Development of Albacore Tuna Fishery and Estimation of Allowable Biological Catch for Resource Management in the Indian Ocean

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Albacore tuna, or ALB for short, is a highly migratory fish distributed in all oceans and is economically important in the white meat tuna supply chain. Reports have indicated that the global annual ALB catch has increased since 1950s. For ALB resource management, a six-stock model is considered in six regions, *i.e.*, two in the Pacific Ocean, two in the Atlantic Ocean, one in the Mediterranean Sea, and one in the Indian Ocean. The Indian Ocean Tuna Commission (IOTC) is the tuna regional fisheries management organization (tRFMO) in the Indian Ocean, of which four Southeast Asian countries, namely: Indonesia, Malaysia, Philippines, and Thailand are among the Contracting Parties. Although several methods of stock assessment were adopted to estimate the maximum sustainable yield (MSY), there was still high uncertainty in the results due to the limited biological information on ALB stock in the Indian Ocean. Besides MSY, the allowable biological catch (ABC) could also be considered as an effective method for ALB resource management in the Indian Ocean. This article, therefore, describes the ALB fishery in the Indian Ocean, as well as compares the values of the calculated ABC and the MSY estimated by the IOTC. The data on ALB fishery in the Indian Ocean had been accessed from the IOTC website, and the ABC calculation rule 2-2 was performed using a series of ALB catch statistics.

Albacore tuna or ALB (*Thunnus alalunga* (Bonnaterre, 1788)) is one of the most economically important species (**Figure 1**), particularly in Thailand, and is utilized mainly as raw materials for the white meat tuna products (Chumchuen and Songphatkaew, 2019). From 2011 to 2015, Thailand imported more than 30,000 t/year of ALB, mostly captured from the Indian Ocean and used for the country's tuna processing industry. The country has been considered as one of world's largest exporters of tuna products with exports valued at more than US$ 20 billion annually, contributing more than 40 percent to the global export volume (NFI, 2016).

ALB is an oceanic scombrid species distributed in tropical and temperate waters of all oceans as well as in the Mediterranean Sea, extending between 50° N and 40° S, but not at the surface between 10° N and 10° S (**Figure 2**). Their depth distribution is from the surface down to at least 380 m in the Pacific Ocean and believed to occur as deep as 600 m in the Atlantic Ocean. ALB migrates over great distances in schools of single species and appears to form separate groups at different stages of its life cycle. Their schools may be associated with floating objects, including sargassum seaweeds (Collette and Nauen, 1983), but association with floating objects is not common (ISSF, 2019).

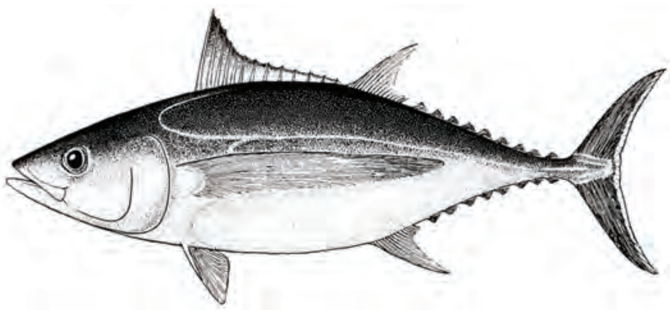

Figure 1. Albacore tuna *Thunnus alalunga* (Bonnaterre, 1788)
Source: Collette and Nauen (1983)

