SCIENTIFIC COMMITTEE
EIGHTH REGULAR SESSION

7-15 August 2012
Busan, Republic of Korea

Distribution and trend of abundance for porbeagle (*Lamna nasus*) in the Southern Hemisphere

WCPFC-SC8-2012/EB- IP-03

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Abstract

The knowledge on distribution is important element for the effective management and conservation of species. For bycatch species, fundamental information on its range and distributional pattern is often insufficient. Porbeagle (*Lamna nasus*) in the Southern Hemisphere is the common bycatch sharks in the tuna longline fishery but its distribution and abundance are largely unknown. Investigation of the fishery and survey data revealed the common occurrence of porbeagle in the pelagic waters in the South Pacific, southeastern Indian Ocean and off Cape in all seasons. Analysis of temperature at catch and ontogenetic stage suggested that porbeagles penetrate into higher latitude according to growth. Pregnant females were recorded in the Indian Ocean and Tasman Sea, but most frequently recorded around Cape between June and July. The trend of abundance estimated from the longline fishery and driftnet survey data indicated no continuous decreasing trend for porbeagle in the Southern Hemisphere during the period from 1994 to 2011 and from 1982 and 1990, respectively.

Considering the circumglobal distribution, stock status of this population should be assessed using information from coastal and pelagic waters and the international coordination across the oceans is necessary for the effective management of this population.

Introduction

The relationship between distribution and abundance of species are one of central theme in ecology and its importance in the management and conservation has been recognized widely. Practically, the knowledge on geographical range and core area of habitat of certain species is imperative for the reliable assessment of population status and effective fisheries management for exploited species. To evaluate the impact of fishery on the population, the overlap between fishery effort and geographical distribution of species has to be considered precisely. In case of bycatch species, available information from fishery on its distribution tend to be limited by the spatio-temporal distribution of fishing effort which is chasing the migration of target species and thus this is not always overlapped with the core habitat area of bycatch species. Generally, pelagic sharks are caught as bycatch of tuna fisheries and the information from fisheries should be evaluated from the viewpoint of its representativeness before used for stock assessment. Therefore, the integration of information from various sources is necessary to grasp the outline of its distributional pattern especially for sharks with wide geographical range.

Porbeagles (*Lamna nasus*) are lamnid sharks that inhabit temperate, subarctic, and subantarctic waters. This species are distributed in the North Atlantic Ocean and supposed to occur in a circumglobal band in the southern Pacific, Atlantic and Indian Oceans (Last and Stevens 1994, Yatsu 1995, Compagno 2001). Among Lamnidae, porbeagles prefer cooler temperature than species of *Isurus* and *Carcharodon* and are caught frequently at temperatures from 5 to 10 ℃(Campana and Joyce 2004). They are common littoral and epipelagic shark, most abundant on the continental offshore fishing banks, but also found far from land (Compagno 2001). Although recent satellite tagging research revealed that they conduct large-scale movement to off-shelf or oceanic regions in both sides of North Atlantic (Pade *et al*. 2009, Saunders *et al*. 2011), the detailed distributional pattern in the pelagic ocean is largely unknown in both hemispheres.

In common with other Lamnidae species, the reproductive system of this species is aplacental viviparity with oophagy and the litter size is reported to be four (Francis and Stevens 2000, Jensen *et al*. 2002). The gestation period is estimated to be shorter than one year (8-9 months both in North Atlantic and southwest Pacific) and one-year reproductive cycle has been indicated for the northern population. Coupled with late maturity (50% age at maturity for male: 8-11 years, for female: 13-18 years, Jensen *et al*. 2002, Francis *et al*. 2007) and slow growth rate (Natanson *et al*. 2002, Francis *et al*. 2007), the productivity of this species is estimated to be low (Dulvy *et al*. 2008, Cortés *et al*. 2010). Regarding the interaction with human, porbeagles of North Atlantic have history of intense exploitation and collapse. The target fishery for porbeagle began first in the northeast Atlantic since at least 1920s (Gauld 1989, Francis *et al*. 2008) but collapsed in the 1960s due to the intense and unregulated fishery. Much of the effort in the east shifted to the western area in 1961, followed by the collapse in the 1960s and again in the 1990s in the western North Atlantic (Camhi 2008, Campana *et al*. 2008). Consequently, strict management restrictions on catch have been introduced in each fishing country and regional fishery management organization. In Northeastern Atlantic, no fishery has been allowed since the implementation of a zero total allowable catch (TAC) in 2010. In the Northwestern Atlantic, Canada and the United States adopted domestic TAC with the closure of mating grounds to target fishery to target fisheries in the Canadian EEZ. Although the stock status has remained low level, the sign of recovery has been indicated for northwest population (ICCAT 2009). In New Zealand, catch quotas were introduced in 2004 and there is a general finning ban in Australia.

The concern about the deterioration of stock status has been also developed in the southern population based on the similar life history trait (Francis and Stevens 2000, Francis *et al*. 2007) and the decline of population which was suggested in the limited area (southwest Atlantic; Pons and Domingo 2010). However, there are some differences in the situation surrounding the population between the North Atlantic and the Southern Hemisphere. First, the range of southern population is supposed to be wider than that of northern population judging from the fragmental record. The distributional pattern and the stock structure is necessary to be investigated to elucidate the implication of decline in the limited area. The distribution in the pelagic water was confirmed in some areas (Compagno 2001), but not for throughout the Southern Hemisphere. Second, porbeagles in the Southern Hemisphere have not been targeted but caught mainly as bycatch in the longline fisheries targeting for southern bluefin tuna (*Thunnus maccoyii*) as well as other species in the high latitude (Francis *et al*. 2008). The impact of fishery for this population is suggested to be different between northern and southern population, but it is largely unknown for southern population.

In the Southern Hemisphere, the knowledge on the biology and the quantitative evaluation of fisheries on the stock has been limited compared to the northern population. Although some dedicated studies were made in the Southwest Pacific (Francis and Stevens 2000, Francis *et al*. 2001, Francis and Duffy 2005), the research from the comprehensive view throughout the Southern Hemisphere is insufficient. Considering the widespread attention for this species and relative insufficient knowledge for southern population, it is important to integrate the available information fragmentally collected throughout the Southern Hemisphere for better understanding.

