootmorn, 2021), while the Eastern Indian Ocean is secondary; harvest is by commercial purse seines and longlines. Juvenile bigeye tuna often school near the surface, especially under floating objects, associating with yellowfin and skipjack tunas. However, as they mature, they are less likely to be found in such associations (IOTC, 2010a). The total catch of bigeye tuna in the Indian Ocean has exhibited a steady increase since the 1970s, rising from approximately 20,000 t to over 160,000 t by the late 1990s. However, since 2007, the catch has declined and was recorded at 78,438 t in 2019 (IOTC, 2022a). Throughout the period from 1970 to 2021, bigeye tuna accounted for 8% of the total catch in the Indian Ocean (IOTC, 2022a).

The Indian Ocean Tuna Commission (IOTC) is the Tuna Regional Fisheries Management Organization (tRFMO) entrusted with evaluating and overseeing the stocks of tuna and tuna-like species in the Indian Ocean, aiming to encourage collaboration among its Contracting Parties and Cooperating Non-Contracting Parties (CPC), ensure sustainable tuna stock conservation, and promote responsible fisheries development through effective management (Chumchuen and Chumchuen, 2019). The bigeye tuna fishery in the Indian Ocean involves a considerable number of countries, with around 35 nations participating. This includes 25 Contracting Parties, one Cooperating Non-Contracting Party of the IOTC, and three Non-Contracting Parties (Table 1). The management of the Indian Ocean tuna fishery, especially concerning bigeye tuna, has

Table 1. Contracting Parties, Cooperating Non-Contracting Parties, and Non-Contracting Parties of the Indian Ocean Tuna Commission (IOTC), with catch data available (+) or unavailable (-) for the period between 1950 and 2021 in the IOTC area of competence.

Contracting Parties			
Australia	+	Maldives	+
Bangladesh	+	Mauritius	+
China	+	Mozambique	+
Comoros	+	Oman	+
Eritrea	-	Pakistan	-
European Union	+	Philippines	+
France	+	Seychelles	+
India	+	Somalia	-
Indonesia	+	South Africa	+
Iran	+	Sri Lanka	+
Japan	+	Sudan	-
Kenya	+	Tanzania	+
Korea, Republic of	+	Thailand	+
Madagascar	+	United Kingdom	+
Malaysia	+	Yemen	-
Cooperating Non-Contracting Parties			
Liberia	-	Senegal	+
Non-Contracting Parties			
Guinea	+	Russia	+
Vanuatu	+		

Note: China includes China and Taiwan, Province of China reached a crucial point (Langley *et al*., 2009; IOTC, 2022a). Despite scientific advice to limit fishing effort, the fishery has undergone rapid expansion over the past two decades, resulting in increased exploitation rates for bigeye tuna and other key species. The occurrence of this trend is unsustainable and requires urgent attention from fishery managers. It is necessary to generate management information for this target stock, which can then be used to develop a sustainable and appropriate management plan that considers catch by year, by gear, and by geographic area, stock assessment and management measures.

Thailand's commitment to fisheries management is evident through its active membership in the IOTC. With a 2024 catch quota, it plays a significant role in the bigeye tuna fishery. The country benefits from its proximity to productive fishing grounds, supported by a dedicated fleet (both commercial and research vessels), well-developed infrastructure, and deep-water ports. Its leading position in processed tuna exports highlights its importance in the global market. Regular engagement with the IOTC fosters knowledge sharing and capacity building, promoting sustainable fisheries management practices.

The bigeye tuna is currently under several conservation and management measures adopted by IOTC, including Resolutions 05/01 and 14/02, as well as 15/10 on target and limit reference points and decision frameworks (IOTC, 2005; 2014a; 2015a). This study aims to examine the current status of bigeye tuna in the Indian Ocean, as well as the challenges and opportunities for its management and allocation policies in Thailand. The hypothesis for this study is that the bigeye tuna stock in the Indian Ocean is overfished and subject to overfishing, and that the current management and allocation policies are insufficient to ensure its sustainability. To achieve this, the study will analyze catch data, discuss stock status and trends, assess the legitimacy of IOTC and Thailand's management efforts, and explore allocation policies and challenges in IOTC negotiations and potential quota schemes in Thailand's future management.

MATERIALS AND METHODS

Data

This study employed a mixed-method research design (Creswell and Plano Clark, 2018), which involves the combination of quantitative and qualitative data analysis. Data on the bigeye tuna fishery, including catch by country, fishing gear, and area, from 1950 to 2021 in the IOTC area of competence, was obtained from the IOTC website (IOTC, 2023b). Furthermore, IOTC documents on status of bigeye tuna, concept on allocation regime and all resolutions related to bigeye tuna from IOTC website (IOTC, 2010a; 2011a, 2011b; 2012; 2013; 2014b; 2015b; 2016; 2017; 2018; 2019a; 2020; 2021a; 2022a; 2022b; 2023a) were reviewed, as was Department of Fisheries policy for analysis on the quota scheme in Thailand (FAO, 2017).

Data analyses

The study analyzed the catch data of the bigeye tuna fishery in the Indian Ocean between 1950 and 2016. Descriptive statistics and trends in annual catch were used to describe the fishery's development. The spatial distribution of catches in the Indian Ocean by gear types was visualized using ArcView software. The study examined trends in catches of bigeye tuna in the Indian Ocean between 1950 and 2016, analyzing them by gear type and country. Spearman's rank correlation was used to detect monotonic trends in the time series of catch data. Monotonic trends are consistent patterns in data that increase or decrease over time without significant fluctuations in the opposite direction. Spearman's rank correlation was used to detect such trends in catch data. The study identified significant turning points between two sets of years using the maximum weight rank (r_S^2) method (Conti *et al*., 2012) to understand notable shifts in catch data. Furthermore, the study also examined any discontinuity between the two trends by identifying the most significant turning point between the two sets of years. This turning point was calculated using the maximum weight rank (r_S^2) (Conti *et al*., 2012).

$$r_s^2 = \frac{(n_1 r_1^2 + n_2 r_2^2)}{n}$$

where n, n_1 and n_2 are total years in consideration and number of years in the first and second sub-series, respectively, while r_1 and r_2 are Spearman's rank correlation for the first and second sub-series.