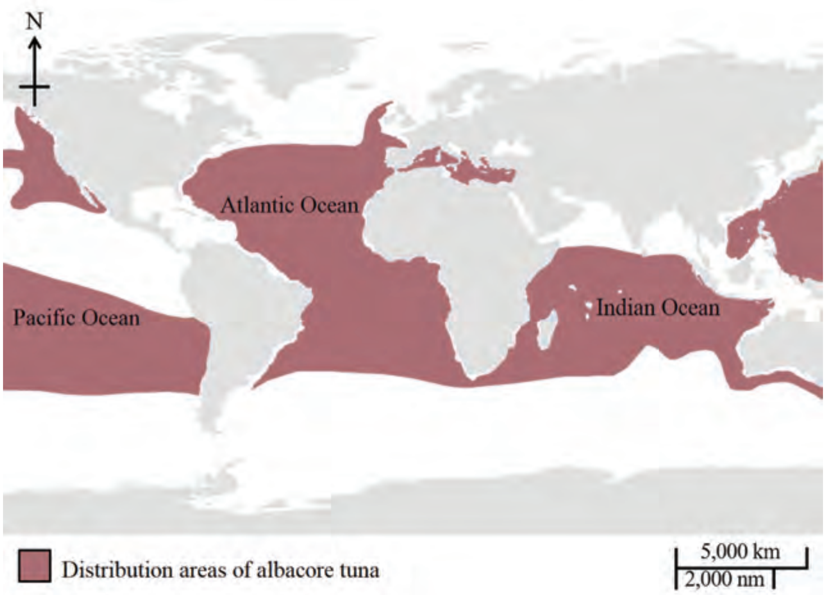

Figure 2. Geographical distribution of albacore tuna
(Modified from FAO, 2019a)

ALB is a pelagic predator feeding on fishes, crustaceans, and squids (Consoli *et al*., 2008). Mature ALB spawn in spring and summer in the tropical and sub-tropical waters. In one spawning season, a 20-kg female may produce between two and three million eggs, released at least in two batches. The sex ratio in catches is about 1:1 for immature specimens, but males predominate among mature fishes possibly due to differential mortality of sexes and differential growth rate after maturity (Collette and Nauen, 1983).

Production from Albacore Tuna Fishery

The main fishing grounds of ALB fishery are in temperate waters, and the basic types of fishing gears include longline, trolling line, pole and line, and purse seine. Small-sized individuals of ALB are mainly caught by trolling line, pole and line, and purse seine, while large-sized individuals mainly caught by longline (Collette and Nauen, 1983). Based on the available information on the global annual ALB catch between 1950 and 2017, the annual catch was about 100,000 t in early 1950s and reached 200,000 t in late 1960s. Between 1970s and 2000s, the annual catch fluctuated and ranged about 170,000 - 260,000 t (**Figure 3**). Recently, the annual catch was more than 200,000 t during 2013-2017 (FAO, 2019a; ISSF, 2019).

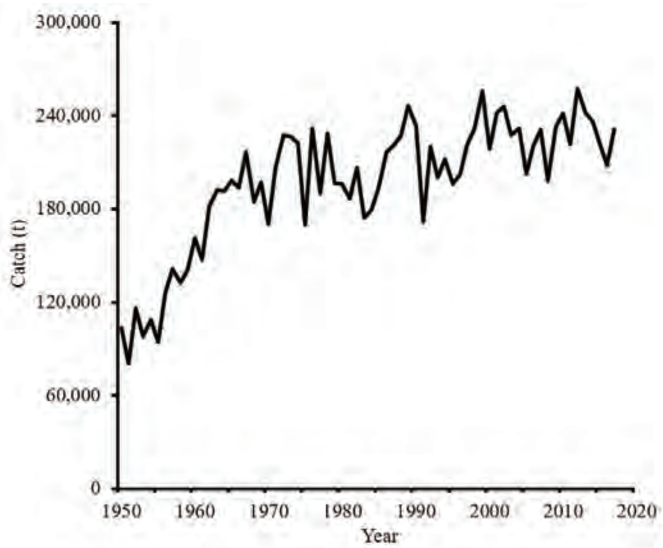

Figure 3. Global albacore tuna catch (t) between 1950 and 2017 (1950-2016 data from FAO (2019a) and 2017 data from ISSF (2019))

Due to the continued global exploitation of ALB resource, this species was listed as near threatened by the IUCN because of the decreasing population trend and continuing decline of mature individuals (Collette *et al*., 2011). As of 2004, the stock has been considered overexploited in the North Atlantic, fully exploited in the Indian Ocean and North Pacific, moderately exploited in the South Atlantic and South Pacific, and the stock status is unknown in the Mediterranean (Majkowski, 2007). At present, six stocks of ALB are being assessed and managed by several tuna regional fisheries management organizations (tRFMOs) in six regions including the North Pacific Ocean, South Pacific Ocean, North Atlantic Ocean, South Atlantic Ocean, Mediterranean Sea, and Indian Ocean (Nikolic and Bourjea, 2014). Effective management measures are now in place in many regions; however, up-to-date and standardized information on the fishery is necessary to accurately report the abundance and determine if overfishing would indeed happen (Collette *et al*., 2011).