Fishery-dependent survey provides the information on the distribution of various species which interacts with the fishery. The longline fishery for southern bluefin tuna (hereafter indicated as “SBT”) has been developed in the temperate area in the Southern Hemisphere (Shingu 1978). The observer program for SBT fisheries and other fishery survey interacting with porbeagle can be a useful source to obtain new knowledge on its distribution and biological traits for the population.

The aim of this study is to (1) describe the geographical range and the distributional pattern of porbeagle in the Southern Hemisphere based on the SBT observer data and fishery survey data, and (2) to estimate the trend of abundance for this population using the data of Japanese tuna longline fishery and driftnet survey.

Materials and Methods

Data

Catch, effort and size data for porbeagle from commercial distant-water longline operation and longline and driftnet survey were used in this study. Data from commercial distant-water longline were obtained by the on-board observer data for Japanese southern bluefin tuna longline fishery (hereafter, indicated as “SBT observer”) and logbook data from Japanese tuna longline fishery (hereafter, indicated as “logbook data”). Data from longline survey and driftnet survey were obtained from the new fishery resources survey conducted by Japan Marine Fisheries Resources Research Center (present Marine Fisheries Research and Development Center, Fisheries Research Agency; hereafter, indicated as “JAMARC”). For the description of distribution, SBT obsever data and JAMARC data were used. For estimation of historical trend of porbeagle abundance, SBT observer data, logbook data and the driftnet survey data of JAMARC were used. The brief summary of each data source was shown in Table1.

(i) SBT observer data

The SBT observer data was obtained from the scientific observer program of Commission for the Conservation of Southern Bluefin Tuna (CCSBT) for Japanese distant-water longline fishery. The data was available from 1992 to 2010. The main fishing ground observed was waters off Cape, southeastern Indian Ocean and Tasman Sea (Figure 1). The observed area ranged from tropical to temperate area. The outlines in the observed set is as follows; number of branch lines between floats is 6-11, mean number of hooks per set is about 3100, and the shallowest and deepest depth of gear are approximately 50-100 m and 120-180 m, respectively. The gear setting started in 6:40 am and gear retrieving started in 4 pm, respectively.

The observer also collected information about longline operation (i.e., date, location and time of gear setting and retrieving, number of branch lines between floats, total hook number developed, sea surface temperature at noon position), catch number and weight (round or processed) of porbeagle, and biological data (i.e., body length, weight, sex, maturity status, and number of embryo for pregnant females) of porbeagle. In this program, precaudal length (PCL: cm) has been used as the standard body length for porbeagle. The measurement of body length was conducted to the nearest centimeter and body weight (round and/or processed) was weighed to the nearest kg (for large animals more than 10 kg) or 100 g (for smaller animals below 10 kg) on the board.

(ii) Tuna longline logbook data

Catch number of porbeagle and effort (hook number) data per set was available from

Japanese tuna longline fishery in the Southern Hemisphere between 1994 and 2011. For the estimation of population abundance, filtering of logbook data was conducted by extracting the cruise data of which reporting rate (number of set with shark catch / total number of set in one cruise) was more than 80 % (Matsunaga 2009, Matsunaga 2012).

(iii) JAMARC longline survey (indicated as “JAMARC LL survey”)

JAMARC conducted longline survey for butterfly kingfish (*Gasterochisma melampus*) between1987 and 1994 (JAMARC 1987~1994). This survey was conducted from subtropical to subantarctic area exclusively in the South Pacific Ocean (Figure 1). The gear configuration in JAMARC LL survey is as follows; number of branch lines between floats is 6-8 except two surveys between 1994 and 1996, mean number of hooks per set is about 2400, and the shallowest and deepest depth of gear are 50-120 m and 150-225 m, respectively. The gear setting started in 3 am and gear retrieving started in 12:30 pm, respectively.

JAMARC LL data consists of operational data which is same with SBT observe data and catch number and weight (round and processed) of porbeagle.

(iv) JAMARC driftnet data (indicated as “JAMARC DN data”)

JAMARC conducted large mesh driftnet survey targeting for *Allothunnus fallai* between 1982 and 1990 (JAMARC 1982~1989) and for pomfret (Bramidae spp.) between 1984 and 1986 (JAMARC 1984~1987). Both surveys were combined for analysis because the gear configurations were almost same. A series of survey was conducted exclusively in the South Pacific Ocean mainly between July and April (Figure 1). The net was set before the sunset and retrieved four to eight hours after the setting. The mesh size of 150 mm, 160 mm, and 180 mm were used most frequently and the net depth was approximately 10 m. The mean number of net per set is 690 and mean length of net is 33.8 m, respectively.

JAMARC DN data consists of details of operation (e.g. date, location and time of setting, the number, mesh size, length and depth of driftnet, sea surface temperature at setting) and catch number and weight (round and processed weight) of porbeagle.

These data was used for both analysis of distribution and estimation of population abundance in the South Pacific.

Analysis

Distribution

For the description of distribution, the catch and effort data was compiled by 5° by 5°degrees and CPUE was calculated separately for SBT observer, JAMARC LL data, and JAMARC DN data. The definition of CPUE was the catch number of porbeagle per 1000 hooks for longline gear and the catch number of porbeagle per 1000 m for driftnet gear. Two types of CPUE were calculated. For overview of spatial distribution, CPUE was calculated by aggregating the data of all year and all month (hereafter, indicated as “overall CPUE”). For overview of spatio-temporal distribution, seasonal CPUE was calculated by dividing the catch and effort data into four seasons but all year aggregated (hereafter, indicated as “seasonal CPUE”). The season was divided into four quarters as follows; spring (October to December), summer (January to March), autumn (April to June), and winter (July to September).

For the overview of ontogenetic distributional pattern, the size data with the information of sex in the SBT observer data was mainly used. Each individual in the SBT observer was classified into three ontogenetic stages (i.e., neonate, juvenile, and adult) based on the criteria below. The pregnant females were treated as the separate stage and spatio-temporal information was summarized. The record of single individual with round weight in JAMARC LL and JAMARC DN survey was converted into PCL using the length-weight equation estimated by Morinobu (1996). The converted PCL data only from JAMARC LL survey was included in the analysis of ontogenetic distribution. The definition of neonate was decided as the individuals between birth length and the estimated size at 1 year old using growth equation estimated by Morinobu (1996). For males, juvenile and adult were separated based on the length at maturity (midpoint of estimated size range) by Francis and Stevens (2000). For females, the length at maturity was set as the minimum size of pregnant females in the SBT observer data because of the discrepancy of estimates by Francis and Stevens (2000) and observed size of pregnant females in our data.

