Information Papers

1. Harvest control rule as a rebuilding plan and limit, Trigger or Threshold Reference Points for Pacific bluefin tuna

2. Progress Report after "Pacific Bluefin Tuna and Albacore Tuna Ageing Workshop" - 1. Annual Age Determination -

3. Progress Report after “Pacific Bluefin Tuna and Albacore tuna aging workshop” -2. Daily age determination -

4. Current Status of spawning grounds and periods of Pacific Bluefin Tuna.

July 2014

1. Harvest control rule as a rebuilding plan and limit, Trigger or Threshold Reference Points for Pacific bluefin tuna

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Summary

According to the most recent stock assessment of Pacific bluefin tuna conducted in Feb. 2014, spawning stock size is at near historical lowest level (ISC 2014) in most recent years. Furthermore, from 2009, recruitment strength continue to remain low level comparable to the level recorded during 1980s, when recruitments had been low level for about a decade. ISC PBF WG did not conclude the cause of recent low recruitments. This working paper does not attempt to pick up the cause. However if recent low recruitment continues, continuations of conservation measure by IATTC and WCPFC in 2014 in the future cannot expect to increase the stock size. This working paper rather attempt to present a rebuilding plan / harvest control rule (HCR) based on the harvesting scenarios proposed by WCPFC NC9, which can keep the stock safe zone in the sense that can likely to allow produce average recruitment level comparable to average recruitment during the stock assessment period (1952-2011) through simulations. This paper is in a position that if ISC should put first priority to agree with stock rebuilding plan for PBF, which can potentially turn out to HCR after rebuilding. This paper also suggests that limit reference point may be derived to keep the productivity of the stock healthy in the sense to prevent from recruitment overfishing and to allow large enough average recruitment which can allow long term sustainable fishing. The proposed HCR may be sufficient for this objective.

Introduction

As for biological reference points for Pacific bluefin tuna, ISC conducted extensive discussion, in particular, ISC10 plenary, which resulted in the listing of a suite of commonly used biological reference points with their pros and cons for use as limit reference point or target reference point. However until ISC13 there were few discussions further more. WCPFC-NC also held a workshop with managers and scientists on BRPs for “northern stock” but made no conclusion (ISC2010a, ISC2010b). As WCPFC developed a hierarchical approach to determine limit reference points of WCPFC stocks(WCPFC 2012), WCPFC NC made questionnaires on north Pacific albacore tuna and north Pacific swordfish to ISC to request provision of information to determine these species to a specific level of the hierarchical approach. For Pacific bluefin tuna, ISC13 tried adopting similar approach on Pacific bluefin tuna based on the questionnaires on north Pacific albacore but completed partially. Under current severely overexploited stock status, the establishment of stock rebuilding plan with rebuilding target and its objective, that can increase stock size enough is very urgent. 2014 ISC PBF stock assessment attempted to provide probability reaching potential rebuilding targets within 10 or 15 years in response to the WCPFC NC9's request (Attachment F of NC9 report, WCPFC 2013).

Catch reduction as described by scenario 6 of WCPFC NC9's request as stock rebuilding plan.

According to the results of the latest stock assessment conducted in February 2014(ISC2014), spawning stock size has been declining for more than decade and was nearly historically lowest level in recent years. "The recruitment level in 2012 was estimated to be relatively low (the 8th lowest in 61 years), and the average recruitment level for the last five years may have been below the historical average level" (ISC 2014). Although the 2014 PBF stock assessment did not conclude the cause of the possible recent low recruitments, there are two views with regard to the cause; 1) due to the reduced spawning stock size in recent years, 2) due to the possible low recruitment phase by the change of productivity of the stock or changes of environmental conditions which might affect recruitment strength. However the harm of continued low recruitment is evident. With continued low recruitment if management measures taken by both WCPFC and IATTC continue to 2015 and thereafter, SSB is not expected to increase. Even worse there is non-negligible risk of further decline of the stock. On the other hand, the scenario 6 out of 7 alternative scenarios (this includes scenario 1which is essentially continuation of management measures in 2014 in to future) is expected to increase median SSB in 2025 to about 68000t (ISC 2014). The next section will make considerations if this amount of increase sufficient in the sense to avoid the risk of recruitment overfishing.