In the Indian Ocean, the Indian Ocean Tuna Commission (IOTC) is the tRFMO that assesses and manages the stocks of tuna and tuna-like species. The IOTC aims to promote cooperation among its Contracting Parties and Cooperating Non-Contracting Parties in ensuring the conservation and optimum utilization of stocks, and encouraging sustainable development of the fisheries based on such stocks through appropriate management. Four Southeast Asian countries, namely: Indonesia, Malaysia, Philippines, and Thailand are among the Contracting Parties of the IOTC. ALB fishery management in the Indian Ocean has been substantial since the First Meeting of Working Parties on Temperate Tunas (WPTmT) organized by the IOTC in 2004. The Meeting considered the information on stock assessment of ALB and provided scientific advice on maximum sustainable yield (MSY) for the ALB fishery management (IOTC, 2004). Subsequently, WPTmT meetings were organized every 1-4 years to improve and develop the stock assessment of ALB fishery in the Indian Ocean.

In order to estimate the MSY of ALB, several methods of stock assessment (*e.g.*, non-equilibrium production model, age-structured production model, Bayesian biomass dynamic model and Stock Synthesis) were used in the past (Langley, 2019). However, the results were still highly uncertain because of limited biological information on ALB stock in the Indian Ocean (IOTC, 2016; 2019a). In addition to the MSY, allowable (or acceptable) biological catch (ABC) could also be considered as an effective method for fisheries resource management. ABC was developed and used in Japan from 1996 to the present (Watanabe, 2018). Various procedures (ABC calculation rules) were utilized to generate the values of ABC (FRA, 2018). Depending on available information of the concerned resource, the ABC calculation rule 2-2 is one of the ABC procedures that would require catch statistics data only. This procedure is a harvest control rule using an operating model based on a production model (Ohshimo and Naya, 2014), which aims to stabilize stock size and ensure the sustainable utilization of the resource (Harlyan *et al*., 2019). Therefore, for data-limited ALB fishery involving multi-fishing fleets and gears, ABC could be an alternative method to manage the ALB resource in the Indian Ocean.

The objectives of this article were to describe the ALB fishery in the Indian Ocean, and to compare the values of calculated ABC and MSY estimated by the IOTC.

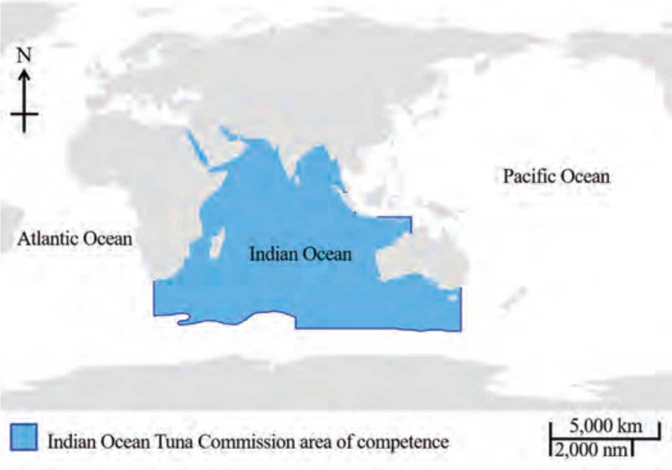

Figure 4. The Indian Ocean Tuna Commission area of competence
(modified from FAO, 2019b)

Fishing data

The data on ALB fishery in the IOTC area of competence (**Figure 4**) was accessed from the IOTC website (IOTC, 2019b). The data collected includes ALB catch, fishing fleets, and fishing gears.

ABC calculation rule 2-2

The ABC calculation rule 2-2 was performed to express the maximum level of resource utilization (ABClimit) and target level of resource utilization (ABCtarget) based on historical catch data. The procedure assumed that the catch in year *t* (C_t) reflects the stock abundance index in year *t*.

