Distribution and temporal trend of standardized CPUE of porbeagle (*Lamna nasus*) in the Southern Hemisphere from Japanese research and logbook data.

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Abstract

The information on the distributional pattern and the trend of relative abundance of porbeagle (*Lamna nasus*) in the Southern Hemisphere was reported. Traditionally, the distribution of this species has been believed to be concentrated in the coastal area and the knowledge on the distribution in the high seas has been relatively scarce, especially in the Southern Hemisphere. However, the records from a series of past research and ongoing observer cruises in Japan indicated the wide distribution and frequent occurrence of this species in the high seas in the Southern Hemisphere, and suggested the possible connectivity among oceans in the Southern Hemisphere. Standardized CPUE (catch number per 1000 hooks) based on Japanese tuna longline logbook data suggested that the relative abundance of this species in the Southern Hemisphere was relatively stable between 1994 and 2011.

Considering the wide distribution and relatively stable trend of abundance, stock status of this population should be assessed using the information from both coastal areas and pelagic waters. The international coordination across the oceans is necessary for the effective management of this species in the Southern Hemisphere.

Introduction

Porbeagles (*Lamna nasus*) are lamnid sharks that inhabit temperate, subarctic, and subantarctic waters. They are common littoral and epipelagic shark, but most abundant on the continental offshore fishing banks and can be found far from land (Compagno 2001).

Recently, the stock status of North Atlantic population has drawn attention as the current level of stock was suggested to be low in the stock assessment by ICES/ICCAT in 2009. Although this population has been traditionally utilized as food source for a long time with additional removal as bycatch by tuna longline fishery, the recovery plan for this population (e.g. compliance of TAC, size restriction) has been in action and the sign of recovery has been indicated for northwest population （ICCAT 2009）. While most of the catch has been from directed fishery (mainly by longline gear) in the North Atlantic, they are caught as bycatch in the Southern Hemisphere (Francis *et al*. 2008). As to the Japanese longline vessels, this species has been caught as bycatch both in the North Atlantic (while targeting Atlantic bluefin tuna, *Thunnus thynnus*) and the Southern Hemisphere (while targeting southern bluefin tuna, *Thunnus maccoyii*).

Corresponding to the increasing attention on its stock status, the knowledge on its biology and its fishery statistics for population in the North Atlantic has been accumulated compared to in the Southern Hemisphere (reviewed in Francis *et al*. 2008). For example, tagging research provided new information on spatial ecology of this species; porbeagles were believed to occupy localized areas on the continental shelf in general and their large movement was not known, but satellite tag 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). On the other hand, in the Southern Hemisphere, the biological information and fishery statistic is largely unknown except a few reports in a limited country (Francis and Stevens 2000, Francis *et al*. 2001, Francis and Duffy 2005). As the basic information on the distribution is unknown in the Southern Hemisphere, the connectivity of population is uncertain, which hampers reliable stock assessment and management for population in this region.

Japan has conducted scientific observer program for southern bluefin tuna fishery since 1992 and collected catch and size data on the porbeagle with high precision. Additionally, research on the potential fishery resources was conducted in the South Pacific in the past, in which the catch information of porbeagle was recorded. Summary of this information would provide the new knowledge of distribution of porbeagle in the Southern Hemisphere and work as basic information for further research and effective stock management for this population.

The aim of this document is to (1) describe the distributional pattern of porbeagle based on the past research data and ongoing observer data and (2) to report the preliminary result of CPUE standardization for porbeagle using the logbook data of Japanese tuna longline fishery in the Southern Hemisphere.

Materials and Methods

Data

Two different sources of data were used in this document. For the description of distribution, the observer data for the southern bluefin tuna longline fishery (Real Time Monitoring Program for SBT: hereafter, indicated as “RTMP”) and the research data for new fishery resources which was conducted by Japan Marine Fisheries Resources Research Center (known as “JAMARC”, Present Marine Fisheries Research and Development Center <JAMARC>, Fisheries Research Agency) were used. For CPUE standardization, the logbook data from Japanese tuna longline fishery was used.

(i) Research and observer data

<u>Pelagic longline</u>: Longline gear was used in RTMP (1992-2009) and “Gastero” (*Gasterochisma melampus*) research cruise (1987-1994) by JAMARC.

Data from RTMP includes both fishery data (such as location and date of catch, catch number and effort) and biological data for porbeagle (such as body length, body weight, processed weight, sex, maturity, and number of embryo with sex). In RTMP, precaudal length (PCL: cm) has been used as the standard body length for porbeagle.

The research data from “Gastero” consists of operational data (e.g. location and date of catch, hook number) and catch data (e.g. catch number, round weight, and processed weight) for porbeagle in the South Pacific.

Driftnet: Large mesh driftnet gear was used in “Allothunnus” (*Allothunnus fallai*) research (1982 - 1990) and pomfret research (1984 to 1986) by JAMARC. Data from these researches consists of operational data (e.g. location and date of operation, number of driftnet) and catch data (e.g. catch number/weight) for porbeagle in the South Pacific.

The detail information and yearly trend of effort for each research was indicated in Table 1 and Figure 1, respectively.

As an index of abundance, CPUE was calculated and mapped for longline and driftnet fishery, respectively. For longline, CPUE was defined as catch number per 1000 hooks and for driftnet, CPUE was defined as catch number per 1000 tan after standardizing the length of 1 tan as 50m after Yatsu (1995).