The catch-based allocation schemes, by country, were analyzed under three options, i.e., option 1: catch 2000–2016, option 2: 2012–2016, option 3: best 5 years averaged from within the period 1950–2016. These options are part of the IOTC's agreement for sustainable management of tuna resources in the Indian Ocean (IOTC, 2023a). The differences in mean catches among the options were tested by one-way ANOVA at alpha = 0.05.

This study applied Soft System Methodology (SSM) (Checkland, 1999; Checkland and Poulter, 2006; Nurani *et al*., 2018) to analyze the management and allocation policies for bigeye tuna in Thailand, appropriated in the Indian Ocean. It identified stakeholders, their concerns, objectives, as well as system constraints and opportunities. Utilizing a detailed portrayal of the fishery and conceptual models, the study aimed to gain a comprehensive understanding of the problems and propose potential solutions to enhance the management and allocation policies for bigeye tuna in the region.

RESULTS AND DISCUSSION

Catch of bigeye tuna in the Indian Ocean

The time series of total catch from 1950 to 2021 exhibited a significant range, fluctuating between 21 and 162,220 t. The catch was initially contributed by two countries in 1950 and increased to 32 countries by the year 2021. The catch declined since 1999 to less than 100,000 t from 2014 to 2021. Figure 1 displays the bigeye tuna catch by the main CPCs. The majority of the catch was attributed to vessels flagged to Taiwan, Province of China (24.08%), Indonesia (17.34%), Japan (15.89%), other countries (13.29%), EU (12.04%), Korea Republic (8.56%), Seychelles (4.77%), China (2.07%), and Sri Lanka (1.97%) during the period from 1950 to 2021. Thailand's catch accounted for 14,676 t between 2000–2015 (0.30% of the total catch between 1950 and 2021). IOTC (2022b) reported that Indonesia (23.7%) followed by Taiwan, Province of China (15.4%) and Seychelles (15.3%) and the 30 other fleets catching bigeye tuna contributed 45.8% of the total catch between 2017 and 2021 (IOTC, 2022a). The majority of vessels have become part of the Indonesian fleet in recent years; meanwhile, Japan's catch decreased by more than 50% of catch since 2009.

The bigeye tuna fishery in the Indian Ocean underwent development from 1950 to 2021 with the use of various fishing gears, such as gillnet, handline, longline, bait boat, purse seine, and other small-scale fishing gears. Longline fishing gear was the most commonly used gear, accounting for 70.90% of the total catch, followed by purse seine (20.70%) and handline (5.50%). The remaining catches taken with other gears contributed to 2.9% of the total catch (Figure 2). Moreover, Thailand's catch reported for 2000–2015 was from purse seine (83.05%), distance longline (16.87%) and surface longline (0.08%). The IOTC reported that most of the harvest (mean annual catch 2017–2021) of bigeye tuna was taken by purse seine (41.7%), followed by longline (37%) and hand line (13.5%). The remainder, taken by other gears, contributed to 7.8% of the total catch (IOTC, 2022a). The predominant fishery has changed from longline to purse seine during recent years; the purse seines are mainly used with drift aggregating devices, followed by free-school and other purse seine practices (IOTC, 2022a). Fish aggregating devices (FAD) effectively increase the catch proportion of juvenile bigeye tuna as well as the aggregation of fish.

Bigeye tuna are distributed widely across the tropical zone of the Indian Ocean, with the main catch occurring in the western region, followed by the eastern region (as shown in Figure 3a). The fishing grounds for purse seine are mainly located off the east coast of Somalia, the Bay of Bengal, and the west coast of Sumatra (as shown in Figure 3b), while longline catch is distributed across the entire Indian Ocean, with a concentration in the