The calculation of ABClimit requires the catch statistics over the past 20 years, and uses the Equation (Eq.) 1 below (Hiramatsu, 2004):

$$\text{ABClimit}_{t+1} = \delta_t \times C_t \times [1+k(b/I)] \qquad \text{Eq. 1}$$

where ABClimit_{t+1} is ABClimit for the year $t + 1$; δ_t is the coefficient depending on the stock status level in year *t*; *k* is the weighted coefficient; *b* is the slope (trend) of catch calculated from the last three years or $[(C_t - C_{t-2})/2]$; and *I* is the average catch for the last three years or $[(C_{t-2} + C_{t-1} + C_t)/3]$.

For obtaining the δ_t value, C_t and thresholds (Clth: catch at lower threshold and Cuth: catch at upper threshold) are considered. The thresholds are determined by Eq. 2 and Eq. 3 using the maximum catch (Cmax) and the minimum catch (Cmin) over the past 20 years.

$$\text{Clth} = (2\text{Cmin} + \text{Cmax})/3 \qquad \text{Eq. 2}$$

$$\text{Cuth} = (\text{Cmin} + 2\text{Cmax})/3 \qquad \text{Eq. 3}$$

Regarding the stock status level in year *t*, three scenarios are considered for calculating the δ_t values based on Eq. 4 (FRA, 2018):

$$\delta_t = \begin{cases} 0.8 & \text{if } C_t < \text{Clth} \\ 1.0 & \text{if Clth} \leq C_t < \text{Cuth} \\ 1.0 & \text{if } C_t \geq \text{Cuth} \end{cases} \qquad \text{Eq. 4}$$

For the three scenarios: (1) stock status is at low level (δ_t = 0.8) if C_t is less than Clth; (2) stock status is at medium level (δ_t = 1.0) if C_t is equal to or higher than Clth, but less than Cuth; and (3) stock status is at high level (δ_t = 1.0) if C_t is equal to or higher than Cuth.

In fisheries management, total allowable catch (TAC) is set as an output control strategy. TAC should correspond to the ABCtarget (Hamada, 2007) calculated using ABClimit in Eq. 5 (FRA, 2018):

$$\text{ABCtarget} = \text{ABClimit} \times \alpha \qquad \text{Eq. 5}$$

where α is the coefficient for precautionary measure for the resource, which varies between 0 and 1.

In order to calculate the ABClimit and ABCtarget, *k* and α values should be set using their standard values (FRA, 2018) which are 0.5 and 0.8, respectively.

Data analyses

The historical ALB catch by fishing fleets and gears was analyzed using descriptive statistics in order to describe the development of ALB fishery in the Indian Ocean, trend of annual ALB catch, and proportion of ALB catch by fishing gear. The comparison between the values of the ABC calculations and the MSY estimated by the IOTC was carried out by paired samples t-test at significant level of 0.05. The values of MSY assessed by IOTC were acquired from the WPTmT meeting reports from 2004 to 2019 at *https://www.iotc.org/meetings*.

Results and Discussion

Albacore tuna fishery in the Indian Ocean

The accessed data contained 2,118 datasets for ALB fishery in the Indian Ocean recorded by the IOTC from 1950 to 2017. The ALB fishery in the Indian Ocean involved at least 37 countries, of which 26 are Contracting Parties and one Cooperating Non-Contracting Party of the IOTC (**Table 1**). ALB fishery in the Indian Ocean had developed between 1950 and 2017 through the introduction of different types of fishing gears (*i.e.*, handline, trolling line, gillnet, longline, purse seine, Danish seine, pole and line, and lift net) (**Figure 5**). The

Table 1. The Indian Ocean Tuna Commission (IOTC) Contracting Parties and Cooperating Non-Contracting Parties that are present (+) or absent (-) in the data compiled on albacore tuna fishery in the IOTC area of competence between 1950 and 2017

