Factors Influencing the Assessment of Albacore Tuna Resources in the Indian Ocean

Santiago Arrizabalaga✉
Marine School, Georgian College
Ontario L4M 3X9
Canada
Email - santiago@georgiancollege.ca

Zhuo Li
College of Marine science and Engineering, Shanghai Maritime University
Shanghai 201306
China

Abstract

Several models have been used for resource assessment of Thunnus alalunga, but the assessment results of these models are uncertain. Therefore, this paper analyzes the factors affecting resource assessment of Thunnus alalonga. The analysis results show the following results: (1) The quality of catch volume, body length composition or age composition data of the Indian Ocean albacore tuna fishery is affected by unreported, unreported or misreported fishery data, too low sample number and changes in sampling protocol, etc. (2) Although the catch per unit effort (CPUE) was standardized, the quality of standardized CPUE data was still seriously affected by the change of target species and spatial distribution of catch effort. (3) Studies on population ecology and reproductive biology of albacore tuna in the Indian Ocean are still relatively weak, and information on population structure, reproduction, growth and natural death is relatively lacking. In resource assessment, relevant parameter Settings need to be borrowed from the research results of other ocean regions. (4) The Marine environment has a significant impact on the resource change and spatial distribution of albacore tuna in the Indian Ocean, but the assessment model seldom considers the impact of Marine environment. Due to the above problems, the current assessment results are uncertain. In the future, we should continue to explore ways to improve the quality of resource assessment and establish a management strategy evaluation framework to avoid the impact of the uncertainty of fishery resource assessment results on the sustainable development of the fishery.

Keywords

Indian Ocean; Albacore tuna; Resource assessment; Fishery data; Population structure; Marine environmental impact.

Introduction

Thunnus alalunga is distributed in the Indian Ocean between 25N and 40S, and is one of the main target species in the Indian Ocean tuna fishery. The development of albacore tuna in the Indian Ocean began in the 1950s and was used by longline fishing, purse Seine, gill net and other small coastal fisheries. The main fishing countries or regions include Indonesia, Japan, South Korea, China and Taiwan. In recent years, Indian Ocean albacore tuna is also the target species of China's tuna fishery (Laconcha et al., 2015). Therefore, it is of great significance to strengthen scientific research on Indian Ocean albacore tuna and timely grasp its resource status for the development of China's tuna fishery. Currently, several biomass dynamic models and age structure models have been used for resource assessment of albacore tuna in the Indian Ocean. Although the results of stock synthesis are used to determine the current resource status of albacore tuna in the Indian Ocean, there are still large uncertainties. This paper attempts to summarize the factors affecting the assessment of albacore tuna resources in the Indian Ocean in order to provide reference for the scientific assessment and management of the resources (Farley et al., 2013).

Fishery Resource Assessment Model

Assessment models for albacore tuna in the Indian Ocean can be divided into two categories: biomass dynamic model and age structure model. Biomass dynamic model including: stock production model incorporating covariates, ASPIC, Bayesian biomass dynamic model, BBDM, Bayesian state - space production model, BSPM). Although the data required by the three biomass dynamic models mentioned above are similar, namely, the parameterization methods or parameter estimation methods of the models are quite different (Williams et al., 2015). ASPIC adopts maximum likelihood method to estimate parameters, while BBDM and BSPM use Bayesian method to estimate parameters.

The difference between BBDM and BSPM is that BBDM provides a prior estimate of the intrinsic growth rate of the parameters, while BSPM increases the estimate of the shape parameters and process error of the yield model (Goni et al., 2011). The age structure model requires more complex data than the biomass dynamic model. In addition to catch and standardized CPUE data, age or body length composition data, population structure and biological information, such as growth, natural death, reproduction (time, place and capacity) and sex ratio, are also required.

The difference between SS3 and SCAA lies in that SS3 is more flexible and more complex, and can use both age composition data and body length composition data, while SCAA can only use age composition data (Williams et al., 2012). Due to the above assessment model assumptions and data requirements vary, such as the resource assessment results have much difference, but the model's assessment of the effect often depends on the extent of the assumptions and data is needed to meet, in the data or information is under the condition of uncertainty, the model of the Indian Ocean albacore tuna resources state judgment has the reference value, therefore, should be paid attention to in the fishery resources assessment evaluation model selection and caused by the uncertainty.

Fishery Data

Fishery data for the assessment of albacore tuna resources in the Indian Ocean mainly include catch length or age composition and standardization CPUE and other data (Lehodey et al., 2015). The quantity and quality of these data directly affect the quality of assessment of albacore tuna resources in the Indian Ocean.

Overview of Albacore Tuna Fisheries in the Indian Ocean

Commercial fishing of albacore tuna in the Indian Ocean began in the early 1950s, and ultra-low temperature longline fisheries of Japan, Taiwan, China and South Korea entered the Indian Ocean to catch albacore tuna in the early (1952), middle (1954) and late (1957) of this era respectively. Until 1986, Indian Ocean albacore tuna were mainly used by ultra-cold longline fisheries in Taiwan, Japan and South Korea. From 1986 to 1991, the drift-net fishery in Taiwan caught a similar amount of fish as the ultra-low temperature longline fishery (Cosgrove et al., 2014).

However, in 1992, the use of drift-net was banned by the United Nations. Subsequently, the albacore tuna yield fluctuated and reached a peak in 2001 (about 4×10^4 t, accounting for 88% of the total output) in ultra-low temperature longline fishery (mainly Taiwan ultra-low temperature longline fishery). Subsequently, its output decreased year by year and maintained at 1.3×10^4 t in recent years.