(ii) Tuna longline logbook data

Catch and effort data for porbeagle from the logbook of Japanese tuna longline fishery in the Southern Hemisphere was available from 1994 to 2011. This data was used for CPUE standardization after the data of cruise with over 80% reporting rate (number of operations with shark catch / total number of operations in one cruise) was extracted for the analysis, based on the past documents which treated shark catch data in Japanese logbook (Matsunaga and Nakano 2002, Matsunaga 2010).

Distribution

For description of distribution, the catch and effort data from research and observer data was compiled by 5° by 5°degrees and CPUE was calculated by each research. At first, the distribution of effort and CPUE was described by aggregating year and month by each research. Then, CPUE was described by season (definition was indicated below) for RTMP and Gastero research. For two gillnet researches, data was combined and divided into 4 seasons.

Based on the information of body length and sex, each individual was classified into three ontogenetic stages (i.e. juvenile, subadult, and adult) using data from RTMP. Each stage was defined after Francis and Stevens (2000) as follows;

Juvenile: < 125 cm PCL for males, < 145 cm PCL for females

Adult: >=125 cm PCL for males, >=145 cm PCL for females
Based on this criterion, the distribution of each ontogenetic stage as well as pregnant female was described.

CPUE standardization

Standardized CPUE (catch in number per 1000 hooks) was estimated using a Generalized Linear Modeling (GLM) approach through GENMOD procedure of SAS (version 9.2).

For GLM analysis, negative binomial distribution was assumed as the error distribution because the ratio of "zero catch" in the data was high (ca. 90%) in every year but no apparent yearly trend was observed for the ratio of zero catch (Figure 2). As the explanatory variables, *year*, *area*, *season* and *gear* were treated as categorical and set as main effect.

$$\text{Catch number} = (\text{Effort})*\text{Exp}(\text{Intercept} + \textit{year} + \textit{quarter} + \textit{area} + \textit{gear} + \text{interaction} + \text{error})$$

$$\text{error} \sim NB(\alpha, \beta)$$

where gear reflects the depth of gear, which was classified by the number of hooks per basket (number in bracket); gear1 (6~10)and gear 2 (11-15) and quarter was divided as follows; quarter1 (October to December), quarter2 (January to March), quarter3 (April to June), and quarter4 (July to September). Considering the distribution of effort and CPUE (Figure 3) and coverage of filtered data, the fishing area was divided into 4 subareas (Figure 4).

For selection of variables, the main effect and interaction term which was statistically significant at 0.01% were included in the final model. Based on the final model, LSMEANS (least square means) was calculated and yearly trend of CPUE (i.e. standardized CPUE) was plotted.

Results

General Distribution

The effort in RTMP data was distributed in fishery ground of southern bluefin tuna, such as off Cape, off Freemantle, off Albany and around New Zealand (Figure 5). CPUE indicates that porbeagle occurs in the pelagic area commonly both in the South Indian Ocean and the southeast Atlantic Ocean (Figure 5). Although the amount of effort in the area south of 45 ° S was much smaller than northern area, the level of CPUE in this area was similar to that in northern area, which may suggest the frequent occurrence in the area at higher latitude.

Gastero survey was conducted in the South Pacific and CPUE distribution indicates that porbeagle was constantly recorded in areas south of 30 ° S and CPUE in the area south of 40 ° S was much larger than that in the northern area (Figure 6). Despite of relative low amount of effort in the area south of 40 ° S, CPUE in this region, especially in the southwestern Pacific, is higher than other area. Similar to the case in the RTMP data, this result suggests common occurrence of this species in high latitude south of 40 ° S.

Figure 7 and Figure 8 shows the distribution of effort and CPUE for porbeagle, recorded in the two gillnet researches. The effort of Allothunnus research expands widely in the South Pacific with intense effort in the area between the dateline and 160° W and middle South Pacific north of 40 ° S (Figure7). The pomfret research was conducted in the area between the dateline and 135° W with high effort in the western area (Figure8). In both data, the CPUE of porbeagle was high especially in the southern area (south of 40 ° S in the Allothunnus survey and south of 35 ° S in the pomfret survey). Additionally, the CPUE distribution of Allothunnus survey indicates high abundance in the area east of New Zealand compared to the southeastern region, and continuous distribution of porbeagle in the open ocean in the South Pacific (Figure 7).

Seasonal Distribution

Figure 9 indicates the seasonal distribution of porbeagle CPUE calculated from RTMP data. Although the distribution of effort was different among seasons, seasonal change of scale in CPUE was observed in some region. In areas around Tasman Sea, porbeagles were recorded in higher abundance in the winter than in the autumn.

Figure 10 indicates the seasonal distribution of porbeagle CPUE in the South Pacific, derived from Gastero research. In areas east of 120° W, the area with high abundance moved from north in spring to south in autumn.

Figure 11 indicates the seasonal distribution of porbeagle CPUE recorded in two gillnet researches (i.e. Allothunnus and Pomfret research). Both data was combined and seasonal CPUE was calculated. Comparing spring and summer, porbeagles were observed in the area between 35° S and 40° S in spring, but was absent in this area in summer, and relative abundance in the area south of 40° S in summer was larger than in spring.

Ontogenetic Distribution

The distribution by ontogenetic stage was similar between juveniles and adults (Figure 12). However, in the waters off Cape, adults are frequently observed in the area south of 40° S and juveniles are caught also in more temperate area.