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

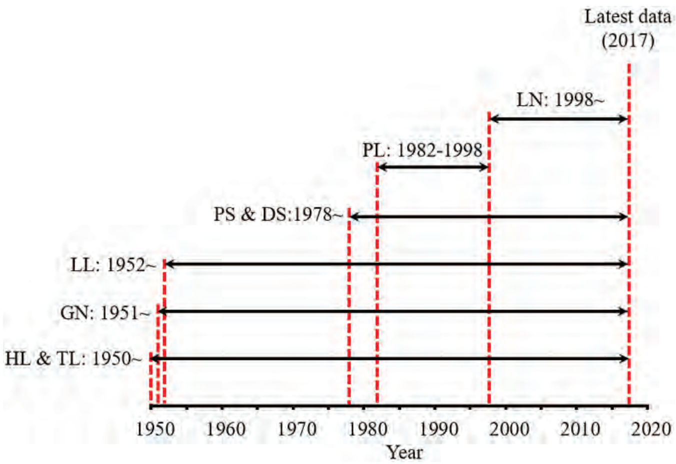

Figure 5. Development of albacore tuna fishery in the Indian Ocean through the introduction of fishing gears between 1950 and 2017. Each vertical red broken line indicates the year of earliest or latest data of particular fishing gear that captured albacore tuna. Each horizontal black arrow indicates the period of particular fishing gear that captured albacore tuna. TL: trolling line, HL: handline, GN: gillnet, LL: longline, PS: purse seine, DS: Danish seine, PL: pole and line, LN: lift net

fishing gears are categorized into four main types, namely: longlines, purse seines, gillnets, and other gears.

Comparing with the report of WCPFC (2018), where ALB fishery in the WCPFC area of competence involved about 30 countries, of which some countries' fishing fleets operated in the Indian Ocean to capture ALB (*e.g.* fishing fleets from Australia, China (including Taiwan), Indonesia, Japan, Korea, and the Philippines). For the main fishing gears in the WCPFC area of competence, ALB is mostly captured by longline, pole and line, purse seine, trolling line, and other gears. This revealed that fishing fleets and gears that exist in ALB fishery are common to both Indian Ocean and Pacific Ocean.

Albacore tuna catch in the Indian Ocean

From the historical catch between 1950 and 2017, the ALB catch during 1950-1951 was 8-18 t captured by handline, trolling line, and gillnet. When longline was introduced in 1952, the ALB catch increased during 1953-1958 from 1,100 t to about 7,300 t. Since 1959, the ALB catch fluctuated with lowest in 1975 (11,485 t) and highest in 2001 (46,103 t), as shown in **Figure 6**.

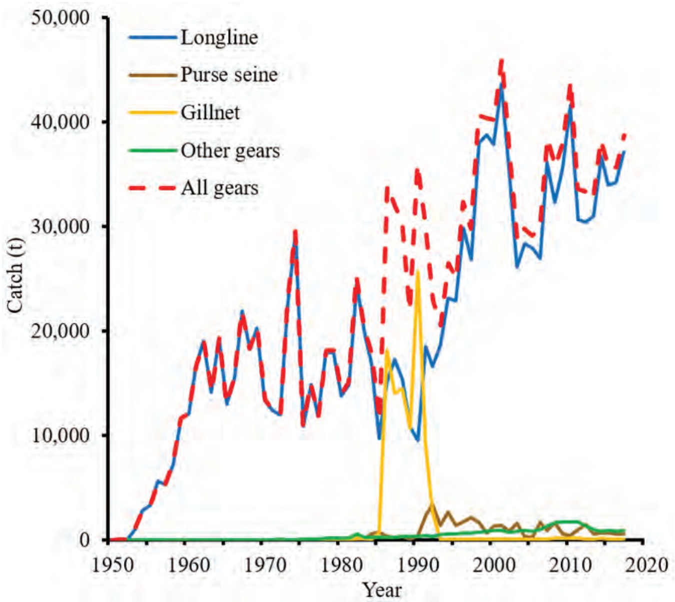

Figure 6. Annual albacore tuna catch (t) from the Indian Ocean between 1950 and 2017 by fishing gears. Other gears include handline, trolling line, pole and line, Danish seine, and lift net

For the last five years (2013-2017), the average ALB catch from all fishing gears was 36,235±2,453 t/year (**Figure 7**), and most ALB was captured by longline (34,641±2,465 t/year or 95.6±0.4 %). The catch data also revealed that the main fishing fleet for ALB fishery in the Indian Ocean was Chinese (including Taiwanese) fleet which accounted for more than 60 % of ALB catch, followed by Indonesian (20 %) and Japanese (7 %) fleets.