The chilled longline fishery, which began in 1974, has been producing more albacore tuna every year. Since 2007, the chilled longline fishery (mainly in Taiwan and Indonesia) has been producing more than the ultra-cold longline fishery. From 2007 to 2014, the longline fishery's albacar tuna production accounted for about 95% of the total albacar tuna production, while the ratio between the chilled longline fishery and the ultra-low temperature longline fishery was about 61:39 (Montes et al., 2012).

In addition, Indian Ocean albacore tuna is also caught by purse Seine fisheries of seychelles, Mauritius and other countries, and gill nets of Indian Ocean coastal countries, but the proportion of its output is relatively low.

Catch Data

Catches data began in 1950 and early 1990 s before catches more reliable data, but since then, due to some important fishery (longlines fisheries such as Indonesia, Taiwan, China's ice fresh longlines fishery) catches data has such problems as omissions, newspaper, or mixed in, although the Indian Ocean Tuna Commission (Hisamichi et al., 2010). Indian Ocean Tuna themselves, the secretariat of IOTC has estimated or corrected the missing data according to the fish catches, fishing efforts, FishStat database of Food and Agriculture Organization (FAO), port sampling, canister import and other data, but the quality of the fish catches data is still declining.

Due to the lack of catch effort data, it is difficult to determine the fishing position of some fisheries (such as the Indonesian longline fishery), but the spatial resolution of the current assessment model is low, and this effect is rarely considered. Despite the lack of observation on the discarding level (except for purse Seine fisheries), it is generally believed that the discarding level of Indian albacore tuna is very low and is rarely considered in resource assessment.

Body Length or Age Composition Data

Data of body length composition began in 1965, mainly from ultra-low temperature longline fishery and purse Seine fishery and seychelles, and a few data of body length composition from Taiwan and Indonesia.

(1) The body length composition data of ultra-low temperature longline fishery in Japan started in 1965, but since the early 1990s, the number of observation samples has been decreasing year by year, resulting in insufficient observation samples and poor data quality.

(2) The body length composition data of ultra-low temperature longline fishery in Taiwan began in 1980, but the body length data after 2003 were significantly different from that before. It is generally believed that after 2003, the sampling protocol changed, measuring too few small fish and too many big fish, and therefore, the average body length and weight were relatively large (Wells et al., 2013).

(3) The gillnet fishery in Taiwan, China, the offshore gillnet fishery in Iran, Pakistan and other countries, and the longline fishery in Malaysia, India, the Philippines and Oman all lack the data of body length composition. However, the gillnet fishery in Taiwan is very important, and its output is about 50% of the total albacore tuna output in the same period.

(4) The body length composition data of chilled longline fisheries in Taiwan and Indonesia are very limited (a few years), with low sampling coverage and poor data quality. The quality of age composition data depends on the quality of body length composition data and age-length key. Due to the great uncertainty of body length composition data, and the lack of age body length relation table data in the sea area, the quality of age composition data is worse.

The body length or age composition data are mainly used to estimate the selection coefficient, and the selection coefficient is used to calculate the fishing death coefficient of fish of different ages, which has an important influence on the quality of fishery resources assessment (Reglero et al., 2014).

The lack or poor quality of body length or age composition data will make the evaluation model unable to estimate or even misestimate the selection coefficient. For example, in the current resource assessment, the selection coefficient of the gill net fishery in Taiwan, China cannot be estimated, which increases the uncertainty of the resource assessment results.

Standardization of CPUE Data

The standardized CPUE data are mainly from ultra-cold longline fisheries in Taiwan, Japan and South Korea. A lbacore tuna production was high in Japan's ultra-cold longline fishery until 1969, but it quickly fell off and remained low as target species switched to Thunnus maccoyi and Thunnus obesus (Lezama-Ochoa et al., 2010). Since 2006, albacore tuna has been reintroduced as a target species (controversially, bigeye tuna), partly because of lower quotas for southern bluefin tuna.

The change of standardized CPUE in Japan is similar to the change of yield, so it is speculated that the change of standardized CPUE in Japan is still closely related to the change of target species, and may not really reflect the change of albacore tuna resources (Young et al., 2011). Similar situations exist in South Korea's ultra-low temperature longline fishery. The change trend of standardized CPUE is similar to the change trend of fishing yield, and it cannot really reflect the change of resource amount. The CPUE data of the ultra-low temperature longline fishery in Taiwan, China began in 1980.

In the Indian Ocean China Taiwan cryogenic longlines fishery has the following characteristics:

(1) Since the mid 1980's, China's Taiwan cryogenic longlines fishery by modern cryogenic longlines fisheries with the conventional cryogenic longlines fishing together, modern cryogenic longlines fishery has high fishing efficiency, and the main catch with high value of yellowfin tuna (Thunnus albacares), bigeye tuna and southern bluefin tuna.

(2) Ultra-low temperature longline fishing in Taiwan has been transferred from the main catch area of albacore tuna in temperate zone to the main catch area of equatorial bigeye tuna (Nalinanon et al., 2010).

(3) The albacore tuna fishing area, China's Taiwan cryogenic longlines fishery of target species there are changes, such as the albacore tuna fishing area, the main trap ocean southwest tropical tuna, swordfish and southeast area of southern bluefin and bigeye tuna fishing effort quantity increased, and since 2004, its main catch fish oil (Ruvettus pretiosus) increase of the amount of fishing effort.