Stock level that can support "safe" level of recruitment

ISC PBF WG has made long discussion on the stock recruitment relationship in the past stock assessment. From the model run, steepness even slightly below one like 0.96 did not allow convergence of model run except for 2012 stock assessment(p.5 of Carruthers 2013). Iwata 2012 concluded there is high probability of very high steepness through Monte Carlo simulation based on the life history parameters. The WG have not made the discussion of productivity of the stock at low stock size. However, intuitively, average recruitment should be expected to increase if stock size increases from low stock size. Simple analysis based on the scatter plot of SSB and recruitment of the base case run of Feb 2014 is shown in Fig. 1.

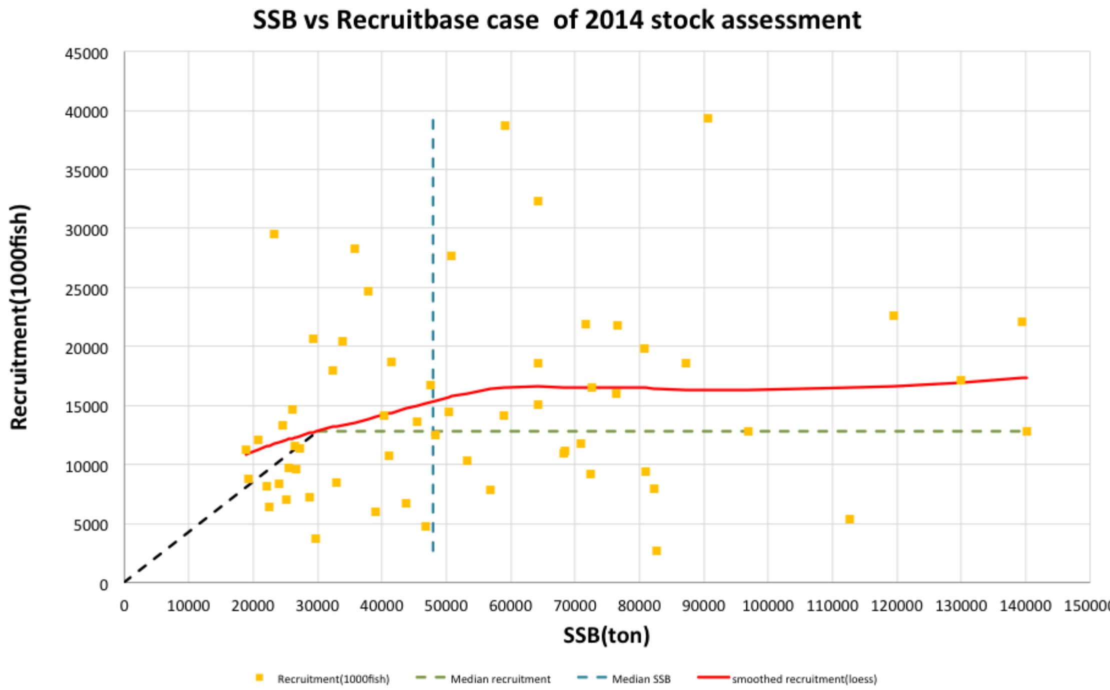

Fig 1 Scatter plot of SSB and recruitment (1952-2012) (square purple) and smoothed (using loess function of R software, local polynomial regression fitting) recruitment (red line), average recruitment (about 150 million fish, horizontal dashed line), median SSB (vertical dashed line, 47,995 ton, point estimate of 2014 base case), black dashed line from the origin to hinge point of hockey stick stock recruitment relationship used in simulations 2 and 3. Although very high variability around regression line, local polynomial

regression of stock recruitment also suggests that, if SSB is larger than median SSB, recruitment is likely to be higher than average recruitment and that if SSB is larger than about 30,000t recruitment may be around historical average.