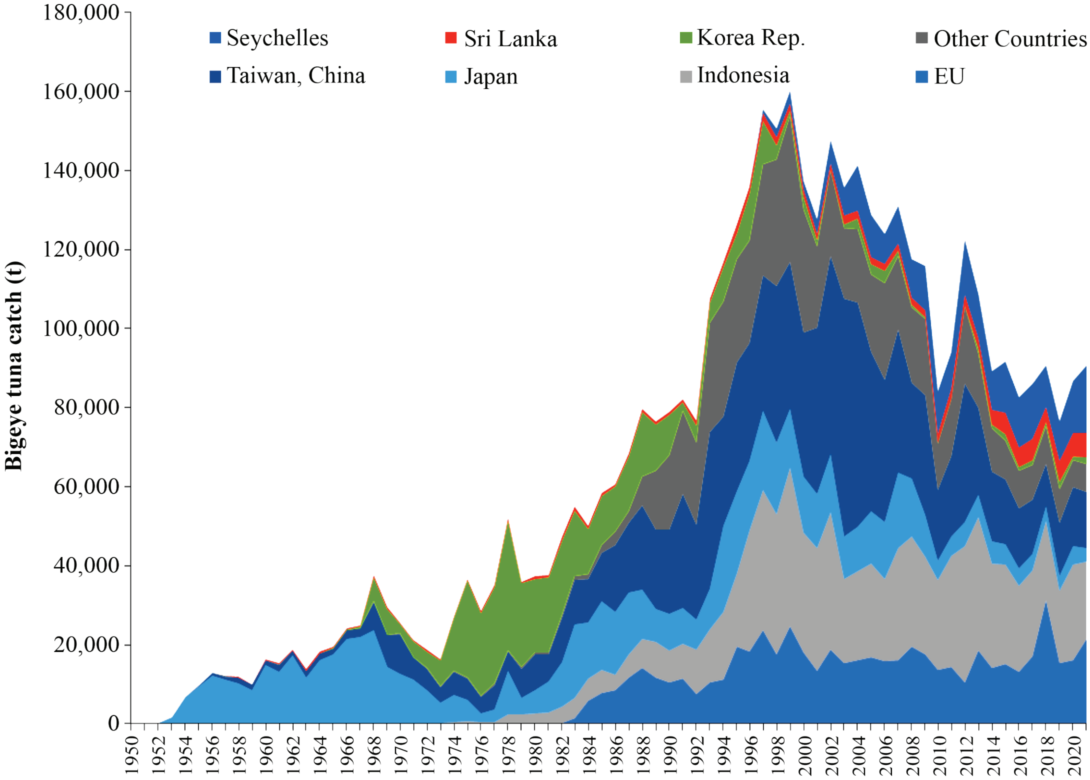

Figure 1. Annual time series of cumulative catches (t) for bigeye tuna in the Indian Ocean during 1950–2021 by the main Contracting Parties and Cooperating Non-Contracting Parties.

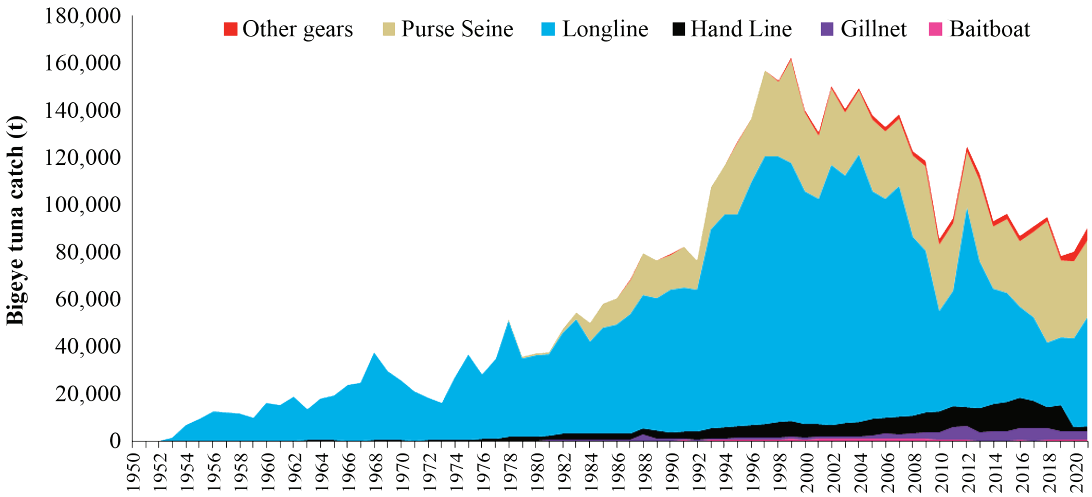

Figure 2. Annual time series of catches (t) by fishing gears for bigeye tuna during 1950–2021.