The characteristics of ultra-low temperature longline fishing in Taiwan indicate that the target species changes at any time, and the target species change will lead to the change of catch coefficient. Despite the GLM (generalized linearmodel) model of CPUE standardization, standardized CPUE longlines but China Taiwan fisheries are still affected by target species, changes in the fishing areas or fishing technology, may still be unable to reflect the change of the resource, such as after 1986, standardized CPUE slash is closely related to target species change, rather than resources fell sharply.

However, due to the importance of Taiwan's ultra-low temperature longline fishery in the Indian Ocean albacore tuna fishery, currently, the resource assessment of Indian Ocean albacore tuna mainly USES the standardized CPUE data of this fishery or closely related to this fishery (Yamashita et al., 2011).

To improve the quality of standardized CPUE, IOTC combined the operational data of ultra-low temperature longline fisheries in Japan, South Korea and Taiwan, China, and used the clustering method to identify the target species in the fleet to remove the impact of target species change, spatial position change and fishing boat effect on standardized CPUE.

However, from the results of CPUE standardization (such as the sharp decline of CPUE before 1970 and the rise of CPUE in the southern sea after 2006), the change of target species still affects the quality of the joint standardized CPUE, making it unable to correctly reflect the change of albacore tuna resources.

In fishery resource assessment, standardized CPUE is an important data to determine the change trend of resource quantity, which has a higher weight than the data of body length composition or age composition, and directly affects the quality of fishery resource assessment (Stephen et al., 2010).

Population Structure of Albacore Tuna in Indian Ocean

In the Pacific and Atlantic oceans, albacore tuna are generally divided into two populations: north and south, which correspond to two ocean circulations (oceangyre) respectively. However, because the area of the northern Indian Ocean is relatively small, there is only one ocean circulation, so it is still assumed that albacore tuna in the Indian Ocean is a single population (Morato et al., 2010).

However, based on morphological and DNA studies, albacore tuna in the Indian Ocean may be divided into two populations with 90°E as the boundary. Other genetic data showed that the Indian Ocean albacore tuna, Pacific albacore tuna have close relations, and the frequency of blood group (blood - group frequencies) microsatellites and the results are showed that albacore tuna in the Indian Ocean, Atlantic Ocean albacore tuna have contact (Wu and Su, 2014).

Because South African continent is not enough to completely divide the southern Indian Ocean and the south Atlantic temperate water mass system, the formation of environmental barriers, therefore, in the southeast of the Atlantic and the southwest Indian albacore tuna may exist between the transatlantic migration, and two seas of albacore tuna gene homogeneity and length distribution characteristic and further support the transatlantic migration hypothesis. There are migratory links between albacore tuna in the south Pacific and the Indian Ocean.

Therefore, the single population hypothesis is worth discussing. The distribution of body length of albacin tuna in the Indian Ocean has significant latitudinal changes, that is to say, there are sexually mature individuals with large body length in the area north of 10°S all the year round, spawning individuals are mainly distributed in the area between 10°S and 30°S, while sexually immature individuals are mainly distributed in the area south of 30°S, and different populations have seasonal characteristics of southern and northern migration.

There is an obvious meridional change in the body length distribution of albacore tuna in the south Pacific, but the existence of such a change in the Indian Ocean is still lacking of data support. Spatial structure division has an important impact on resource assessment results (Briand et al., 2011). The scientific nature of spatial division of the current assessment model is questionable, and there are problems in ignoring the spatial structure of the population or assigning the core area of albacore tuna fishing (sea area between 15°S and 25°S) to the north non-core are.

In addition, because of a lack of discharge data, estimate the difficulty of the Indian Ocean albacore tuna migration, and use area as the fishery (areas - as - fleets) method or more flexible choice model also cannot eliminate by the impact of migratory (Sagarminaga and Arrizabalaga, 2010).

Reproductive Biology of Albacore Tuna in the Indian Ocean

The Sex Ratio

In albacore tuna catches in the north Atlantic, south Pacific, north Pacific, Mediterranean, Indian Ocean and other waters, the proportion of male adult fish increases with the increase of body length. When the body length exceeds a certain length, such as 95 cm, 100 cm or 105 cm, female fish are few or absent (Catalan et al., 2011).

In the Indian Ocean, the results showed that when the body length of albacore tuna was less than 100 cm, the number of females was dominant, while when the body length was more than 105 cm, the number of males was dominant.

There are three explanations for the lack of large individual females:

(1) The difference in growth between males and females, that is, the growth rate of males is higher than that of females, while the individual length of females is smaller.

(2) Females and males have different natural death coefficients, that is, the reproduction of females increases their natural death coefficients, resulting in fewer females with large individuals.

(3) The female and male fish have different fishing coefficients, that is, the female fish have a smaller fishing coefficient, so the proportion of catch is less.

The variation of sex ratio with body length is also different in different sea areas. For example, in some sea areas, the sex ratio is close to 50%, and the largest body length is mainly female fish.

Therefore, whether there is a significant difference in the sex ratio is still controversial. The current resource assessment usually assumes that the sex ratio at the time of supplement is 1:1, and the sex ratio difference is mainly reflected by the growth difference (Reglero et al., 2012). Due to the lack of gender information in fishery data, the effects of gender differences were not considered in natural death coefficient, selective model and catch coefficient setting. If the sex ratio of fishery data varies significantly with body length, and its cause has nothing to do with growth, it may have an important impact on the current resource assessment results.