The distribution of adults was plotted after dividing into male, non-pregnant female, and pregnant female (Figure 13). Off Cape, all of them occurred, while in the southeastern Indian Ocean and the Tasman Sea, only adult male and non-pregnant female were reported.

CPUE

The final GLM model adopted in this analysis is,

$$\text{Catch number} = (\text{Effort})*\text{Exp}(\text{Intercept} + year + quarter + area + gear + area*gear + \text{error})$$

$$\text{error} \sim \text{NB}(\alpha, \beta)$$

and ANOVA table was shown in Table 2. The distribution of data in each categorical variable made it difficult to calculate the interaction terms with year. As a result of examination on other 3 interactions, only interaction between area and gear was significant at 0.01% level. The estimated CPUE for 2004 was unnaturally low (nearly zero) and the reason of this is unknown at present. Overall trend of standardized CPUE was relatively stable with some fluctuation until around 2007(Figure 14). The estimates after 2008 were more variable than other years, which was also observed in the trend of standardized CPUE based on RTMP data (Matsunaga *et al*. 2012) and nominal CPUE (Figure 15).

Discussion

This document summarized the distributional pattern of porbeagle in the Southern Hemisphere in various scales. The research data collected in various researches indicated the wide and common distribution of porbeagle in the open ocean in the Southern Hemisphere.

With regard to Japanese fishery, porbeagles are commonly caught in the southern bluefin tuna fishery, but the distribution of effort and CPUE suggests that they occurs in high density in the area of high latitude (e.g. south of 50° S) where effort in the southern bluefin tuna fishery is not deployed in large scale. The seasonal change of distribution was not indicated clearly because of different distribution of effort by season, which may be revealed by the research using satellite tag in the future. Similarly, segregation by size and sex was not clearly indicated in this level of resolution. Although personal communication, according to one researcher on the past JAMARC Allothunnus research, aggregation of pregnant female occurred in the high latitude of the southeastern Pacific (Sawadaishi *per. Comm*.). Further research is necessary to understand the distribution and impacts by fishery to this population in the Southern Hemisphere.

Combining the past report on the coastal occurrence of this species (e.g. Francis *et al*. 2001) and the results in this document, it was suggested that porbeagles inhabit wide habitat in the Southern Hemisphere and its distribution is continuous at least between the South Pacific and the Indian Ocean, possibly between the Indian Ocean and the southeast Atlantic. Molecular study using mitochondrial DNA supports no sub-populations of this species in the southern bluefin tuna fishery ground and indicates that individuals from the South Atlantic and Indian Ocean are grouped in the same group (Kitamura and Matsunaga 2009). Additionally, haplotype diversity and nucleotide diversity of porbeagle in this fishery ground (N=94) are high, which suggests no trend of decline in the porbeagle stock in the southern bluefin tuna fishery ground (Kitamura and Matsunaga 2009). The GLM analysis reported in this document supports the result of this molecular study and no apparent continuous declining trend of stock was indicated for population in the Southern Hemisphere.

Although regional decline of stock is concerned in the waters off Uruguay (Pons and Domingo 2010), it should be cautious to draw conclusion that porbeagles in the Southern

Hemisphere are threatened with extinction, considering the wide range and the relatively stable trend of abundance, which was estimated based on the fishery data with wide coverage of its distribution. The international coordination across the oceans and the combination of fishery data by relating countries are necessary for the effective management of this species in the Southern Hemisphere.

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Table1. Summary of data used in this document.

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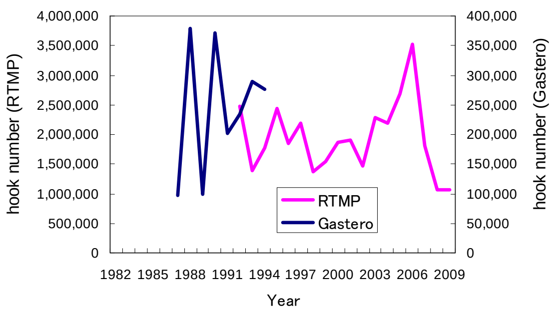
Type	Research title	Fishery	Period	Month (major research month)	Research area	Effort (number of hook or tan)	Number of Porbeagle
Survey	RTMP	Longline	1992 - 2009	Year round (5 -11)	Southern Hemisphere	34,879,196	11,954
Survey	Gastero	Longline	1987 - 1994	Year round	South Pacific	1,949,554	494
Survey	Allothunnus	Driftnet	1982 - 1990	9 - 3 (10 -2)	South Pacific	461,119	3,897
Survey	Pomfret	Driftnet	1984 - 1986	7 - 4 (8 -2)	South Pacific	237,616	237,616
Logbook	Tuna longline		1994 - 2011	Year round	Southern Hemisphere	177,842,293※	24,163※

※ data after filtering

Table2. ANOVA table of the model adopted for standardization.

Source	DF	Chi-Square	Pr > ChiSq
yr	17	498.95	<.0001
area	3	388.36	<.0001
qt	3	129.91	<.0001
gear	1	302.1	<.0001
area*gear	3	118.28	<.0001



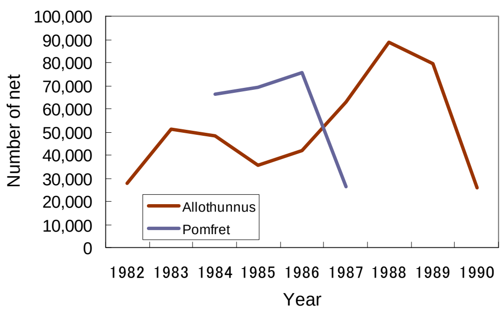


Figure 1 Temporal change of effort for research and observer data by fishery type. Number of hook and net was used as index of effort in longline (left) and driftnet (right) data.