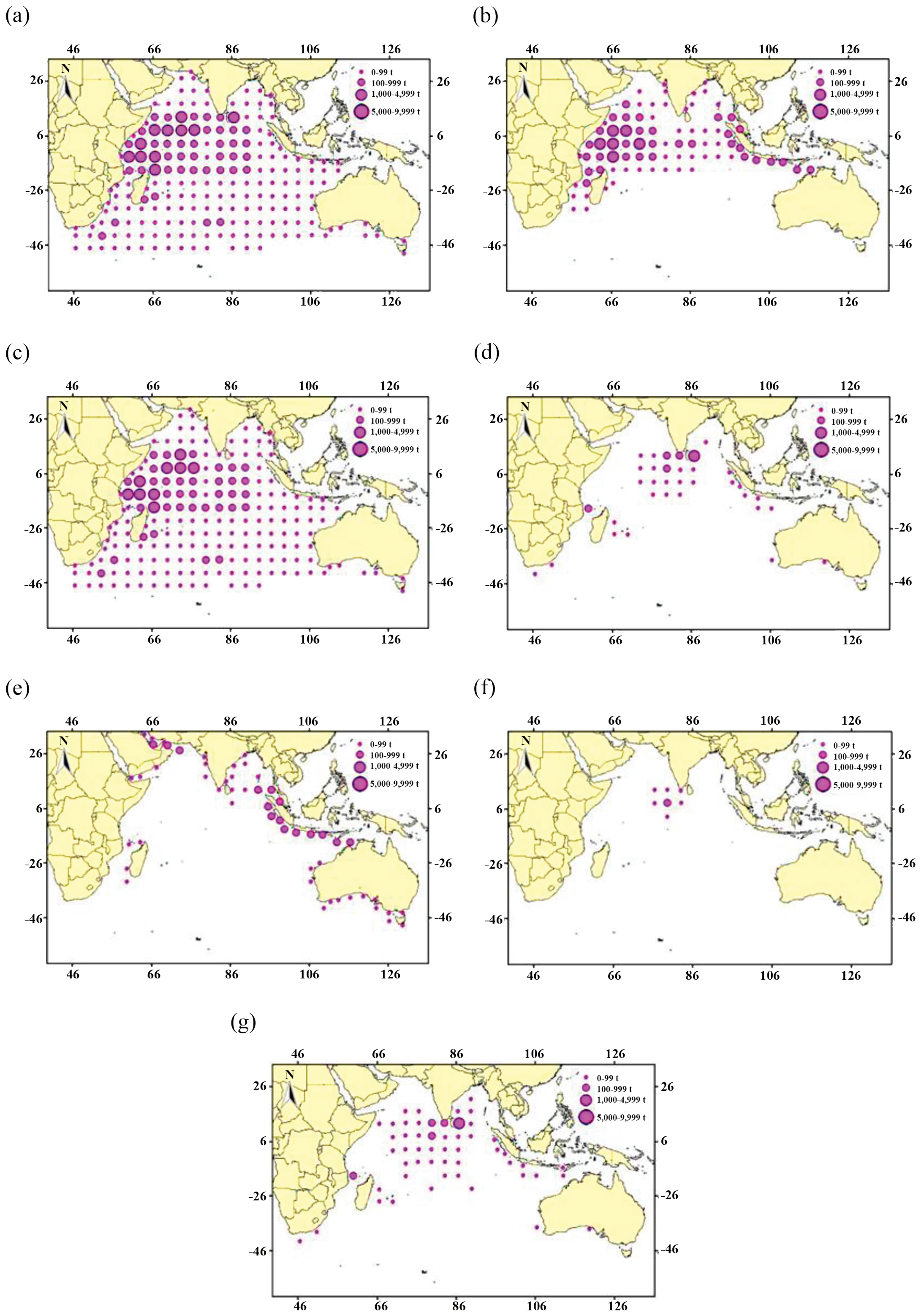

Figure 3. Catch distribution of bigeye tuna by main fishing gears in the Indian Ocean during 2010–2020: all gears (a), purse seine (b), longline (c), hand line (d), gillnet (e), bait boat (f) and other gears (g).

western region and around the Maldives (as shown in Figure 3c). Catch by hand line is distributed off the middle Indian Ocean, the west coast of Sumatra, and Mozambique Channel (Figure 3d). The distributions of catch by gillnet, bait boat and other gears are presented in Figures 3e, 3f, and 3g. From 2000 to 2006, Thai tuna longliners operated in four zones in the Indian Ocean: the Bay of Bengal, the west coast of Indonesia, Somalia and the Seychelles, and the southern part of the Indian Ocean (Nootmorn *et al*., 2010b). In addition, six Thai industrial tuna purse seine fishing vessels used the fishing ground of the tropical part of the Indian Ocean, especially the western Indian Ocean (Nootmorn *et al*., 2010a).

Status of the bigeye tuna stock in the Indian Ocean

The IOTC conducted stock assessments for bigeye tuna within its area of competence in the Indian Ocean between 2010 and 2022 (IOTC, 2010a; 2011b; 2012; 2013; 2014b; 2015b; 2016; 2017; 2018; 2019a; 2020; 2021a; 2022a), as presented in Table 2. The primary model used for the bigeye tuna stock was Stock Synthesis (SS3), which was selected to provide scientific advice. From 2010 to 2018, the stock was likely not overfished, and overfishing was unlikely. Nonetheless, it appears that the bigeye tuna stock in the IOTC's area of competence was likely approaching its maximum sustainable yield (MSY) during the period from 2010 to 2022. This situation raised concerns about potential overfishing, as uncertainties persisted and a noticeable decrease in catch rates was continuously observed (highlighted by the green shading in Table 2). To ensure sustainable management, it was recommended that catches of bigeye tuna in the Indian Ocean be maintained at or below the MSY levels, which decreased from 114,000 t in 2010 to 87,000 t in 2018. From 2019 to 2022, new stock assessments (JABBA, SS3, and SCAS) were conducted to update the bigeye tuna stock status determined in 2016. The assessment of the stock status was conducted using the SS3 model framework, which incorporated 18 different model configurations. These configurations were strategically devised to encompass various sources of uncertainty, including the stock recruitment relationship, the impact of tagging data, and the selectivity patterns of longline fleets (IOTC, 2019a). The portion of the bigeye tuna stock subject to overfishing was determined to be 34.60% in 2019, 34.60% in 2020 and 79.00% in 2021 (red in Table 2). Considering the collective evidence in this study (as of 2022), it was concluded that the bigeye tuna stock had entered a state of overfishing and was also classified as overfished,

Table 2. Status of bigeye tuna in the Indian Ocean from 2010 to 2022.

Year		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Stock overfished	Stock subject to overfishing										34.60%	34.60%	79.00%
	Stock not subject to over fishing										0%	0%	2%
Stock not overfished	Stock subject to overfishing										38.20%	38.20%	17.00%
	Stock not subject to over fishing										27.20%	27.20%	2.00%
Catch estimate (t)		102,200	87,420	115,793	109,343	100,231	92,736	86,586	90,050	93,515	73,165	83,498	94,803
MSY (t)		114,000	114,000	132,000	132,000	132,000	104,000	104,000	104,000	87,000	87,000	87,000	96,000
Assessment models		SS3	SS3	SS3	SS3	SS3	SS3	SS3	SS3	SS3	SS3	SS3	SS3
			ASPM	ASPM						JABBA	JABBA	JABBA	SCAS