Ratio of Sexual Maturity

Fifty percent of the sexually mature body length of albacore tuna in the Indian Ocean is 85.3cm (female), which is slightly lower than that of 87cm in the south Pacific and 90cm in the Atlantic, but higher than that of 66cm in the Mediterranean.

The 100% sexually mature body length of Indian Ocean albacore tuna is about 94 cm, and all oceans are basically the same. Meanwhile, in the south Pacific, 50% of the sexually mature length of albacorn tuna changes with latitude, longitude and time (Young et al., 2010). If the length increases southward with latitude, the length gradually increases. For 10°S, the value is 75 cm, and for 25°S to 45°S, the value is 88 cm. 50% of the sexually mature length of the south Pacific albacore tuna is related to the temporal and spatial distribution of specific individuals, so the temporal and spatial coverage of the observed sample will affect the estimation of this parameter.

Due to the relatively limited spatial and temporal distribution of observed samples, their results still need to be further confirmed. Albacore tuna is 50% sexually mature at age 5 in the Atlantic and north Pacific and 4.5 in the south Pacific, while albacore tuna is 100% sexually mature at age 6 or 7. Similarly, the 50% age of sexual maturation of albacorn tuna in the south Pacific significantly changes with latitude, that is, with the increase of latitude to the south, the age becomes larger, for example, at 10°S, it becomes 2 years old, and at 25°S - 45°S, it becomes 5 years old.

Body length is more closely related to sexual maturity than age, and albacore tuna's sexual maturity receptor is long driven. Mature biomass is the key parameter in counting spawning stock biomass (SSB), and spawning biomass is not only an important management parameter, but also an important parameter in calculating supplementary content using the parent-feed relationship (Cardona et al., 2012). At the same time, the results still lack the relationship between the proportion of sexual maturity and age.

Therefore, in the resource assessment of Indian Ocean albacore tuna, the relationship between sexual maturity ratio and age is generally adopted by the research results of the south Pacific, and the change of sexual maturity ratio with latitude is generally ignored. It is not clear whether the difference in the setting of sexual maturity rate has a serious impact on the assessment results of albacore tuna resources in the Indian Ocean.

Location, Time and Amount of Spawning

Currently, the spawning grounds of Indian Ocean albacore tuna are not very clear, and it is generally believed that the spawning grounds are between 10°S and 30°S. The main spawning grounds may be located off the east coast of Madagascar, and the spawning time is from October to January the next year, and the main spawning months are from November to December.

In addition, the mozambique channel, near the equator of the western Indian Ocean, the cape of good hope, around Christmas island and northwest Australia are all possible spawning grounds, and the surface water temperature of the spawning location is generally over 24℃. Albacore tuna can be partial to spawn, its partial fertility (batchfecundity) and the size of the ovaries, and gonad growth associated with the body length, so the partial fertility increases with the length or age, and with the spawning time increase and decrease, which lay eggs early partial fecundity, spawning late partial low fertility, and large individual of spawning time.

As the fecundity of batching varies with the spawning time and is affected by individual conditions, there are great differences in the batching fecundity of individuals with different conditions and individuals with different fishing time, which affects the relationship between batching fecundity and body length and causes great changes in the relationship between batching fecundity and body length (Arrizabalaga et al., 2015). Meanwhile, the research results showed that there was no significant relationship between the battering fecundity and weight of albacore tuna in the Indian Ocean.

In the parent-recruit relationship, spawning biomass SSB is often used to calculate the recruit amount, which implies that the reproduction potential of the population is proportional to SSB, and the survival rate of larvae has nothing to do with parental age, body length or individual status, and the spawning amount per unit body weight does not change with time and other assumptions (Childers et al., 2011). This would affect the hypothesis if batch fertility was independent of weight.

At the same time, it may be more reasonable to calculate the population reproductive potential using body length data, but this method is rarely used in albacore tuna resource assessment. In the resource assessment of albacore tuna in the Indian Ocean, the spatial division is only used to organize fishery data, and there is no independent population dynamics in each spatial region, so there is no need to set the supplementary position, and the supplementary time is set as the fourth quarter, i.e. the peak spawning period.

In the resource assessment of the south Pacific albacore tuna, the allotment amount was allocated in proportion to 8 regions and 4 seasons, and the allotment proportion was estimated by the model. There is currently no discussion of the impact of additional location or timing Settings on estimates.

Parental Supplementation

The beverton-holt (b-h) or Ricker models are commonly used in the parent-supplement relationship model. The problem with estimating recruitment using these models is the steepness estimate or assumption (Ahmad and Benjakul, 2010).

It has an important impact on resource evaluation results. For Indian albacore tuna, the value is generally considered to be between 0.7 and 0.9, and it is usually fixed at 0.8. This is consistent with the south Pacific hypothesis, but quite different from the north Pacific estimation (0.84 - 0.95) or hypothesis (0.9). Calculation method of parent. Currently, SSB is mainly substituted into b-h and other models as reproductive potential to calculate recruitment, but the calculation of reproductive potential may be affected by many factors and change with time, which will affect the estimation of recruitment and other parameters.

Weight setting of supplement quantity processing error. In general, the processing error of supplement quantity is assumed to be a random variable subject to lognormal distribution, and its weight is determined by its standard deviation on the logarithmic scale. This standard deviation directly affects the change of supplement volume, and its value is generally assumed to be 0.6.