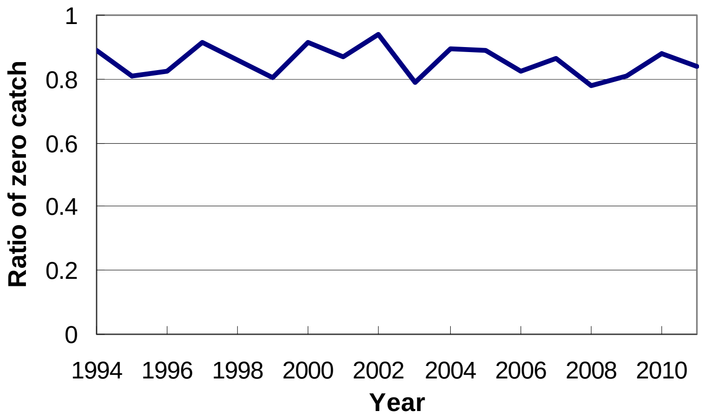


Figure2. Yearly trend of the ratio of zero catch in the logbook data after filtering.

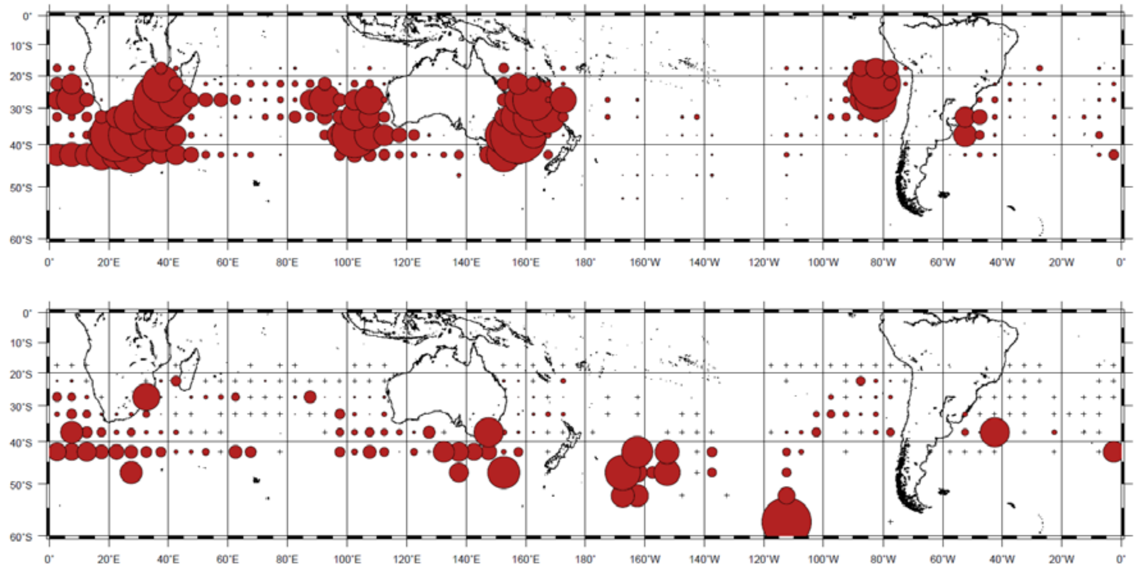


Figure3. The distribution of effort (upper) and CPUE (lower) calculated from filtered logbook data (1994-2011). The data in the area north of 15° S is not indicated. The effort and CPUE was transformed by calculating square root of original effort divided by 10000000 and of original CPUE divided by 10, respectively. Cross denotes the position where CPUE is zero.