Neonate: < 78 cm PCL for both sexes

Juvenile: < 129 cm PCL for males, < 153 cm PCL for females

Adult: >= 129 cm PCL for males, >= 153 cm PCL for females

For individuals without information of sex, if the PCL is smaller than 129 cm, it was treated as juvenile and if the PCL is larger than 153 cm, it was treated as adult. Individuals between 129 cm and 153 cm were removed from the ontogenetic analysis.

The individual data with assigned category was compiled into the catch number by category per set. This catch number and effort data for each category were aggregated into 5° by 5°degrees with year and month aggregated and CPUE for each category was calculated.

In order to evaluate the ontogenetic distributional pattern focusing on the environmental factor, sea surface temperature at catch was compared among ontogenetic stage by one-way ANOVA. All data from SBT observer and converted size data from JAMARC LL and DN survey were used for the analysis. As the temperature is affected by month, ANOVA analysis was conducted by each month, but year and area (indicated in Figure 2a) were combined because of the biased distribution of observation.

For the sex ratio, all data was divided into strata consisting of ontogenetic stage, month, and area (indicated in Figure 2a), and the strata without individuals with gender undetermined were extracted. For the selected strata, sex ratio was tested by binomial test.

Relative abundance

Standardized CPUE was estimated using a Generalized Linear Modeling (GLM) approach through GENMOD procedure of SAS (version 9.2).

In GLM analysis for tuna longline fishery data, negative binomial distribution was assumed as the error distribution because of high ratio of sets with zero catch for porbeagle (ca. 90%) in every year but no apparent yearly trend for the ratio of zero catch. At first, the following form was assumed as a full model.

Catch number of porbeagle = (Effort)*Exp (Intercept + *year* + *quarter* + *area* + *gear* + interaction + error) error~ NB (α, β)

where Effort is offset variable (log-transformed hook number), *year* is effect of year (1994-2011), *quarter* is the effect of season (1~4), *area* is the effect of area (1~4), *gear* is the effect of gear depth (1~2), and interactions is two-way interactions. All explanatory variables were treated as categorical. For *gear* effects, the depth of gear was classified by the number of branch lines between floats (number in bracket); gear1 (6~10) and gear 2 (11-15). For *area* effect, the Southern Hemisphere was divided into 4 subareas based on the distribution of fishery data (Figure 2a).

In GLM analysis for the driftnet survey data between 1982 and 1990, log-normal error distribution was assumed because of the pattern of catch and much smaller AIC compared to the model assuming negative binomial error distribution. The following model was assumed for standardization,

Log (CPUE+constant) = Intercept + *year* + *area* +*SST* + error, error~N (0, σ^2)

where log is natural logarithm, *year* is effect of year (1982-1990), *SST* was included as categorical variable consisting of 8 categories (5~7.9℃, 8~9.9℃, 10~11.9℃, 12~13.9℃, 14~15.9℃, 16~17.9℃, 18~19.9℃, 20℃~). SST was included instead of quarter because of the shallow gear depth and the result of model selection indicating much smaller AIC than that of the model including quarter. The mesh size was not included as the main effects because of common mesh size among surveys. In order to overcome the problem of zero catch, the one-tenth of mean CPUE was uniformly added to each value of nominal CPUE as the constant term. Survey ground was divided into four subareas (Figure 2) based on the oceanographic characteristics described in Yatsu (1995).

In these standardizations, model selection was conducted by stepwise F-test and the variables with statistical significance at 0.01% were included in the final model. Based on the final model, LSMEANS (least square means) was calculated and yearly trend of standardized CPUE was constructed.

Results

General Distribution

The overall CPUE from SBT observer data and JAMARC LL survey indicates that porbeagles are widely distributed longitudinally in the pelagic waters of the Southern Hemisphere (Figure 3). The northern and southern limit of occurrence was recorded at 28°30’ S and 53°39’ S in SBT observer and 22°18’ S and 60°S in JAMARC LL, respectively. Continuous distribution was indicated at least between the South Pacific and the southeastern Indian Ocean and between the southwestern Indian Ocean and the southeastern Atlantic Ocean. Latitudinaly, CPUE in the area south of 40°S was larger than that in the north of 40°S except in the southeastern Indian Ocean. CPUE in the south of 50°S was notably larger than that in northern area of the South Pacific. In relation to the temperature, porbeagles were caught in temperature ranging from 3.0 °C to 24.0 °C in JAMARC LL survey and from 6.5 °C to 20 .9 °C in SBT observer data. The highest CPUE was recorded in 10.5 °C in the former and 9.3 °C in the latter, respectively.

The CPUE in JAMARC DN survey indicates that the occurrence of porbeagles is clearly different at 35°S latitudinally (Figure 3). The northern and southern limit of occurrence was 28°16’S and 56°44.3’S, respectively. Between 25°S and 35°S, CPUE was very small compared to the southern area of 35°S. In area south of 35°S, porbeagle was constantly recorded across the South Pacific. Longitudinally, CPUE between the dateline and 140°W was higher than that in more eastern area. The continuous CPUE within the South Pacific supplement the result of JAMARC LL. In relation to temperature, porbeagles were caught in the temperature ranging from 5.0 °C to 19.6 °C and the highest CPUE was reported at 13.3 °C.

Seasonal Distribution

Figure 4 indicates the seasonal CPUE for porbeagle recorded in SBT observer data and JAMARC LL survey. As the effort was not distributed evenly among seasons, seasonal change in CPUE was not clearly indicated. In the summer, high abundance was recorded in the area south of 40°S across the South Pacific. In areas east of 120° W, the area with high abundance moved from south in spring and summer to north in autumn and winter.

Figure 5 indicates the seasonal CPUE for porbeagle recorded in JAMARC DN survey. Regarding the area west of 140°W, CPUE in the south of 40°S increased in the summer compared to the spring. Porbeagles were absent between 140°W and 100°W in the north of 40°S in the spring, while CPUE increased in the same area in the winter. These results suggest the south-north movement between spring and winter.