However, it is doubtful whether this value is suitable for albacore tuna in the Indian Ocean. Supplement quantity is not only related to parents, but also affected by the environment. At the same time, there is no observation data reflecting the variation of supplement quantity in the model, so the estimation of supplement quantity is likely to be misestimated due to various factors.

The Growth of Albacore Tuna in the Indian Ocean

Age and Body Length

Hard tissue identification (fin, scales, vertebra and otolith), length analysis and marker discharge method are often used to estimate the age and growth of albacore tuna, but it is generally believed that the age and growth estimated by otolith is more accurate.

There are differences in the estimation of the maximum age of albacore tuna in different sea areas, for example, the north Pacific is 15 years old (otolith), the south Pacific is 14 years old (otolith), the north Atlantic is 13 years old (scales), the south Atlantic is 12 years old (fin), the Mediterranean is 11 years old (fin), and the

Indian Ocean is 9 - 10 years old. Meanwhile, non-parametric models are also used to express the relationship between age and body length. For albacore tuna, the von Bertalanffy growth equation is mainly used. However, the results showed that the growth of albacore tuna in the south Pacific was more suitable by using Logistic growth equation (Table 1).

It is generally believed that there are gender differences in the growth of albacore tuna. When the growth of albacore tuna exceeds a certain age, the body length of male fish is significantly larger than that of female fish. Therefore, females and males should adopt different growth equations. In addition, there are regional differences in the growth of albacore tuna.

For example, in the south Pacific, the progressive body length and growth parameters of eastern and central long-fin tuna are larger than those of western ones. However, this difference may be caused by fishing gear selectivity or migration related to body length. The estimation of Indian Ocean albacore tuna growth equation is mainly based on fin ray, scale, vertebra or length analysis method (Table 1).To some extent, the age identification based on fin, scale and vertebra lacks verification, which is not as reliable as the age identification based on otolith, while the estimation of growth parameters based on length analysis method also has considerable uncertainty.

Meanwhile, studies on the growth of albacore tuna in the Indian Ocean rarely consider gender differences. Therefore, in the resource assessment of albacore tuna in the Indian Ocean, the growth equation of this area is not adopted, but the results are adopted to distinguish the impact of gender differences on growth. However, there are differences between the results and the existing growth equation of the Indian Ocean (Table 1). Whether the results are appropriate and their possible impact on the evaluation results need to be further analyzed.

Table 1. Growth equation for Thunnus Alalunga.

Ocean	Growth Equation	Estimation Method
Indian Ocean	$L=113.7*[1-e^{-0.194*(t+8.39)}]$	P
Indian Ocean	$L=163.7*[1-e^{-0.1019*(t+2.06)}]$	V
Indian Ocean	$L=128.13*[1-e^{-0.1620*(t+0.89)}]$	S
Indian Ocean	$L=136*[1-e^{-0.1590*(t+1.68)}]$	E
Indian Ocean	$L=147.2*[1-e^{-0.1330*(t+1.49)}]$	E
Indian Ocean	$L=124.7*[1-e^{-0.23*(t+1.5)}]$	E
North Atlantic	$L=122.2*[1-e^{-0.485*(t+0.98)}]$	P+T
North Atlantic	$L=147.5*[1-e^{-0.735*(t+0.83)}]$	P
South Atlantic	$L=121.37*[1-e^{-0.209*(t+1.3)}]$	P
Mediterranean	$L=94.7*[1-e^{-0.258*(t+1.14)}]$	O
North Pacific Ocean	$L=124.1*[1-e^{-0.164*(t+1.35)}]$	O
North Pacific Ocean	$L=108.5*[1-e^{-0.292*(t+2.23)}]$	O

Note: The growth equations except those from Indian Ocean were selected as they were published in recent years or used in recent stock assessment. S denotes scales. V denotes vertebrate; P denotes spines. E denotes length frequency analysis. T denotes tag-recapture estimates and O denotes otoliths.

Relationship between Body Weight and Body Length

Albacore tuna is used by a variety of fisheries (such as longline fishing, purse Seine, gill net, etc.), and there are differences in the size of catches in different fisheries, and samples from different fisheries will affect the relationship between body weight and body length. For example, the catch of gill net fishery is mainly immature juvenile fish with small individuals, while the longline fishery mainly catches sexually mature adult fish with large individuals, which makes the weight predicted by the model based on gill net fishery data relatively small, while the weight predicted by the model based on longline fishery data relatively large. There are also differences in the relationship between body weight and body length in different ocean regions.

Generally, when the body length is less than 80 cm, the predicted body weight difference is small, but with the increase of body length, the predicted body weight difference gradually increases. In addition, there may be gender differences, regional differences and seasonal changes in the relationship between body weight and body length in the same ocean area. The reasons for this difference or change may be related to the ecological or life history processes such as population composition, baiting or spawning migration. Scholars are commended the use of Penney model (Table 2) based on the position of each body weight and body length curve, the coverage range of body length data and the population relationship with albacore tuna in the Indian Ocean (Parrish et al., 2015).

The data of this model came from albacore tuna in the south Atlantic Ocean. Current research results indicate that there are gender and regional differences in the relationship between weight and body length of Indian albacore tuna.