Note: Green = stock not subject to overfishing; Orange = stock subject to overfishing; Yellow = stock not subject to overfishing; Red = stock subject to overfishing as indicated in Table 2. The reported of bigeye tuna catches in 2021 totaled 95,400 t, a 5% increase from 2020 (ISSF, 2023). Between 2017 and 2021, the primary fishing method utilized was longlining, accounting for 35% of the total. However, the catches attributed to this method underwent a significant decline following a peak in 2004. This decrease was mainly a result of vessels shifting away from their usual fishing areas to evade piracy threats. Notably, there was a notable surge in longline catches in 2012, which was followed by subsequent declines. In contrast, purse seine vessels contributed to 43% of the catches on average during the 2017–2021 period, with their catch levels remaining relatively stable since the year 2000. The stock was determined to be overfished and subject to overfishing (orange zone of the Kobe plot) (ISSF, 2023). The other tRFMO reported bigeye tuna stock, namely that of the Eastern Pacific Ocean, was determined not to be overfished, but subject to overfishing (yellow zone of the Kobe plot) (ISSF, 2023). The MSY for bigeye tuna in the Eastern Pacific Ocean was determined to be 86,800 t, with a range of 72,200 t to 106,400 t, but it has been considerably reduced through the harvest of small individuals. Conversely, the Western Pacific Ocean's bigeye tuna stock was determined to not be overfished and not subject to overfishing, with an MSY of 140,700 t that has been reduced to less than half its level prior to 1970 through the harvest of small individuals. In the Atlantic Ocean, the bigeye tuna stock is determined to be overfished and subject to overfishing, with an MSY of 86,800 t that has also been reduced considerably through the harvest of small individuals. Although the current catches in the Atlantic Ocean are below the MSY at 46,000 t, the situation for bigeye tuna in the Indian Ocean is comparatively poor. In this regard, IOTC agreed on a bigeye tuna Management Procedure (IOTC Resolution 22/03); it should be noted that the stock assessment is not used to provide a recommendation on the Total Allocation Catch (TAC) (IOTC, 2022a).

Trends of the bigeye tuna by country (Figure 4a), based on the two phases of the catch data series revealed a trend inversion, i.e., opposite sign of rank correlation (r_s) for the two sub-series, for South Korea and Taiwan, Province of China, as well as other countries. After increases in bigeye tuna catch for a certain period of years (1970–2003), the catch from South Korea started to decline in 1979; meanwhile, declines were observed in the early 2000s in Taiwan and other countries. Positive and then non-significant trends, which could imply full development of the fisheries, were found in China and Indonesia. A decline after full redevelopment of the bigeye tuna fishery was found in both France and Japan; meanwhile, continuous development of the fishery was found in the European Union, Sri Lanka and Seychelles. In terms of fishing gear types (Figure 4b), two patterns were detected: 1) trend inversion, observed from bait boats and longlines, where the reverse trend was observed in the early 2000s for both fishing gears; and 2) a trend of continuous development was observed for gillnet, hand line, purse seine, and other gears. Continuous increases of the catch by gillnet and hand line were found from 1950–2019 (70 years), meanwhile increases from 1978–2019 (42 years) occurred for purse seine and other gears.

While SS3 is a comprehensive method for assessing the status of bigeye tuna, additional statistical analyses like Spearman's rank correlation and maximum weight rank are still important. These methods provide insights into the trends and complex relationships within the data. They can complement the SS3 model's results by examining specific aspects of the data or by adding further evidence to support the findings. Moreover, statistical analyses are particularly valuable for detecting trends and relationships in the data, especially when dealing with large datasets. By using both the SS3 model and statistical analyses, researchers can have a more comprehensive understanding of the stock status and ensure accuracy.

Allocation scheme for bigeye tuna in the Indian Ocean

The Indian Ocean Tuna Commission (IOTC) was established in 1995, and although its founding agreement in 1993 did not explicitly refer to allocation, discussions on quota allocations began in 2009 in response to a performance review of the Commission. The review recommended that the IOTC examine the potential advantages and