With regards to the main fishing fleets and gears in ALB fishery, the results were similar to the study of Brouwer *et al.* (2018) in the South Pacific Ocean, who reported that Chinese (including Taiwanese) fleet was the key fishing fleet which accounted for 59 % of ALB catch, and the main fishing gear

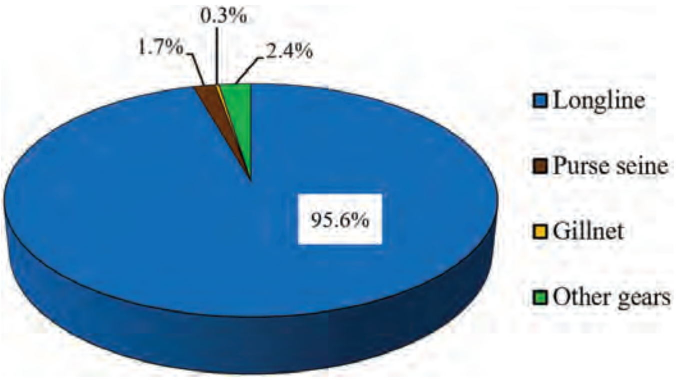

Figure 7. Proportion of average annual albacore tuna catch in the Indian Ocean between 2013 and 2017 by fishing gears. Other gears include handline, trolling line, Danish seine, and lift net

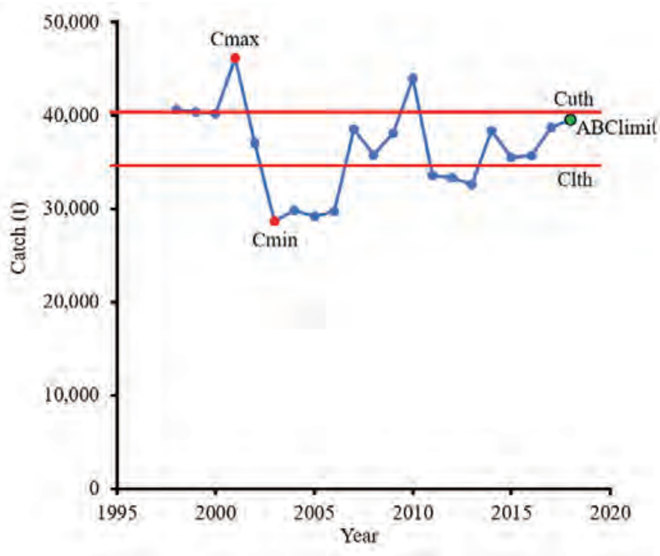

Figure 8. Total albacore tuna catch (t) in the Indian Ocean over the past 20 years (1998-2017) and predicted allowable biological catch (t) for 2018 (Cmin: minimum catch, Cmax: maximum catch, Clth: catch at lower threshold, Cuth: catch at upper threshold, ABClimit: allowable biological catch at limited level for 2018)

that captured ALB was longline which represented 98 % of the total ALB catch from all fishing gears. This emphasized that Chinese (including Taiwanese) fleet focused on ALB resource and had the highest fishing capability on ALB fishery among the various fishing fleets. Besides, ALB was mainly targeted by longline rather than other fishing gears.

On the other hand, other fishing fleets and gears in the Indian Ocean also targeted other species. For example, the Indonesian longline fleet targeted yellowfin and bigeye tunas with ALB ranking third and accounting for about 6 % of tuna catch (Rochman *et al*., 2019), and Mauritian longline fleet targeted swordfish where ALB also accounted for 6 % of total catch (Shung and Sheikmamode, 2019). For other fishing gears, purse seine fisheries mainly targeted tropical tunas, *i.e.* skipjack, yellowfin, and bigeye tunas (Justel-Rubio *et al*., 2017). The volume of ALB captured by trolling line as well as pole and line was not significant in the Indian Ocean unlike in other oceans (Langley, 2019).