If scatter plot is divided into the group of pair of SSB and recruitment by bellow and above median SSB (47,995t), average recruitments of the pairs with SSB below and above the median SSB were 12815 thousand fish and 16727 thousand fish respectively. Student-t test is not significant (P=0.076) if the median SSB is used a threshold, while it becomes significant (P=0.03) if 30,000t is used instead. This may suggest, if SSB is increased to the moderate size of SSB in the future, future average recruitment can be increased to the level more than the average level of recruitment of stock assessment period. If the average recruitment increases to that size, risk of recruitment overfishing should be reduced/minimized.

Simple simulation results

Feb 2014 stock assessment demonstrated that reduction of catch by scenario 6 is effective to increase the stock size under low recruitment. Scenario 6 can be a good candidate of the stock rebuilding plan from the current extremely low SSB size. Also ISC has repeatedly made conservation advice to reduce F by or below the F_{0204} (average F in 2002-2004). Then it comes to the simple idea to formulate simple harvest control rules as constant F strategy advocated by ISC, variants of scenario 6. This section shows the results of three simulation results as follows.

All the simulations assumed F is reduced to half of F_{0204} for 10 year from 2015 to 2024 using from the base case run of 2014 stock assessment to make starting stock size large enough, then from 2025 different harvest control rule is applied.

Simulation 1

This simulation used constant F strategy of F_{0204}. Future recruitment assumed to be randomly drawn from whole stock assessment period (average recruitment scenario) instead from the low recruitment period. This demonstrates under average recruitment stock can be maintained around median SSB without risk of stock collapse (Fig.2).

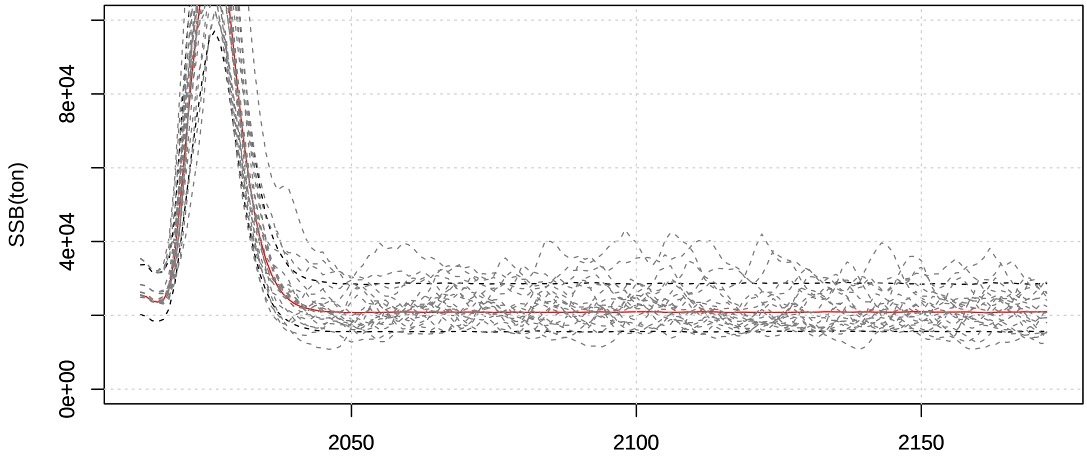

Fig 2 Median (red line) and lower and upper 10 percentiles (black dashed lines) of future SSB from simulation 1 with reduced F to 50% of F_{0204} for 10 years (2015-2014) and increased to F_{0204} afterward based on 2014 base case 300 SS bootstrapping runs. Future projection starts from 2012. From each bootstrap replication 20 future projections with randomly sampled recruitment in whole assessment period (1952-2011) were conducted. SSB will fluctuate around historical median SSB with negligible risk of declining to very low level after initial decline from 2025. Also in order to indicate fluctuations of future SSB of individual simulation 5, future SSB trajectories from 6000 replications were randomly sampled and shown in grey dashed lines.