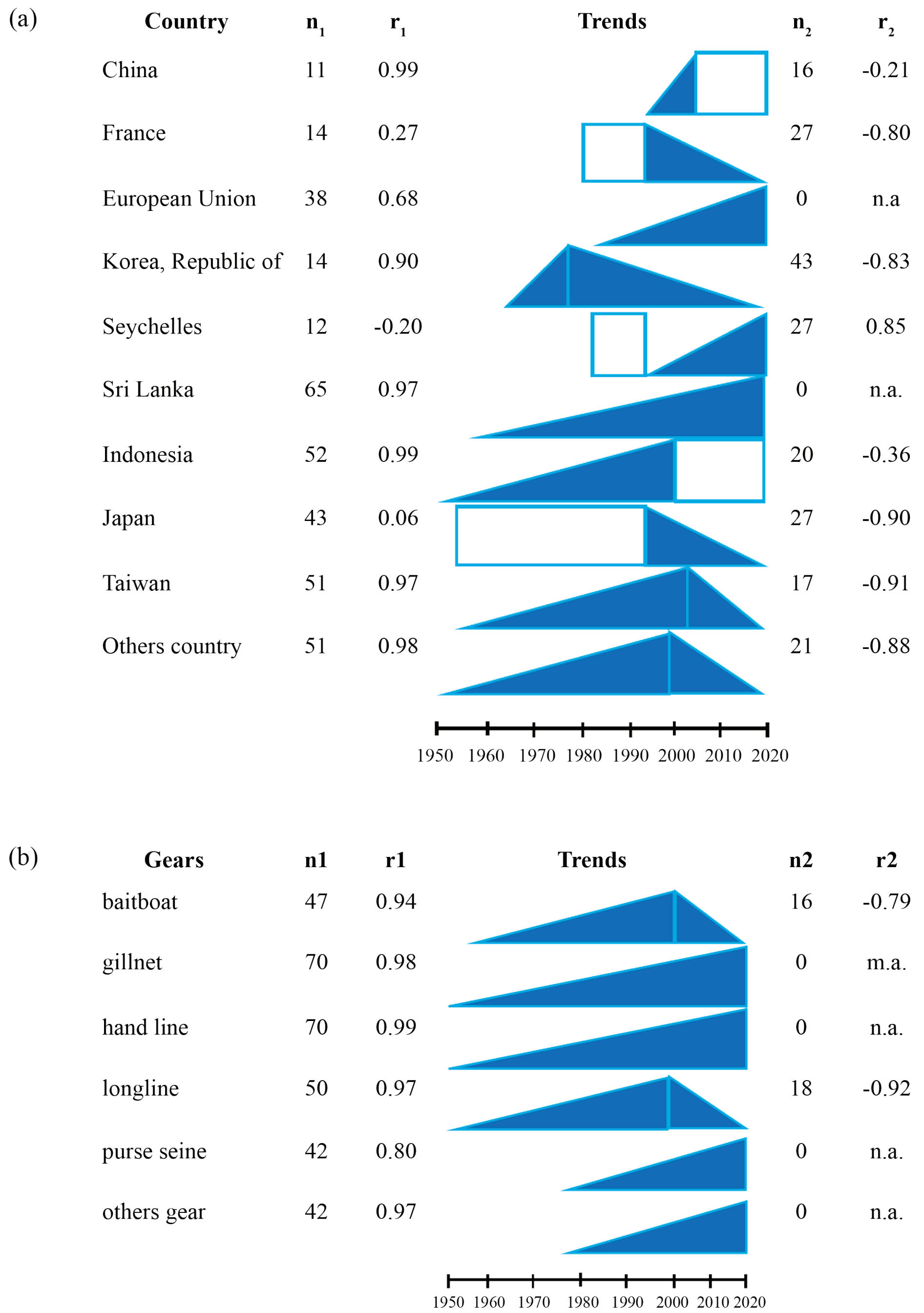

Figure 4. Patterns of bigeye tuna catches in the Indian Ocean from 1950 to 2020. Monotonic trends were identified by Spearman's rank correlation. Proceeding from the left side of the figure, the analysis encompasses various aspects, including countries (Figure 4a) and fishing gears (Figure 4b), the number of years contained within the initial sub-series (n_1), Spearman's correlation coefficient for the first sub-series (r_1), a depiction of the observed trend, the number of years encompassed by the subsequent sub-series (n_2), and the corresponding Spearman's correlation coefficient for the second sub-series (r_2). Trends of significance are denoted by shaded blue areas, while non-significant trends are represented by white shapes.

disadvantages of implementing an allocation system (IOTC, 2009; Serdy, 2010). The quota allocation process was initiated by the IOTC Working Party on Fishing Capacity and Resolution 10/01. This resolution created an action plan on allocation, which involved the establishment of a technical committee to "discuss allocation criteria for the management of the tuna resources of the Indian Ocean and recommend an allocation quota system or any other relevant measures." Additionally, the resolution called for the adoption of "an allocation quota system or any other relevant measure for the yellowfin and bigeye tunas at its plenary session in 2012" (IOTC, 2010b; Seto *et al*., 2021) (Figure 5). From 2011 to the present (2023), the IOTC Technical Committee on Allocation Criteria (TCAC) has held eleven meetings. Throughout this period, multiple suggestions detailing potential frameworks for quota allocation systems have been put forth by members of the IOTC. Starting in 2016, these proposals have predominantly aligned with two prevailing viewpoints that have shaped the negotiation process: the G16, representing a coalition of like-minded coastal states within the IOTC, and the European Union (EU). These proposals have demonstrated a consensus emerging within the TCAC regarding the foundational structure of a quota allocation system. This structure encompasses essential components such as guiding principles, criteria for allocation (encompassing baseline allocation, coastal state allocation, and catch-based allocation), as well as indicators, a formulated methodology for determining allocations, mechanisms for adjusting allocations through correction factors, and a set of operational rules governing the utilization of allocated quotas–such as the potential for quota transfers (IOTC, 2011a; Seto *et al*., 2021). Recent proposals forwarded by both the G16 and the EU to the Commission exhibit shared fundamental elements, yet they continue to diverge on critical matters of significance.

In 2019, both the G16 (IOTC, 2019b) and EU (IOTC, 2019c) sponsored proposals for quota allocation within the IOTC, which included a baseline allocation for all member states, consideration of developing states and SIDS, balance between the rights of Coastal States and DWFNs, and penalties for non-compliance. Nonetheless, notable disparities emerged between these proposals, particularly concerning the methodologies employed for allocation calculations. A significant point of contention remained unresolved, revolving around whether historical catches that occurred within Exclusive Economic Zones (EEZs) should be attributed to the respective coastal state or the flag state when determining quota allocations. The G16 recommended that the entire historical catch be attributed to the coastal state (100%), while the EU's proposition involved attributing 90% of the historical catch to the flag state and gradually transferring the remaining 10% to the coastal state

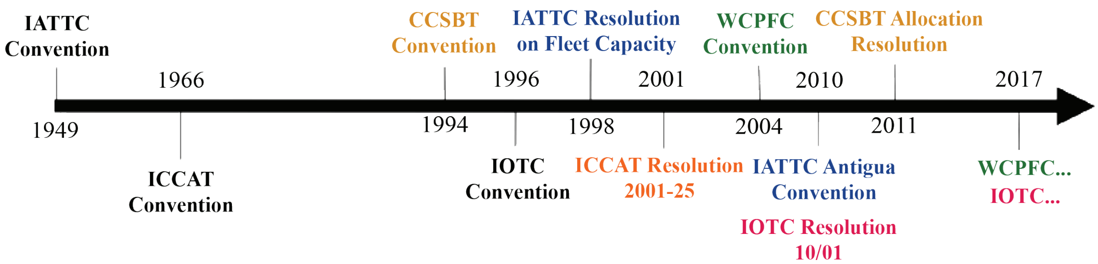

Figure 5. The development of allocation policies within regional fisheries management organizations (RFMOs, by color) has taken place over time. WCPFC and IOTC are actively engaged in policymaking processes related to allocation (Seto *et al*., 2021).