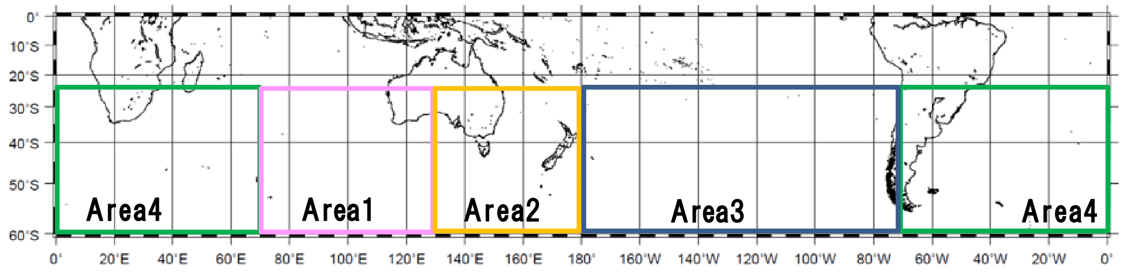


Figure4. The subarea used in the standardization of CPUE

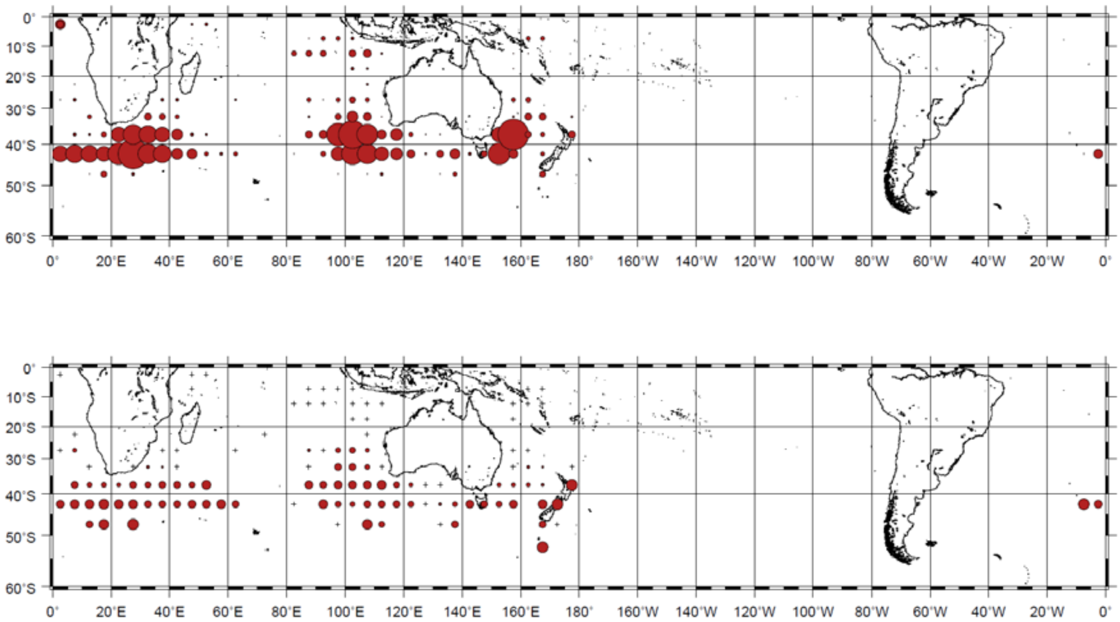


Figure5. The distribution of effort (upper) and CPUE (lower) calculated from the data of RTMP (1992-2009). The effort and CPUE was transformed by calculating square root of original effort divided by 10000000 and of original CPUE divided by 10, respectively. Cross denotes the position where CPUE is zero.

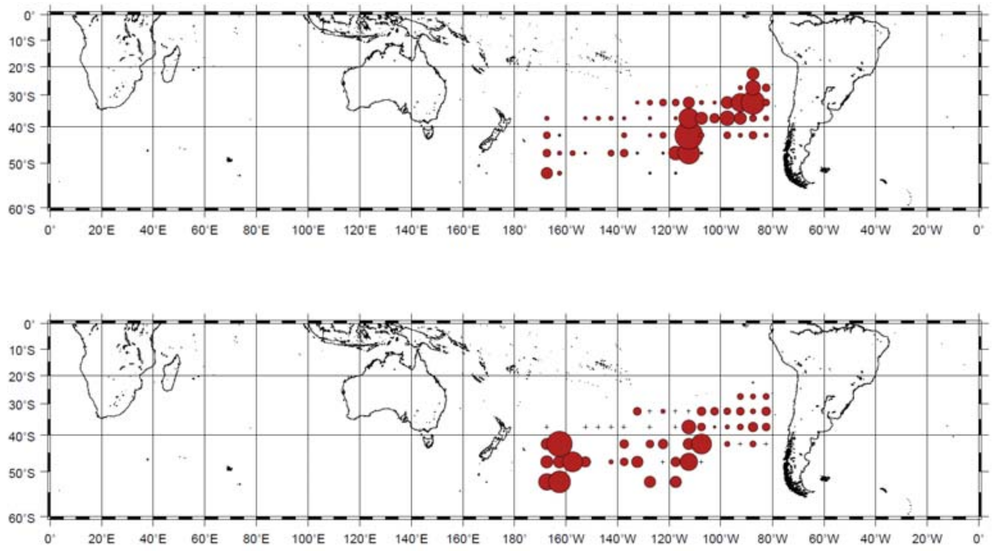


Figure6. The distribution of effort (upper) and CPUE (lower) calculated from the data of Gastero survey (1987-1994). The effort and CPUE was transformed by calculating square root of original effort divided by 1000000 and of original CPUE divided by 10, respectively. Cross denotes the position where CPUE is zero.

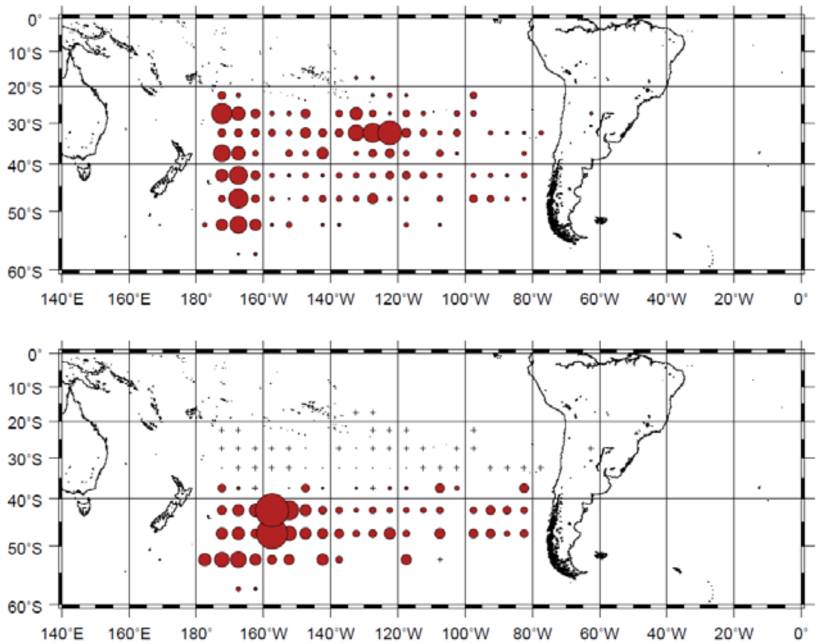


Figure7. The distribution of effort (upper) and CPUE (lower) calculated from the data of Allothunnus survey (1982-1990). The effort and CPUE were transformed by calculating square root of original effort divided by 10000000 and of original CPUE divided by 1000, respectively. Cross denotes the position where CPUE is zero.