ABClimit and ABCtarget from historical catch

From historical catch of ALB between 1950 and 2017, the catch statistics over the past 20 years (1998-2017) was used for ABClimit calculation (**Figure 8**). Cmin and Cmax were found in 2003 (28,687 t) and 2001 (46,103 t), respectively. Clth and Cuth were 34,492 t and 40,298 t, respectively, whereas the latest catch (C_{2017}) was 38,713 t. Consequently, δ_{2017} is equal to 1.0. The average catch for the last three years (2015-2017) or I was 36,690 t/year and the trend of catch (b) was +1,543 t/year. Therefore, ABClimit_{2018} was 39,527 t and ABCtarget_{2018} was 31,622 t.

The results showed that ABClimit_{2018} and ABCtarget_{2018} cover the MSY (35,700 t) for 2018 which was estimated by the IOTC (2019a). In the ABC calculations, k was fixed at 0.5 as a standard value (FRA, 2018), although it could be flexible to reflect the ABCtarget. However, the function of k is likely an accelerator of the harvest control rule, where small values of k lead to slight fluctuation in the changing level of resource utilization, while large values of k result in great fluctuation in the changing level of resource utilization. Harlyan *et al.* (2019) simulated ABC using values of k from 0.5 to 2.5 and emphasized that if k is too large, catch quota would greatly increase even when the biomass is slightly increasing and *vice versa*, leading to high variability in catches due to random fluctuation in the biomass index. Regarding the ABCtarget calculation, the standard value of α as 0.8 (FRA, 2018) which means that the ABCtarget is equal to 80 % of the ABClimit. However, the value of α can be adjusted from 0 to 1 (utilization level from 0 % to 100 %) depending on the resource status and management capability.

Comparison between the ABC calculations and MSY estimated by IOTC

In order to compare the values between the ABC calculations and the MSY estimated by the IOTC, the ABClimit and ABCtarget were generated corresponding to the MSY for the assessed years from 2003 to 2018. For the corresponding years, most values of ABClimit were higher than the values of MSY while values of ABCtarget were not much different from the values of MSY (**Table 2**). The statistical comparison revealed that there was no significant difference between ABClimit and MSY (t = 2.1479; df = 5; p = 0.08) as well as between ABCtarget and MSY (t = 0.4342; df = 5; p = 0.68).

Results of the calculations supported that ABC calculation rule 2-2 is an effective alternative method for the stock management of data-limited situation (*i.e.*, insufficient biological information) of multi-fishing fleets and gears in

Table 2. Albacore tuna catch (t) assessed by allowable biological catch (ABC) calculation rule 2-2 and maximum sustainable yield (MSY) estimated by the Indian Ocean Tuna Commission (IOTC)

Assessed years	ABC calculation rule 2-2		MSY estimated by the IOTC	
	ABClimit (t)	ABCtarget (t)	MSY (t)	Reference
2003	36,301	29,041	26,380	IOTC (2004)
2008	41,345	33,076	n.a.	IOTC (2008)
2011	46,444	37,155	29,900*	IOTC (2011)
2011	46,444	37,155	33,300**	IOTC (2012)
2013	30,935	24,748	34,700	IOTC (2014)
2015	39,810	31,848	38,800	IOTC (2016)
2018	39,527	31,622	35,700	IOTC (2019a)

n.a.: not available
** MSY was estimated in 2011*
*** MSY was estimated in 2012*

ALB fishery in the Indian Ocean. The method has provided a simple calculation procedure despite the requirement for a series of 20-year catch statistics. Although this study was a case for a single species (ALB) applying the ABC procedure, Harlyan *et al*. (2019) validated and considered this procedure as an appropriate tool for multi-species fisheries management.

Conclusion and Recommendations

Many countries had been involved in the development of ALB fishery in the Indian Ocean throughout the period of 1950-2017. Recently, the Chinese (including Taiwanese) fleet was identified as the main fishing fleet followed by Indonesian and Japanese fleets. The ALB catch started to increase after the introduction of longline which was found to be the main fishing gear that captures this species. The comparison between the values of ABC calculations and the MSY estimated by the IOTC suggested that ABC calculation rule 2-2 could be applied for the resource management of data-limited situation of multi-fishing fleets and gears ALB fishery in the Indian Ocean. This demonstrated that the ABC procedure could be considered as a useful tool for stock management of concerned fishery resources. Besides, the ABC procedure could be adopted by the ASEAN Member States (AMSs) for effective resource management of their respective data-limited, multi-fishing gears, and/or multi-species fisheries.

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