Note: Abbreviations refer to the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), and the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (WCPFC).

over a ten-year period (Sinan and Bailey, 2020). Simulations of the two proposals were presented at the TCAC meeting in 2023, but did not significantly advance negotiations (Seto *et al*., 2021). Therefore, IOTC is the most recent tRFMO to embark upon establishing its allocation framework (Figure 5). The IOTC currently bounds and defines resources on a species-by-species basis, with the TCAC for bigeye tuna being applied as an Olympic race until the limit is reached and adjusted proportionally based on existing catch levels for yellowfin tuna, as outlined in Resolution 21/01 on an interim plan for rebuilding the Indian Ocean yellowfin tuna stock (IOTC, 2021b). This resolution has increased the fishing capacity of industrial purse seines to catch juvenile yellowfin tuna and bigeye tuna with drifting FAD. This implies that a particular regulation, which negatively affects juvenile yellowfin and bigeye tunas, and the catch limits imposed on bigeye tuna, have resulted in varying consequences for Hawaii longliners within the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). The WCPFC has implemented a catch limit for bigeye tuna in the region, which has reduced the catch quotas for longliners from Hawaii. In contrast, the IATTC has not implemented such a limit, which has led to an increase in the catch of bigeye tuna by Hawaii longliners in that region. This has created an unfair playing field for Hawaii longliners who operate in the two regions (Ayers *et al*., 2018).

Regarding the allocation regime draft of the IOTC, the allocation criteria for the catch-based allocations will be established under the allocation structure. Each eligible CPC will receive a catch-based allocation, which will consist of a share of TAC. The TAC is established based on historical catches of each CPC, which are determined using criteria outlined in the allocation structure. The historical catch data used to determine a CPC's catch-based allocation for a specific stock shall be based on the best available nominal catch data provided by each CPC, and may be re-estimated through a process approved by the Commission for each stock. The data are then averaged over certain periods, depending on the stock in question. For tropical tuna stocks, there are three options for catch averaging periods, namely option 1: 2000–2016, option 2: 2012–2016, or option 3: best 5 years averaged from within the period 1950–2016 (IOTC, 2023b). Table 3 shows the catch-based allocations for each of the three options, but the results indicate that there is no significant difference between them ($p>0.05$). The total catch-based allocations for options 1 to 3 are 113,475, 99,904, and 198,907 t, respectively. Considering that the estimated MSY in 2016 was 104,000 t, the appropriate option for applying the catch-based allocation in the Indian Ocean competence would be option 2, which includes 24 CPCs with historical catch, except Bangladesh and Kenya. Thailand would gain at least 218 t from the catch-based allocation under option 2, which is less than the allocations under options 1 (917 t) and 3 (2,524 t). However, the process of establishing the allocation regime in the Indian Ocean will be subject to negotiation. TAC12 is scheduled to meet in October 2023.

The allocation regime aims to manage the socio-economic impacts on all CPCs resulting from the shift in current fishing patterns due to its implementation. This will be achieved by implementing allocations in a timely and step-wise manner and by allowing temporary transfer of allocations between CPCs (IOTC, 2023b). The allocation transfers and use will be guided by principles and criteria, and rules for implementation have been included in the allocation regime.

Management

Figure 6 presents a conceptual model that is constructed based on formulated root definitions (RDs). The conceptual model aims to ensure the sustainability of bigeye tuna resources and consists of four key processes through which problems related to these resources can be addressed by the IOTC. Firstly, the Management Procedure (MP) for bigeye tuna is employed as a mechanism for managing and regulating the species. This process involves implementing specific measures and guidelines to control and monitor the harvesting of bigeye tuna. Secondly, the conceptual model includes the recommendation of a TAC for the years 2024–2025. This recommended TAC serves as a quantitative limit on the amount of bigeye

Table 3. Estimates of catch-based allocation (t) of bigeye tuna in the Indian Ocean based on three options.

CPC	Option 1[a]	Option 2[a]	Option 3[a]
Australia	141	100	439
Bangladesh	-	-	0
China	4,398	3,879	7,604
Comoros	252	306	403
EU	16,212	14,693	21,797
France	1,073	1,422	2,340
India	1,788	24	4,142
Indonesia	26,968	28,325	36,099
Iran Islamic rep.	1,241	2,216	2,320
Japan	10,188	5,352	21,854
Kenya	24	-	167
Korea rep.	1,362	1,102	24,886
Madagascar	72	99	120
Malaysia	414	63	941
Maldives	1,317	2,103	2,224
Mauritius	167	527	1,110
Mozambique	673	568	1,048
Oman	78	78	78
Philippines	1,129	1,198	1,920
Seychelles	9,420	12,144	12,461
South Africa	138	140	242
Sri Lanka	2,411	3,797	3,806
Taiwan, Province of China	32,736	21,232	49,888
Tanzania	350	314	488
Thailand	917	218	2,524
United Kingdom	7	3	7
Total	113,475	99,904	198,907

Note: [a] is not significantly different.

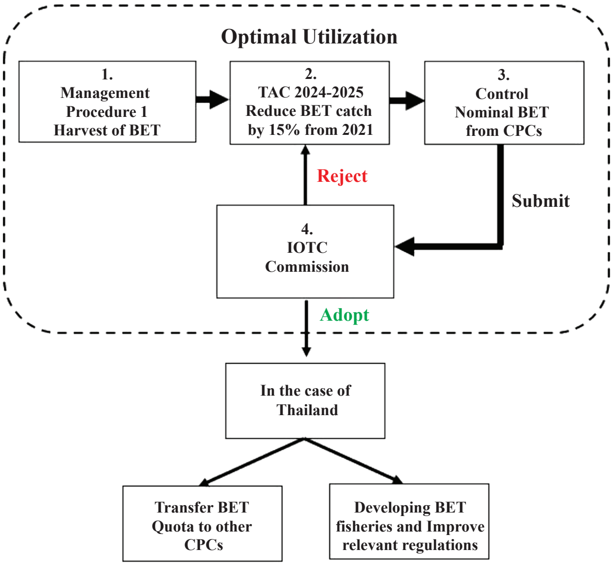

Figure 6. Conceptual model ensuring the sustainability of bigeye tuna.
Note: BET = bigeye tuna

tuna that can be legally caught during the specified period. Thirdly, the control of the nominal catch of bigeye tuna is another important process within the conceptual model. This involves monitoring and regulating the actual catch of bigeye tuna to ensure that it remains within sustainable limits and does not exceed the recommended TAC. Lastly, if the IOTC does not adopt the recommended TAC for 2024–2025, the conceptual model proposes a process of revisiting and potentially readjusting the TAC. This serves as a safeguard to ensure that appropriate measures are in place to manage and maintain the sustainability of bigeye tuna resources. Overall, the conceptual model outlines these four interconnected processes as key elements in addressing issues related to bigeye tuna resources and promoting their long-term sustainability.