Although the sample coverage of these studies is still limited, it is doubtful whether the Penney model is suitable for Indian albacore tuna. In the resource assessment of albacore tuna in three oceans, gender and regional differences in the relationship between body weight and body length were not considered, while seasonal changes in the relationship between body weight and body length were considered only in the north Pacific Ocean. Since the body-length relationship directly affects the calculation of equivalent catch weight, spawning biomass and biological reference points (e.g., maximum sustainable yield), the use of different body-length relationships will affect the parameter estimation and assessment results of the assessment model. However, there is still a lack of research on the sensitivity of the model to the relationship between body weight and body length (Table 2).

Table 2: The weight-length relationships for Thunnus alalonga.

Ocean	Fishery	Sex	Weight-length Relationship
Indian Ocean	LL+GG	C	$W = 0.032411*L^{2.8758}$
Indian Ocean	LL+GG	C	$W = 0.035050*L^{2.8770}$
Indian Ocean	GG	C	$W = 0.056907*L^{2.7514}$
Indian Ocean	GG	C	$W = 0.033783*L^{2.8449}$
West Indina Ocean	ALL	C	$W = 0.033830*L^{2.8676}$
West Indina Ocean	ALL	M	$W = 0.0043378*L^{3.3551}$
West Indina Ocean	ALL	F	$W = 0.0017551*L^{3.5625}$
Indian Ocean	LL	C	$W = 0.0032537*L^{3.4240}$
Indian Ocean	LL	C	$W = 0.43400*L^{2.3430}$
East Indian Ocean	LL	C	$W = 1.00000*L^{2.0550}$
North Indian Ocean	ALL	C	$W = 0.0069587*L^{3.2351}$
South Pacific Ocean	ALL	C	$W = 0.08000*L^{2.7271}$
North Atlantic	ALL	C	$W = 0.013390*L^{3.1066}$
South Atlantic	ALL	C	$W = 0.013718*L^{3.0973}$
Mediterranean	TL+SL	C	$W = 0.031190*L^{2.8800}$

Note: The length–weight equations except those from Indian Ocean were selected as they were used in recent stock assessment. W1, W2, W3, W4 denote body weight in quarter 1, 2, 3 and 4, respectively. GG: gillnet; LL: longline; TL: troll-line; SL: surface longline. ALL denotes the albacore caught by three or more different fishing gears. F and M denote female and male, respectively. C denotes sexes combined.

Natural Death Coefficient of Indian Ocean Albacore Tuna

The natural death coefficient directly affects the estimation of population productivity. If the natural death coefficient is set too large, the estimated population productivity is too high, the estimated biomass is too large, and the estimated fishing death coefficient is too low. Therefore, natural death coefficient is the key parameter in fishery resource assessment.

In general, the natural death coefficient changes with time, age, gender, generation, environment, feeding, inter-species competition, etc., while the single point estimate of the natural death coefficient can only be used as the average value under a certain condition, and the single point estimate has great uncertainty. It is generally believed that young and old individuals and sexually mature females may have higher natural mortality.

There is much discussion about the setting of the natural death coefficient: how the natural death coefficient changes with age (or body length) and time, whether there are gender differences in the natural death coefficient, and how these changes or differences may affect resource assessment. Information about the natural death coefficient of albacore tuna in the Indian Ocean is very limited, and it is inferred that the natural death coefficient of albacore tuna is between 0.2 and 0.5/a based on the life span of albacore tuna (12 to 15 years or longer).

Scholars estimated the natural death coefficient of Indian albacore tuna at 0.2207/a by using longline fishery data and catch curve method, calculated by Pauly empirical formula at 0.2060/a, and estimated by MULTIFAN software at 0.22-0.25. Due to problems in age identification, selectivity in fishery or investigation, fishing level and estimation of fishing death coefficient, the rationality of the above natural death coefficient cannot be determined. Currently, the natural death coefficient of albacore tuna in the three oceans and Mediterranean Sea is assumed to be 0.3/a.

How to reasonably set the natural death coefficient of Indian Ocean albacore tuna is still lacking of reliable scientific basis, which is one of the important sources of uncertainty in the assessment results of Indian Ocean albacore tuna resources (Terio et al., 2010). Marine environment impact on the Indian Ocean albacore tuna in the Indian Ocean albacore tuna resources change and spatial distribution has close relationship with the Marine environment events will cause the Indian albacore tuna resources fluctuations, the spatial distribution of albacore tuna with three main flow system in the Indian Ocean, the monsoon flow, subtropical circulation, circumpolar current, closely related to, the seasonal migration is influenced by factors such as sea surface temperature, temperature front. Fishery resource assessment results indicate that albacore tuna supplement volume has great fluctuations, which may also be related to the impact of Marine environment.

However, there is still a lack of necessary research on the impact of Marine environment on the fluctuation of fishery resources and how to choose and calculate Marine environmental parameters to quantify the impact.

Outlook

Quality problems exist in the Indian Ocean albacore fishery in terms of catches, body length composition or age composition, and standardized CPUE data. Part of the catch and body length composition data can be recovered by using relevant information or verified, corrected or estimated by the relationship between the data, so as to improve their quality.

For example, the body length composition data of Chinese Taiwan gill net can be recovered by the body length composition data of Chinese Taiwan gill net fishery in the south Pacific, or estimated by the data of Chinese Taiwan scholars. The IOTC secretariat does a lot of work on this, updating the data before each resource assessment. However, some data may not be recoverable (such as data on chilled longline fisheries in

Taiwan prior to the year 2000), so it is important to understand the uncertainties caused by these data in resource assessments.