In both fishing gear, the aseasonal occurrence of porbeagles in the pelagic ocean was clearly indicated.

Ontogenetic Distribution

The CPUE by ontogenetic stage was shown in Figure 6. Generally, CPUE of neonate was large in the area north of 40°S except off Cape. According to the growth, porbeagles tend to penetrate into the higher latitude. Especially, in the area south of 40°S off Cape, CPUE of juvenile was much larger than that of neonate. The CPUE of adults was smaller than other categories, but little overlap of distribution was observed between neonates and adults.

ANOVA analysis indicated that the sea surface temperature was different among ontogenetic stages in every month (P<0.05). The box-plot between sea surface temperature and ontogenetic category was shown in Figure 7. According to the growth, the temperature at catch became lower.

Statistical test for the sex ratio was performed to neonate, juvenile, and adults. As a result of exclusion of strata with gender unidentified, the data from 7 strata for neonate and juvenile, and 9 strata for adults were tested (Table2). For neonates, sex ratio was even in 5 strata (April and November in waters off Cape, January and July in the southeastern Indian Ocean, August in Tasman Sea) but female dominated in May (P=0.015) and June (P<0.01) in the southeastern Indian Ocean. For juveniles, sex ratio in all strata was even. However, for adults, sex ratio was biased to males (P<0.05) in 5 strata (July in waters off Cape, August to November in the southeastern Indian Ocean) and even in other 4 strata (May in Tasman Sea, July in the southeastern Indian Ocean and Tasman Sea).

The pregnant females were recorded in the waters off Cape, the southeastern Indian Ocean and Tasman Sea, but most frequently observed in the waters off Cape (Figure 6). In the area off Cape, they were most frequently recorded in June and July. The records in the Indian Ocean and Tasman Sea were obtained in August and July, respectively.

Trend of population abundance

The final GLM model adopted for standardization of longline CPUE was,

Catch number= (Effort)*Exp(Intercept + *year* + *quarter* + *area* + *gear* + *quarter***gear* + *area***gear* + error) error~NB (α, β)

Variable selection based on aforementioned criteria allowed including two interactions between “quarter and gear” and “area and gear”. All factors included were significant (P < 0.0001) as indicated in Table 3. The overall trend of standardized CPUE for porbeagle caught by Japanese tuna longline fishery in the Southern Hemisphere was relatively stable with some fluctuation until around 2007. After 2008, although the fluctuation range became larger, the level of CPUE was relatively high compared to preceding years (Figure 8). To compare with the standardized CPUE estimated from SBT observer data, the estimates in the present study and estimate in Matsunaga *et al*. (2012) were compared. Each series of standardized CPUE was normalized by adjusting the mean of each series as one because of difference in the scale between estimates. Although some time lag was indicated for the trend of CPUE between series, both trends were similar within the overlapped period (Figure 8).

The estimated annual trend of CPUE from JAMARC DN survey was stable approximately between 0.08 and 0.12 during the period analyzed (Figure9). Except year effect, both area and sst were significant as indicated in Table 3. Figure 10 indicates the distribution of standardized residual for these two models and suggests the used data fitted the selected error distribution.

Discussion

Geographical range

The present study indicated the continuous occurrence of porbeagle in the pelagic ocean between the South Pacific and the southeastern Indian Ocean, and between southwestern Indian Ocean and the southeastern Atlantic Ocean. Additionally, the common distribution in the pelagic ocean was also indicated in the Southern Hemisphere.

Combining the existing records on occurrence in this area (Compagno 2001), the distribution of southern population is suggested to be continuous among the South Pacific, South Indian Ocean, and southeastern Atlantic at least, although the occurrence of porbeagle in the central South Indian Ocean was not confirmed in the present study. The genetic study suggests that populations in the South Atlantic and the South Indian Ocean are not genetically separated (Kitamura and Matsunaga 2009). Considering the wide distribution and possible connectivity among oceans, the geographical range of southern population is likely wider than that in the northern population. The strong tendency to concentrate in the coastal region and low abundance in the pelagic ocean which are indicated in the North Atlantic are unlikely applicable to the Southern Hemisphere.

Latitudinally, the present study provided new record on the southern limit (60 °S) of porbeagle in the South Pacific. In the South Pacific, porbeagle is the third most dominant species in the Subantarctic region (approximately south of 40°S with seasonal fluctuation for the boundary) at least in the summer and the early autumn (Yatsu 1995). In the present study, the highest CPUE in longline data was recorded around 10 to 11°C in SST but relatively high CPUE was recorded at 3°C at 60°S in JAMARC LL survey. However, more than 80% of longline operation was conducted in the temperature above 11 °C in SBT observer data. Considering these facts, SBT fishing ground in at least Japanese SBT longline fishery concentrates in the warmer or northern side of habitat of southern porbeagle.

Ontogenetic distributional pattern

The present study indicated that porbeagles tend to penetrate into the higher latitude as they grow and that the distribution between neonate and adults are rarely overlapped. The difference in the sea surface temperature at catch among the ontogenetic stages indicated that the temperature at catch tended to be lower according to the growth.

Many sharks are known to segregate their habitat by size and sex (Springer 1967). For porbeagles, past report suggests the segregation by size (Yatsu 1995) and by sex (Aasen 1963, O'Boyle *et al*. 1998). Yatsu (1995) reported that CPUE in weight increases as the latitude gets higher in the South Pacific. The present study described the spatial difference of distribution more precisely by the ontogenetic CPUE and indicated the same pattern in other oceans.

Regarding the distribution of adults, the southern limit recorded in the present study was 52 °S. The covered area (i.e., southern limit) by SBT observer is limited by the longline operation for SBT and thus our result does not mean that adult porbeagles is not distributed south of 52 °S. Existing knowledge supports the distribution of adults in higher latitude. For example, Svetlov (1976) reported the occurrence of postpartum female of 218 cm total length in the Antarctic waters (54°28' S, 35°29'W). In the South Pacific, aggregation of pregnant female occurred in the high latitude around 60°S (Sawadaishi *per. Comm*.). In the North Atlantic, large sharks are recorded to occur in the North Sea (Gauld 1989) and around New Foundland (Aasen 1963). Considering these available information, adults, especially adult females, are potentially distributed in higher latitude outside of fishery and survey. The difference of temperature at catch among ontogenetic stages suggests that the preference or tolerance to low temperature may change according to the growth.