IOTC has implemented Resolution 22/03, known as MP1 Harvest, as a Management Procedure (MP) for bigeye tuna. Its goal is to maintain the stock within the green zone of the Kobe plot, optimize the fishery's average catch, and minimize variation in the TAC between management periods. The recommended TAC for 2024–2025 is set at 15% below the 2021 catch of 94,803 t. The IOTC Commission will adopt the TAC for 2024 and 2025 based on the MP's outcome in 2023. The first application of the TAC derived from the MP will occur in 2024 and 2025. Subsequently, the TAC will be enforced for three consecutive years following the year it is established by the IOTC Commission (IOTC, 2022a).

Regarding the allocation of the TAC for member countries with developing bigeye tuna fisheries in the Indian Ocean, including Thailand, there is a transfer element incorporated into the allocation regime. This involves specific rules and reporting procedures for the transfer allocation process (IOTC, 2023b). Additionally, Resolution 19/07 focuses on vessel chartering within the IOTC's jurisdiction and provides increased fishing opportunities for member countries, including Thailand (IOTC, 2019d). Thailand has its own regulations to support these measures, such as the Royal Ordinance on Fisheries B.E. 2558 (2015) and its amendment B.E. 2560 (2017). Sections 47 (Thailand's international obligations), 48 (license to fish outside Thai waters), 39 (any person requesting a license), and 49 (license for fishing outside Thailand) are particularly relevant in facilitating quota transfers and chartering vessels (IOTC, 2015a; 2017).

IOTC has not implemented specific measures for bigeye tuna alone. Resolution 21/01 focuses on yellowfin tuna, urging countries to reduce supply vessels by 31 December, 2022. Resolution 19/05 bans discards for purse seine vessels targeting bigeye tuna, skipjack, and yellowfin tuna. Resolution 19/02 outlines FAD management, including limits on buoys and encouraging non-entangling and biodegradable FADs. Traditional FADs must be removed from 1 January 2022. Resolution 16/10 promotes measure implementation, and Resolution 17/02 establishes the Working Party on the Implementation of Conservation and Management Measures (WPICMM) (IOTC, 2022b; ISSF, 2023).

Since becoming a member of the IOTC in 1997, Thailand is expected to adhere to the resolutions for the conservation of bigeye tuna as set by the IOTC. The Royal Ordinance on Fisheries B.E. 2558 (2015) and its amendment B.E. 2560 (2017) are regulations and laws that support Thailand's compliance with the requirements of the IOTC. Under Section 6 of the Royal Ordinance, the Minister of Agriculture and Cooperatives is responsible for its execution and has the authority to issue Ministerial Regulations that establish duties, fees, and matters related to the implementation of the Royal Ordinance. These regulations take effect upon their publication in the Government Gazette. Section 47 of the Royal Ordinance aims to ensure that Thailand fulfills its international obligations regarding the conservation and management of aquatic resources. This includes cooperation with other states, private agencies, and international organizations in line with the objectives of the Royal Ordinance. Furthermore, Section 49 states that license holders for fishing outside Thai waters must comply not only with the Royal Ordinance but also with the laws, rules, and conservation and fisheries management standards of coastal states or international organizations in whose jurisdiction or control they operate (FAO, 2017). These legal provisions demonstrate Thailand's commitment to meeting its international obligations, including those related to the conservation and management of bigeye tuna, as required by the IOTC.

CONCLUSION

The study provides key findings on the utilization and management of bigeye tuna in the Indian Ocean, including catch data, stock status, allocation scheme, and management approaches. Thirty-five countries participated in the fishery, with annual catch levels ranging from 21 to 162,220 t during 1950–2021. However, catches have declined since 2014, dropping below 100,000 t. Taiwan, Province of China, predominantly utilized longline fishing for bigeye tuna in the Indian Ocean. The stock of bigeye tuna was determined to be overfished and subject to overfishing, with a catch of 95,400 t in 2021. The study recommends the application of catch-based allocation option 2 for the allocation regime. A conceptual model was developed to ensure sustainability through management procedure regulation, recommended total allowable catch (TAC), control of actual catch, and revisiting TAC if necessary. Thailand is advised to incorporate IOTC Resolution, quota transfer, and chartering regulations into national legislation (Royal Ordinance on Fisheries B.E. 2558 (2015) and amendment B.E. 2560 (2017)) to fully comply with IOTC Conservation and Management Measures for bigeye tuna. The study's findings can guide fisheries management efforts for the sustainable and responsible exploitation of bigeye tuna in the Indian Ocean.

The study provides crucial insights for bigeye tuna management in the Indian Ocean and fisheries efforts in Thailand. Key recommendations include adopting catch-based allocation, adhering to IOTC measures, and collaborating with researchers for conservation. Incorporating IOTC resolutions into national legislation is vital for sustainable exploitation. Continuous research and implementation will support the long-term health of Thailand's resources and contribute to responsible fishing practices in the Indian Ocean.

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