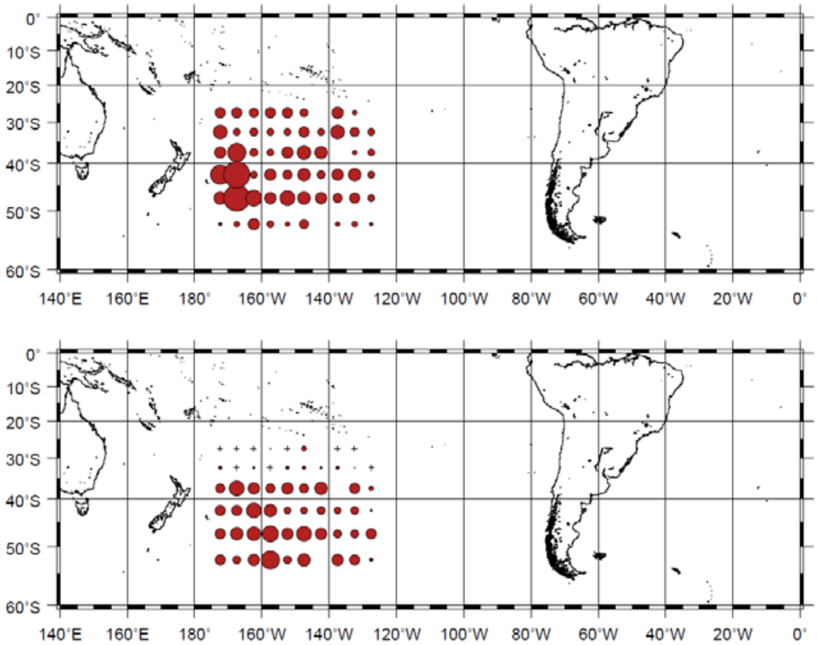


Figure8. The distribution of effort (upper) and CPUE (lower) calculated from the data of Pomfret survey (1984-1986). The effort and CPUE were transformed by calculating square root of original effort divided by 10000000 and of original CPUE divided by 1000. Cross denotes the position where CPUE is zero.

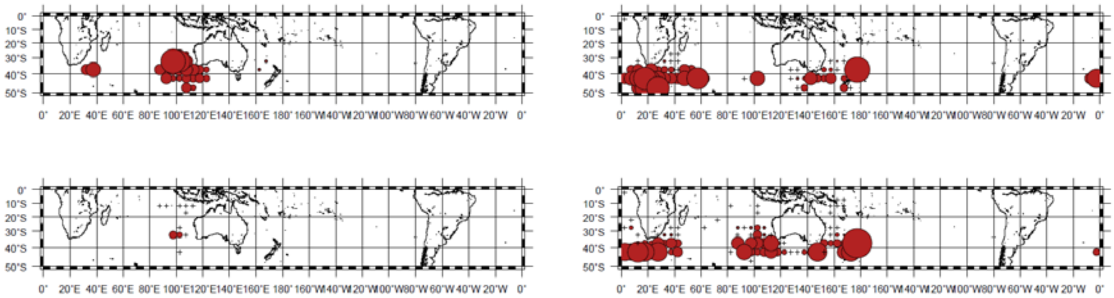


Figure9. Seasonal distribution of CPUE from RTMP data; spring (left, upper), summer (left, lower), autumn (right, upper), and winter (right, lower). CPUE was transformed by calculating square root of original CPUE divided by 10. Cross denotes the position where CPUE is zero.