Occurrence on the pregnant female

We provided new information on the constant occurrence of pregnant female in waters off Cape and one record from the southeastern Indian Ocean and Tasman Sea, respectively. In the area off Cape, pregnant females were recorded almost every year during the period observed. Throughout a year, they were caught from May to September, but mostly in June and July. According to the study in the southwest Pacific Ocean (Francis and Stevens 2000), parturition peaks in June-July (winter). Small neonates between 50 cm (PCL) and 60 cm (PCL) were recorded from May to October with the largest number in June and July in the same area (*Semba unpublished*). In the Southern Hemisphere, there is some record of pregnant female from New Zealand and Australia and they are mostly within EEZ (Francis and Stevens 2000). The information from the present study suggests that pregnant females are distributed in the pelagic area and that the area off Cape may be one of the parturition grounds in the Southern Hemisphere.

Sex ratio

In this study, sex ratio in each ontogenetic stage was indicated by area and month. In immature stage, sex ratio was even except for neonate with dominance of females in May and June in the southeastern Indian Ocean. In adult stage, male dominated except for May and July with even sex ratio in Tasman Sea and July in the southeastern Indian Ocean.

The even sex ratio in premature stage and its shift to male-biased sex ratio in adult stage have been also reported in the southwest Pacific (Francis and Stevens 2000).This change suggests the segregation by mature females from immature sharks and adult males. The temporal change into even sex ratio in adults means that more adult female was caught in May and July than other month. If the peak of mating occurs in the fall same with the North Atlantic (Aasen 1963, Jensen *et al*. 2002), the even sex ratio for adults in May and July may be related to the mating event in these areas.

Trend of population abundance

This study estimated that the trend of population abundance for porbeagle using the tuna longline logbook data and JAMARC DN survey data which covered the wide range in the Southern Hemisphere. The standardized CPUE from SBT observer data was used for comparison of trend because of its high reliability on the catch number of porbeagle. The standardized CPUE estimated from tuna longline logbook data showed relative stable trend between 1994 and 2007 with some fluctuation. Low CPUE in 2004 and high CPUE in 2011 are suggested to be caused by smaller number of observations and would not reflect actual trend of abundance. After 2008, CPUE showed large fluctuation above the level of CPUE in preceding years. The standardized CPUE estimated from SBT observer data also showed no declining trend and this trend was generally similar to the trend from logbook data. Considering with the high reliability of observer data and the correspondence of trend between estimates from these datasets, the estimates from the logbook data reflect the trend of population abundance of porbeagle caught in SBT fisheries. As most porbeagles caught by tuna longline are juveniles (Francis *et al*. 2007), the present study indicates that the trend of abundance of juveniles in the Southern Hemisphere has been relatively stable during the period analyzed. This stable trend of juveniles may reflect that the large-scale fisheries interacting with adult individuals do not exist in the pelagic area south of SBT fishery ground (CCAMLR 2011).

The standardized CPUE estimated from JAMARC DN survey data showed also stable trend in the South Pacific between 1982 and 1990. Because further survey has not been conducted after 1990, the trend of population abundance in the South Pacific after 1990 is unknown. However, the impact by large-scale fishery on porbeagles in this area is suggested to be small because SBT fishery has not been developed in this area and the overlap between the purse seine fishery ground developed in the eastern Pacific and the range of porbeagle is likely small.

Conclusion

The present study showed new aspects of distribution of porbeagle in the Southern Hemisphere in various scales and estimated the trend of abundance in wide range. In population scale, the wide distribution in the pelagic waters was common across oceans and the occurrence in the high latitude was also indicated. In more fine scale, the ontogenetic difference in the distribution suggested the penetration into higher latitude by large individuals. A series of results clearly indicate that the pelagic ocean is an important habitat for this population than previously thought. The area covered in the present study may be northern part of distribution for southern porbeagle where neonates and juvenile dominate..In the Southern Hemisphere, adult individuals including mature females segregate from neonates and juveniles, and are highly likely to be distributed in higher latitude (e.g. south of 50° S) with colder environment where was not covered in this study. The trend of standardized CPUE showing no significant drops indicates that the level of abundance for neonates and juveniles has not changed largely during the period analyzed.

For sustainable management and conservation of this population, continuous investigation on the biological aspects such as the distribution of adults and stock assessment based on fishery statistics from both coastal and pelagic area are necessary.

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Table1. Summary of data used in this document.

Type	Name	Fishery	Target	Period	Month	Research area	Effort (number of hook or driftnet)	Number of Porbeagle	observed size range
Commercial (observer)	SBT observer	Longline	SBT	1992 - 2010	Year round	Southern Hemisphere	34,879,196	11,954	48 -226 cm PCL
Survey	JAMARC LL	Longline	butterfly kingfish	1987 - 1994	Year round	South Pacific	1,949,554	494	8 - 149 kg[*2]
Survey	JAMARC DN	Driftnet	*Allothunnus fallai*	1982 - 1990	9 - 3	South Pacific	461,119	3,897	5 - 125 kg[*2]
		Driftnet	Brama spp.	1984 - 1986	7 - 4	South Pacific	237,616	237,616	3 - 112 kg[*2]
Commercial (logbook)	Tuna longline logbook data	Longline	SBT	1994 - 2011	Year round	Southern Hemisphere	177,842,293[*1]	24,163[*1]	n.a.

※1: amount after filtering
※2: round weight for single catch data

Name	purpose of use				
	spatial distribution	ontogenetic distribution	sex ratio	temperature and ontogenetic stage	abundance
SBT observer	○	○	○	○	×
JAMARC LL	○	partial	×	partial	×
JAMARC DN	○	×	×	partial	○
	○	×	×	partial	○
Tuna longline logbook data	×	×	×	×	○

Table2. The result of binomial test for sex ratio of each category.