The main problem to be solved to improve the quality of standardized CPUE data is to reduce the impact of the spatial distribution of target species and catch effort. Although scholars have made many beneficial attempts, there are still problems. Improving the quality of standardized CPUE is one of the core issues in the future assessment of albacore tuna resources in the Indian Ocean. The biological research on Indian Ocean albacore tuna is still relatively weak, and the population structure, reproduction, growth and natural death information are relatively lacking.

There are still some limitations in the spatial and temporal coverage of existing research sample data and research methods, which need to be further improved. Gender ratio changes with body length, gender and spatial difference of growth, estimation of natural death coefficient and other issues need to be paid priority attention to.

In resources assessment, the Indian Ocean albacore tuna biological data may come from different ocean regions or hypothesis, but the inner relationship between biological parameters not give enough attention, such as natural death coefficient assumptions at the same time will affect the biggest age (age biggest natural death coefficient should be smaller), selection of growth model (Li et al., 2010).

At the same time, in addition to natural death coefficient and steepness, the current resource assessment lacks sensitive analysis of other biological parameters (such as growth equation, weight-body length relationship, etc.), which will underestimate the uncertainty of assessment results. The population structure of albacore tuna in the Indian Ocean is also an important issue requiring priority attention (Bell et al., 2013). If significant trans-oceanic migration does exist, the resource assessment results of the three ocean regions may be unreliable, which is also closely related to the resource assessment and management of albacore tuna in the south Pacific and south Atlantic.

Due to the fisheries data especially the length of less (age), standardized CPUE data are serious quality problems, and biological parameters setting are lack of scientific research support, using complex structure model of age may not give a scientific evaluation results, therefore, dynamic model of biomass, especially the biomass dynamic model based on Bayesian, should be given attention (Foster et al., 2012). Due to the heterogeneity of albacore tuna spatial distribution (e.g., zonal distribution of body length, etc.), and the close relationship between resource variation and Marine environment, it is of great significance to explore the use of evaluation models with higher spatial resolution, such as SEAPODYM (spatial ecosystem and population dynamics model).

The evaluation of albacore tuna resources in the Indian Ocean is faced with a series of problems, such as fishery data quality, biological parameter setting and population structure hypothesis. Research on the establishment of the management strategy evaluation (MSE) framework is an important measure to avoid the uncertainty of fishery resource evaluation results and achieve fishery management objectives, but the construction of the MSE framework is very complex, and the current progress is still relatively slow.

References

Ahmad, M. and S. Benjakul. 2010. Extraction and characterisation of pepsin-solubilised collagen from the skin of unicorn leatherjacket (aluterus monocerous). *Food Chemistry*, 120 (3): 817-824.

Arrizabalaga, H., F. Dufour, L. Kell, G. Merino, L. Ibaibarriaga, G. Chust, X. Irigoien, J. Santiago, H. Murua, I. Fraile, M. Chifflet, N. Goikoetxea, Y. Sagarminaga, O. Aumont, L. Bopp, M. Herrera, J.M. Fromentin and S. Bonhomeau. 2015. Global habitat preferences of commercially valuable tuna. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 113 (SI): 102-112.

Bell, J.D., C. Reid, M.J. Batty, P. Lehodey, L. Rodwell, A.J. Hobday, J.E. Johnson and A. Demmke. 2013. Effects of climate change on oceanic fisheries in the tropical pacific: implications for economic development and food security. *Climatic Change*, 119 (1SI): 199-212.

Briand, K., B. Molony and P. Lehodey. 2011. A study on the variability of albacore (thunnus alalunga) longline catch rates in the southwest pacific ocean. *Fisheries Oceanography*, 20 (6): 517-529.

Cardona, L., I. Alvarez De Quevedo, A. Borrell and A. Aguilar. 2012. Massive consumption of gelatinous plankton by mediterranean apex predators. *Plos One*, 7 (e313293)

Catalan, I.A., A. Tejedor, F. Alemany and P. Reglero. 2011. Trophic ecology of atlantic bluefin tuna thunnus thynnus larvae. *Journal of Fish Biology*, 78 (5): 1545-1560.

Childers, J., S. Snyder and S. Kohin. 2011. Migration and behavior of juvenile north pacific albacore (thunnus alalunga). *Fisheries Oceanography*, 20 (3): 157-173.

Cosgrove, R., I. Arregui, H. Arrizabalaga, N. Goni and M. Sheridan. 2014. New insights to behaviour of north atlantic albacore tuna (thunnus alalunga) observed with pop-up satellite archival tags. *Fisheries Research*, 150: 89-99.

Farley, J.H., A.J. Williams, S.D. Hoyle, C.R. Davies and S.J. Nicol. 2013. Reproductive dynamics and potential annual fecundity of south pacific albacore tuna (thunnus alalunga). *Plos One*, 8 (e605774)

Foster, D.G., S.P. Epperly, A.K. Shah and J.W. Watson. 2012. Evaluation of hook and bait type on the catch rates in the western north atlantic ocean pelagic longline fishery. *Bulletin of Marine Science*, 88 (3): 529-545.

Goni, N., J. Logan, H. Arrizabalaga, M. Jarry and M. Lutcavage. 2011. Variability of albacore (thunnus alalunga) diet in the northeast atlantic and mediterranean sea. *Marine Biology*, 158 (5): 1057-1073.