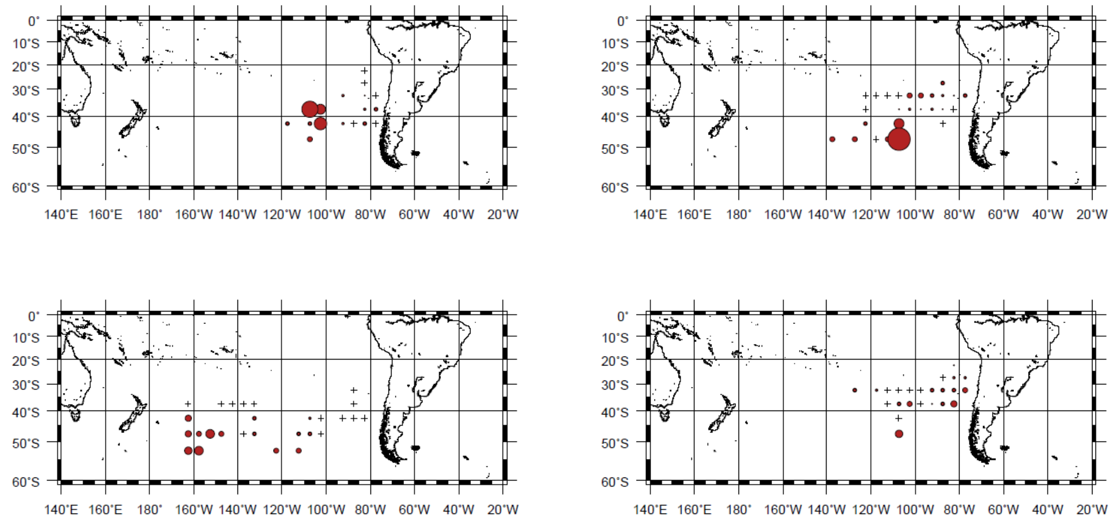


Figure10. Seasonal distribution of CPUE from Gastero research; spring (left, upper), summer (left, lower), autumn (right, upper), and winter (right, lower). CPUE was transformed by calculating square root of original CPUE divided by 100. Cross denotes the position where CPUE is zero.

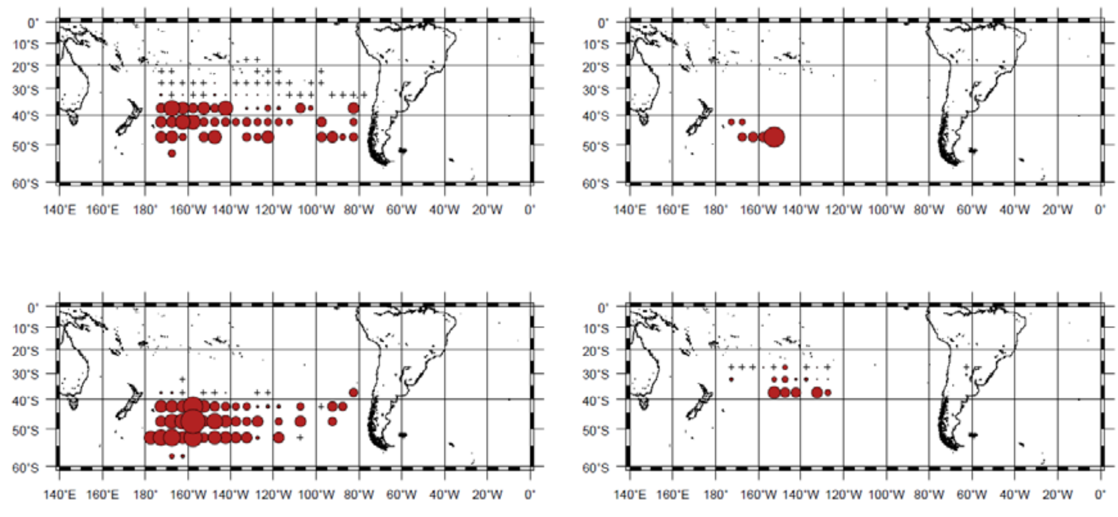


Figure11. Seasonal distribution of CPUE from two gillnet researches; spring (left, upper), summer (left, lower), autumn (right, upper), and winter (right, lower). CPUE was transformed by calculating square root of original CPUE divided by 100. Cross denotes the position where CPUE is zero

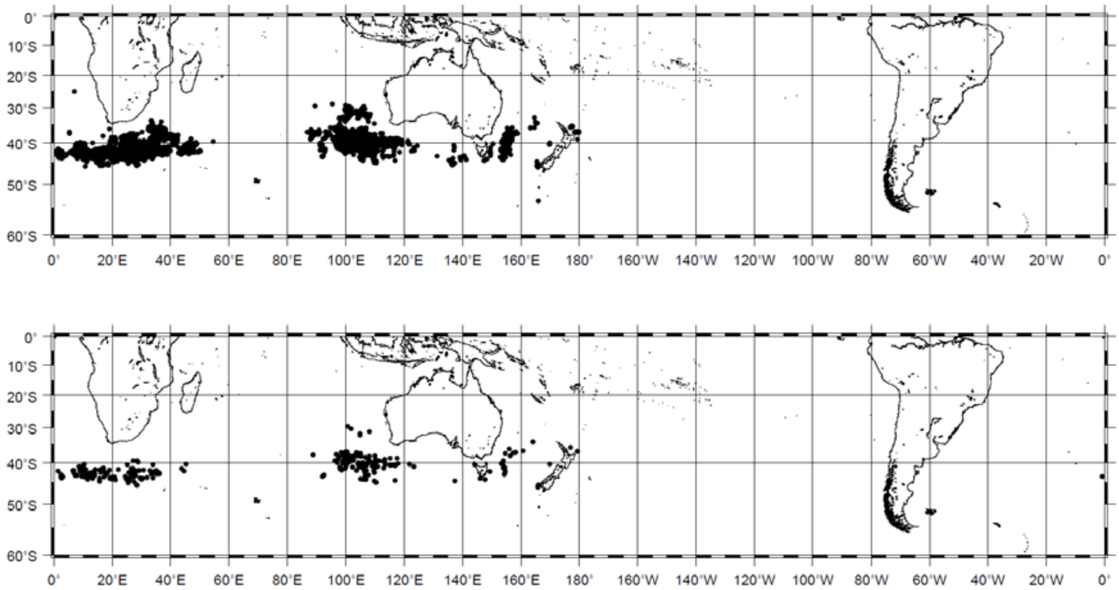


Figure12. The location of catch for juvenile (Upper) and adult (Lower) porbeagle.