(a) neonate

Month	South Pacific	off Cape	Southeastern Indian Ocean
1		even	
2			
3			
4	even		
5		0.01535^{f}	
6		<0.001^{f}	
7		even	
8			even
9			
10			
11	even		
12			

(b) juvenile

Month	South Pacific	off Cape	Southeastern Indian Ocean
1			
2			
3			
4	even		even
5			even
6		even	
7		even	even
8			
9			
10	even		
11			
12			

(c) adult

Month	South Pacific	off Cape	Southeastern Indian Ocean
1			
2			
3			
4			
5			even
6			
7	<0.001^{m}	even	even
8		0.001831^{m}	
9		<0.001^{m}	
10		<0.001^{m}	
11		0.0266^{m}	
12			

f and m indicate the female and male biased sex ratio, respectively.

Table3. ANOVA table of the model adopted for CPUE standardization for longline fishery (left) and driftnet fishery (right).

Effort	df	Chi square	Pr > ChiSq
year	17	540.01	<.0001
area	3	457.02	<.0001
quarter	3	76.78	<.0001
gear	1	144.4	<.0001
quarter*gear	3	59.18	<.0001
area*gear	3	203.16	<.0001

Effort	df	sum of square	mean square	F value	Pr >F
year	8	10.9294803	1.366185	2.28	0.0201
area	3	74.243417	24.7478057	41.36	<.0001
sst	7	280.98471	40.1406728	67.09	<.0001

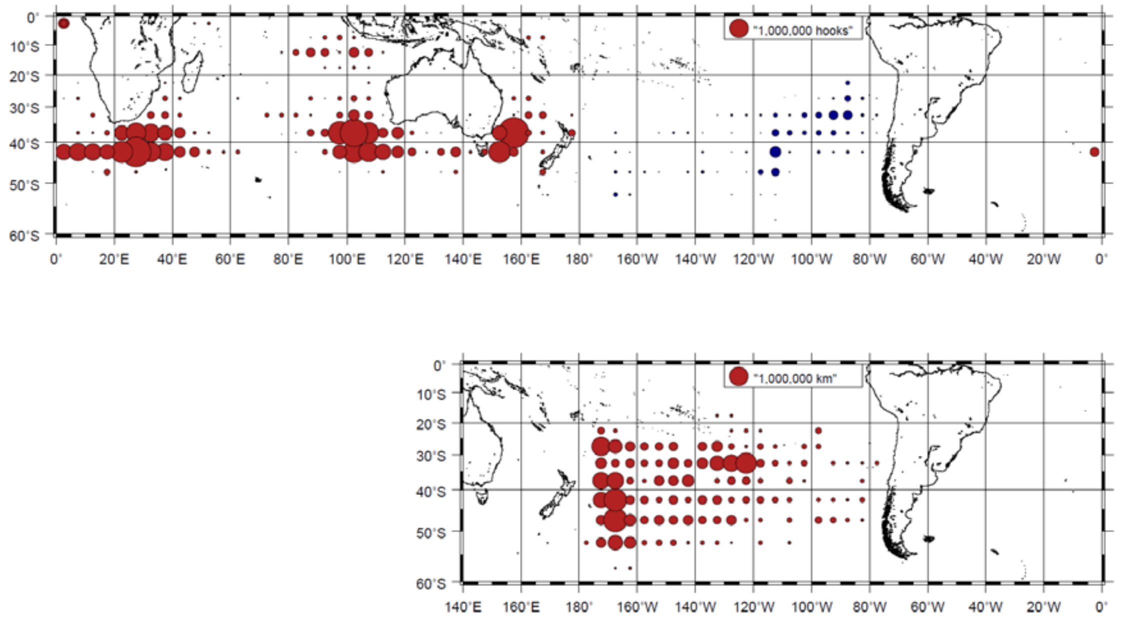

Figure1. Distribution of effort in the longline (upper) research (SBT observer and Gastero survey) and driftnet (lower) survey (for Allothunnus and pomfret). For longline survey, the effort in Gastero survey was indicated by blue circle. For driftnet survey, effort in two surveys was aggregated.

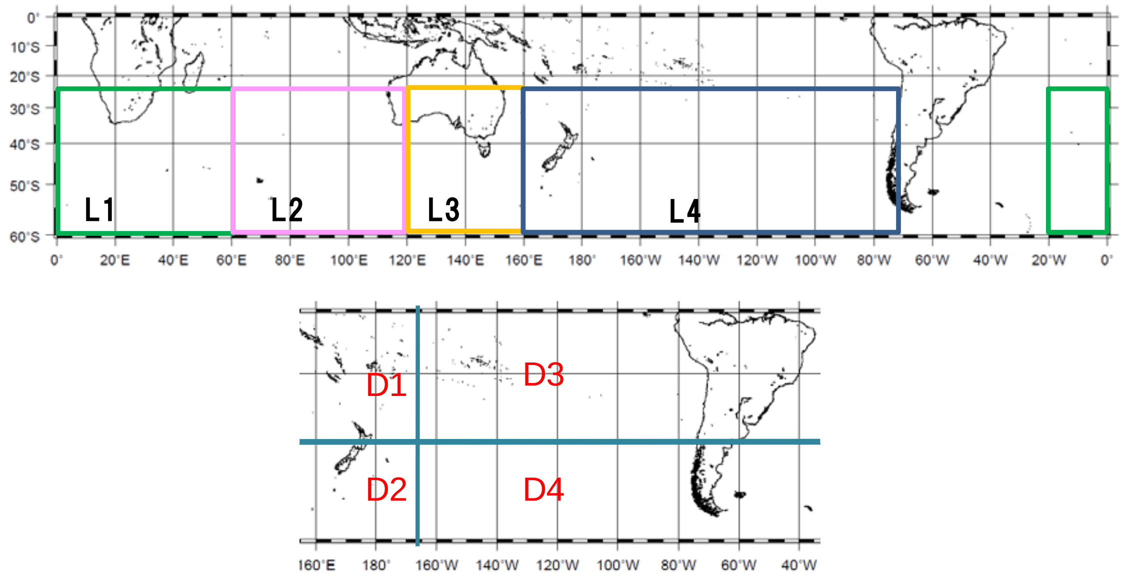

Figure 2: Subareas for CPUE standardization for longline data (upper) and driftnet data (lower).