Hisamichi, Y., K. Haraguchi and T. Endo. 2010. Levels of mercury and organochlorine compounds and stable isotope ratios in three tuna species taken from different regions of japan. *Environmental Science & Technology*, 44 (15): 5971-5978.

Laconcha, U., M. Iriondo, H. Arrizabalaga, C. Manzano, P. Markaide, I. Montes, I. Zarraonaindia, I. Velado, E. Bilbao, N. Goni, J. Santiago, A. Domingo, S. Karakulak, I. Oray and A. Estonba. 2015. New nuclear snp markers unravel the genetic structure and effective population size of albacore tuna (thunnus alalunga). *Plos One*, 10 (e01282476)

Lehodey, P., I. Senina, S. Nicol and J. Hampton. 2015. Modelling the impact of climate change on south pacific albacore tuna. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 113 (SI): 246-259.

Lezama-Ochoa, A., G. Boyra, N. Goni, H. Arrizabalaga and A. Bertrand. 2010. Investigating relationships between albacore tuna (thunnus alalunga) cpue and prey distribution in the bay of biscay. *Progress in Oceanography*, 86 (1-2SI): 105-114.

Li, Z., W. Youravong and A. H-Kittikun. 2010. Protein hydrolysis by protease isolated from tuna spleen by membrane filtration: a comparative study with commercial proteases. *Lwt-Food Science and Technology*, 43 (1): 166-172.

Montes, I., M. Iriondo, C. Manzano, H. Arrizabalaga, E. Jimenez, M. Angel Pardo, N. Goni, C.A. Davies and A. Estonba. 2012. Worldwide genetic structure of albacore thunnus alalunga revealed by microsatellite dna markers. *Marine Ecology Progress Series*, 471: 183-202.

Morato, T., S.D. Hoyle, V. Allain and S.J. Nicol. 2010. Tuna longline fishing around west and central pacific seamounts. *Plos One*, 5 (e1445312)

Nalinanon, S., S. Benjakul and H. Kishimura. 2010. Biochemical properties of pepsinogen and pepsin from the stomach of albacore tuna (thunnus alalunga). *Food Chemistry*, 121 (1): 49-55.

Parrish, C.C., H. Pethybridge, J.W. Young and P.D. Nichols. 2015. Spatial variation in fatty acid trophic markers in albacore tuna from the southwestern pacific ocean-a potential 'tropicalization' signal. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 113 (SI): 199-207.

Reglero, P., D.P. Tittensor, D. Alvarez-Berastegui, A. Aparicio-Gonzalez and B. Worm. 2014. Worldwide distributions of tuna larvae: revisiting hypotheses on environmental requirements for spawning habitats. *Marine Ecology Progress Series*, 501: 207-224.

Sagarminaga, Y. and H. Arrizabalaga. 2010. Spatiotemporal distribution of albacore (thunnus alalunga) catches in the northeastern atlantic: relationship with the thermal environment. *Fisheries Oceanography*, 19 (2): 121-134.

Stephen, N.M., J.R. Shakila, G. Jeyasekaran and D. Sukumar. 2010. Effect of different types of heat processing on chemical changes in tuna. *Journal of Food Science and Technology-Mysore*, 47 (2): 174-181.

Terio, V., P. Di Pinto, N. Decaro, A. Parisi, C. Desario, V. Martella, C. Buonavoglia and M.G. Tantillo. 2010. Identification of tuna species in commercial cans by minor groove binder probe real-time polymerase chain reaction analysis of mitochondrial dna sequences. *Molecular and Cellular Probes*, 24 (6): 352-356.

Wells, R.J.D., S. Kohin, S.L.H. Teo, O.E. Snodgrass and K. Uosaki. 2013. Age and growth of north pacific albacore (thunnus alalunga): implications for stock assessment. *Fisheries Research*, 147: 55-62.

Williams, A.J., V. Allain, S.J. Nicol, K.J. Evans, S.D. Hoyle, C. Dupoux, E. Vourey and J. Dubosc. 2015. Vertical behavior and diet of albacore tuna (thunnus alalunga) vary with latitude in the south pacific ocean. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 113 (SI): 154-169.

Williams, A.J., J.H. Farley, S.D. Hoyle, C.R. Davies and S.J. Nicol. 2012. Spatial and sex-specific variation in growth of albacore tuna (thunnus alalunga) across the south pacific ocean. *Plos One*, 7 (e393186)

Wu, X. and Y. Su. 2014. Growth of staphylococcus aureus and enterotoxin production in pre-cooked tuna meat. *Food Control*, 42: 63-70.

Yamashita, Y., H. Amlund, T. Suzuki, T. Hara, M.A. Hossain, T. Yabu, K. Touhata and M. Yamashita. 2011. Selenoneine, total selenium, and total mercury content in the muscle of fishes. *Fisheries Science*, 77 (4): 679-686.

Young, J.W., A.J. Hobday, R.A. Campbell, R.J. Kloser, P.I. Bonham, L.A. Clementson and M.J. Lansdell. 2011. The biological oceanography of the east australian current and surrounding waters in relation to tuna and billfish catches off eastern australia. *Deep-Sea Research Part Ii-Topical Studies in Oceanography*, 58 (5): 720-733.

Young, J.W., M.J. Lansdell, R.A. Campbell, S.P. Cooper, F. Juanes and M.A. Guest. 2010. Feeding ecology and niche segregation in oceanic top predators off eastern australia. *Marine Biology*, 157 (11): 2347-2368.