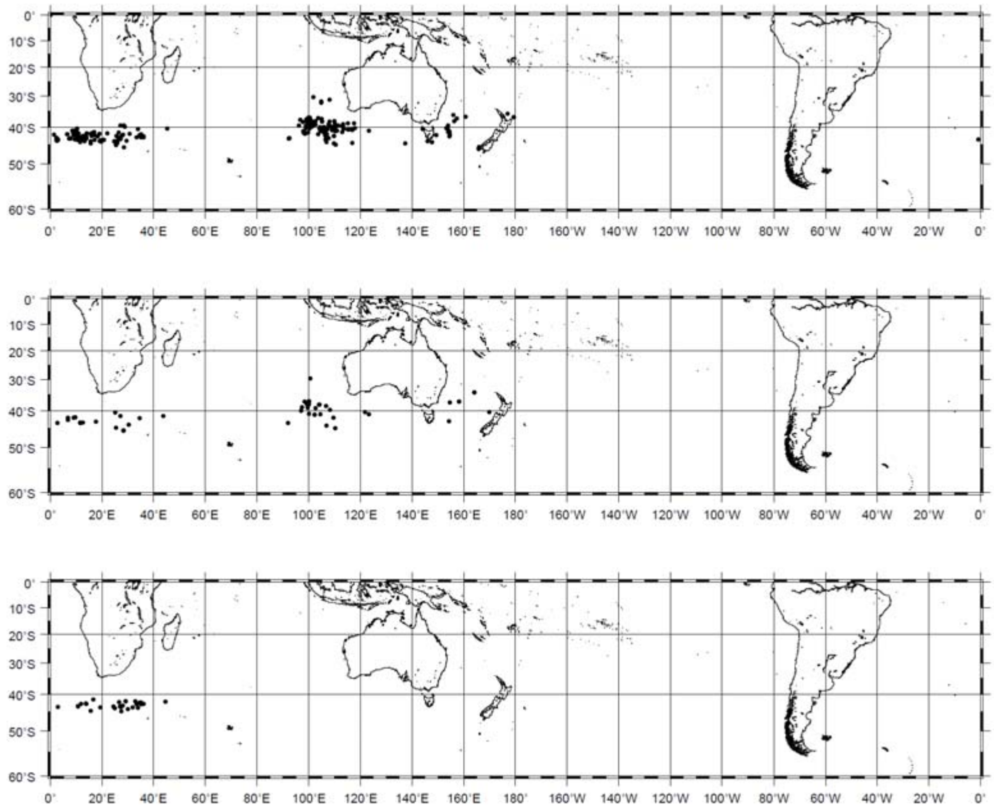


Figure 13. The location of catch for adult males (Upper), non-pregnant females (Middle), and pregnant females (Lower) recorded in RTMP database.

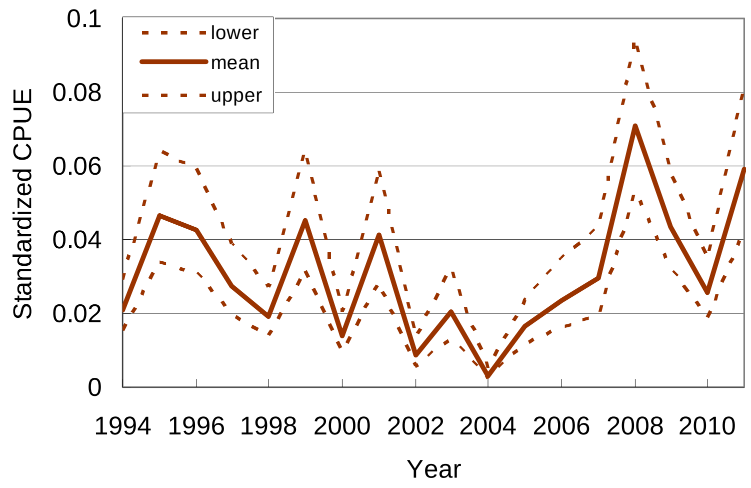


Figure 14. Temporal trend of standardized CPUE of porbeagle in the Southern Hemisphere between 1994 and 2011.

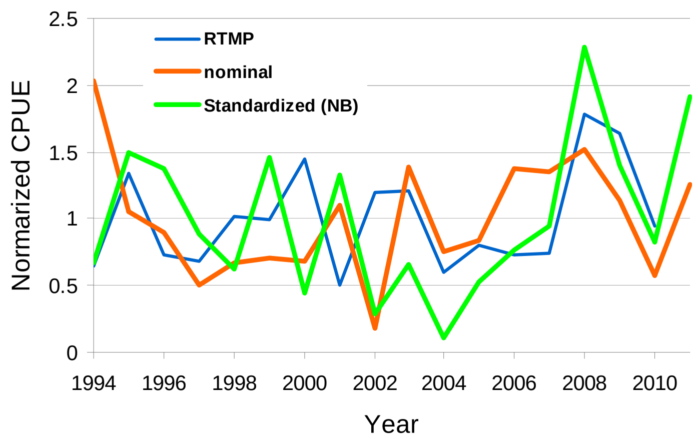


Figure 15. Relative year trends of standardized CPUE calculated from logbook data with nominal logbook CPUE and standardized CPUE calculated from RTMP for porbeagle (Matsunaga *et al*. 2012) in the Southern Hemisphere (average value is set to be 1.0).