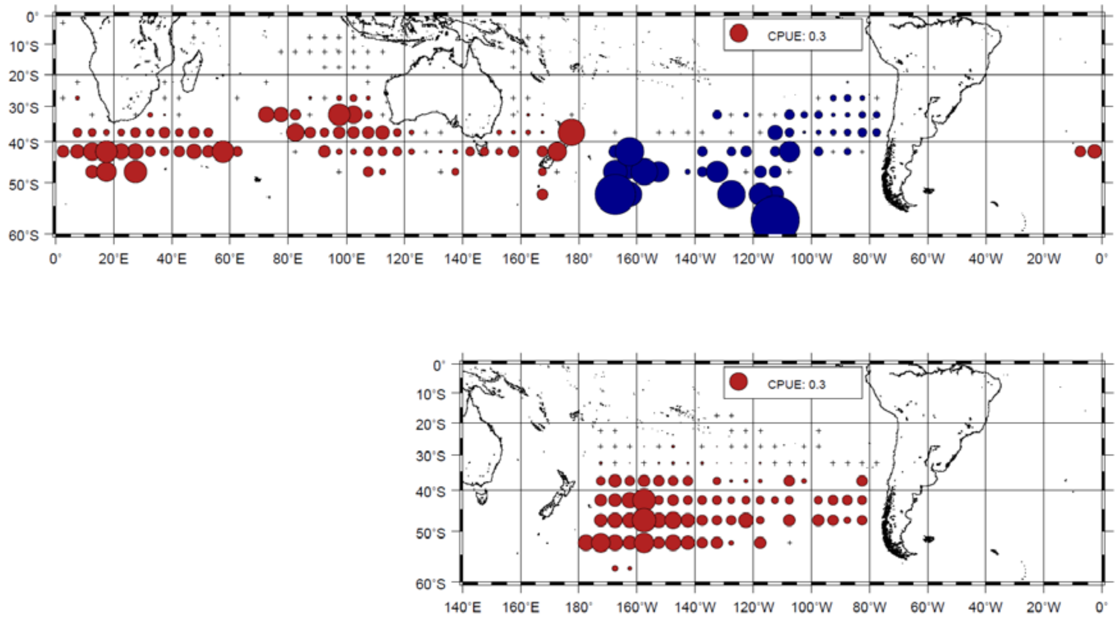

Figure 3: Overall CPUE in 5by 5 degrees for longline (upper) and driftnet (lower) survey. Year and month are aggregated in both CPUE. For longline survey, the CPUE in Gastero survey was indicated by blue. Cross mark denotes no catch.

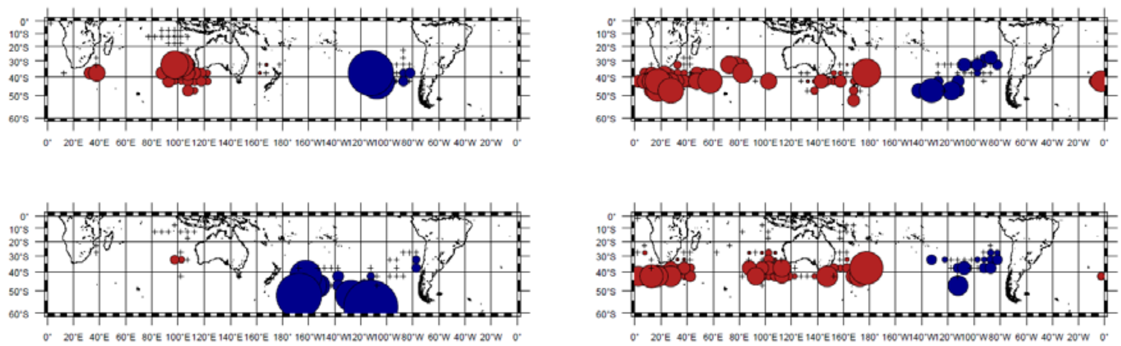

Figure.4: Seasonal distribution of CPUE in 5by 5 degrees from longline research. (left top: spring, left down: summer, right top: autumn, right down: winter). CPUE in Gastero survey was indicated by blue. Cross mark denotes no catch.

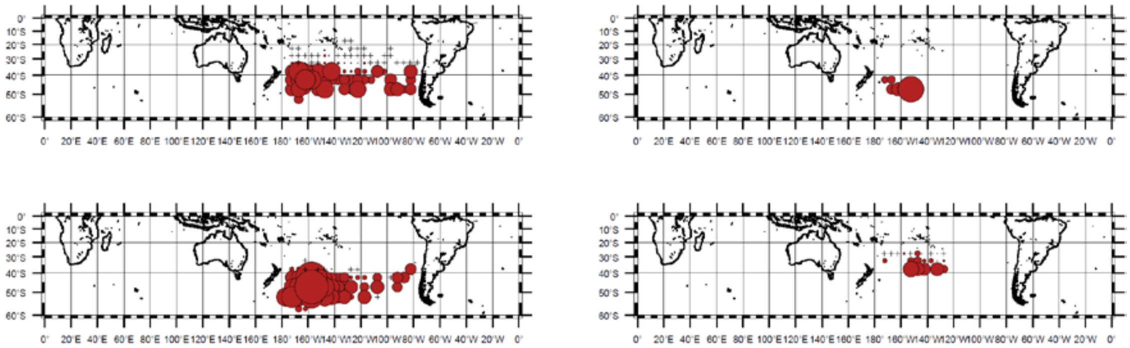

Figure.5: Seasonal distribution of CPUE in 5by 5 degrees from driftnet research. (left top: spring, left down: summer, right top: autumn, right down: winter). Cross mark denotes no catch.

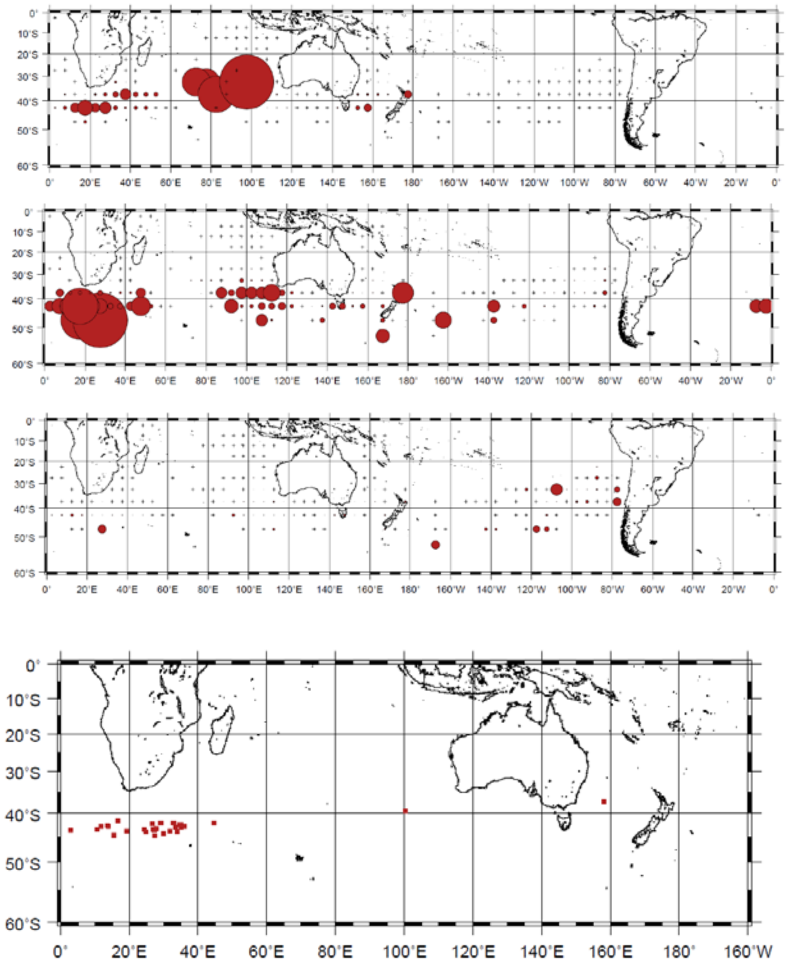

Figure 6. Overall CPUE of each ontogenetic stages (top: neonate, second: juvenile, third: adult) and the locality of record for pregnant females (forth). Cross mark denotes no catch.

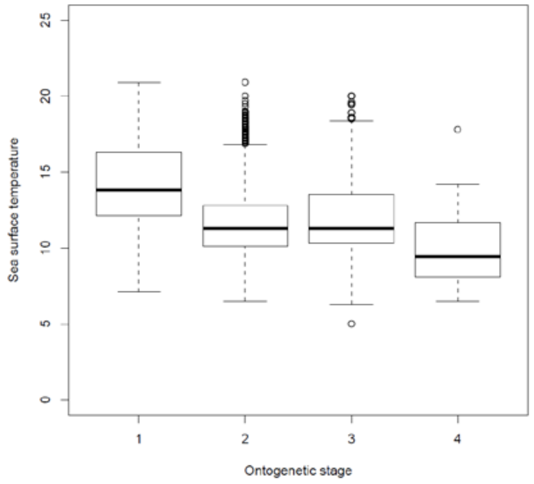

Figure 7. Box-plot for the distribution of temperature at catch by ontogenetic stages (Y-axis: temperature at catch and X-axis is ontogenetic stage:1 neonate, 2 juvenile, 3adult, 4 pregnant female)

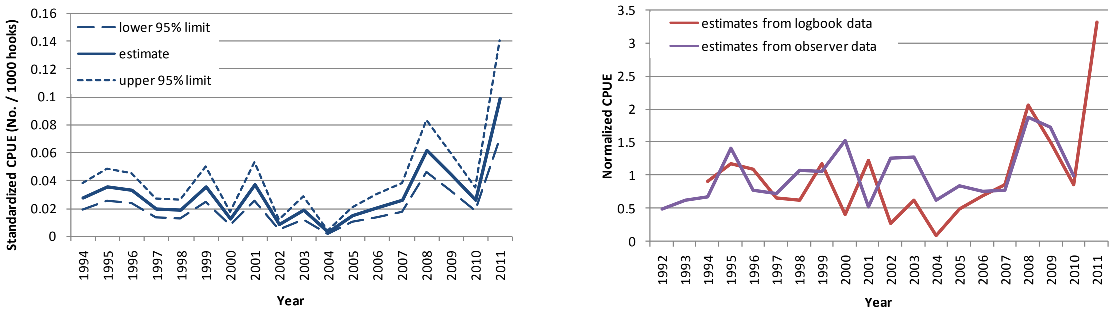

Figure8. Standardized CPUE for porbeagle based on the logbook data from Japanese tuna longline fishery from1994 to 2011 (left) and normalized CPUE of two standardized CPUE series from SBT observer data and logbook data (right).

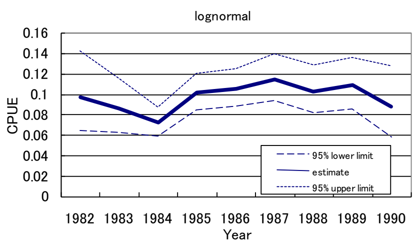

Figure9. Standardized CPUE for porbeagle based on driftnet survey data from 1982 to 1990.

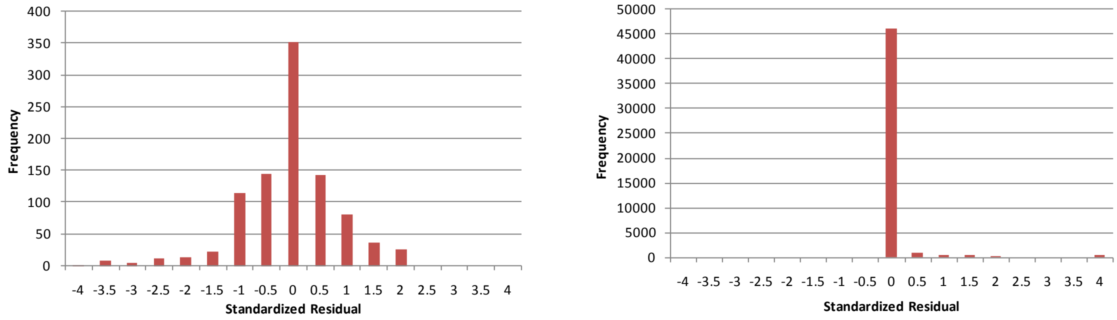

Figure 10. The plot of standardized residual in the selected model for longline (left) and driftnet (right).