Simulation 2

In addition to simulation 1, hockey stick stock recruitment relationship (Barrowman and Myers 2000) is introduced. This simulation suggested that there is certain level of risk of stock collapse due to accidental decline of stock size (Fig 3), if average recruitment decrease with declined stock size. Therefore it would be too optimistic to expect average recruitment remain stable, without any additional measure when stock declined to prevent vicious circle of impaired recruitment. Specifically, this simulation sets 30,000t of SSB as hinge point (if SSB is lower than this, average recruitment will be reduced to be proportional to size of SSB, see Fig. 1) of hockey stick SRR. This simulation revealed that the risk of declining very low level (including historically observed lowest SSB) will increase with F of F_{0204} year by year.

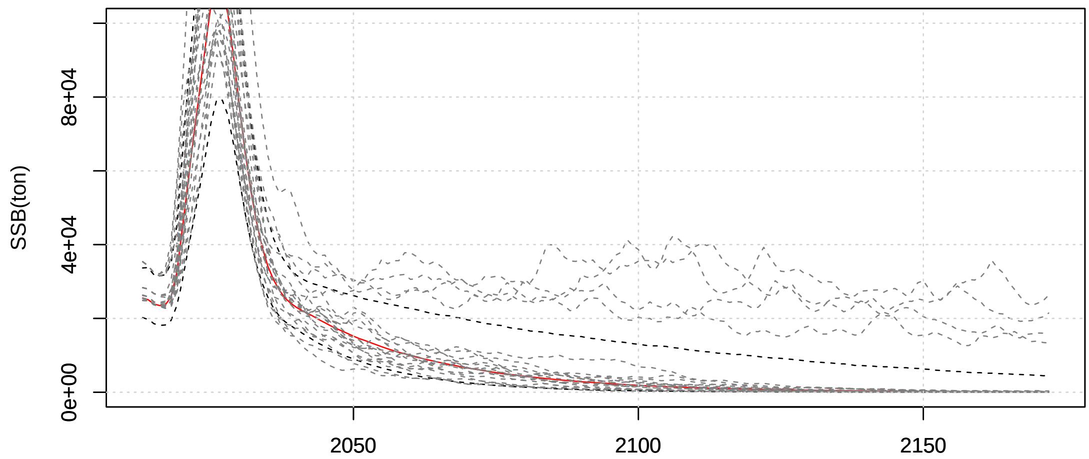

Fig 3 Median (red line) and lower and upper 10 percentiles (black dashed lines) of future SSB from simulation 2 with reduced F to 50% of F_{0204} for 10 years (2015-2014) and increased to F_{0204} afterward based on 2014 base case 300 SS bootstrapping runs. Future projection starts from 2012. From each bootstrap replication 20 future projection with randomly resampled recruitment in whole assessment period (1952-2011) with scaling resampled recruitment to reduce average recruitment if SSB is smaller than hinge point

(30000t) of hockey stick recruitment(see fig 1) were conducted. SSB will fluctuate around historical median SSB on average with non-negligible risk of declining to very low SSB level after initial decline from 2025. Also in order to indicate fluctuations of future SSB of individual simulation 5, future SSB trajectories from 6000 replications were randomly sampled and shown in grey dashed lines.

Simulation 3

In order to reduce the risk of stock collapse as shown in simulation 2, reduction of catch of scenario 6 is applied with constant F of F_{0204} if recent average three year SSB (3 years dropping most recent year as most recent estimate is likely to have larger error) is below a threshold level (fixed to 40,000t in order to account the effect of time lag) from 2025. The decision is made every three year from 2025. The result indicated that stock size can be maintained with large fluctuation but the risk of stock collapse can surely be reduced with suggested HCR (Fig.4). In addition, reduction of catch implicitly implies that F is reduced although the extent of reduction depends on the stock size. The difference of predicted SSB trends between constant F strategy and the HCR suggests the effect of variable fishing in response to the change of stock size on large fluctuation of the stock size in the case of PBF.

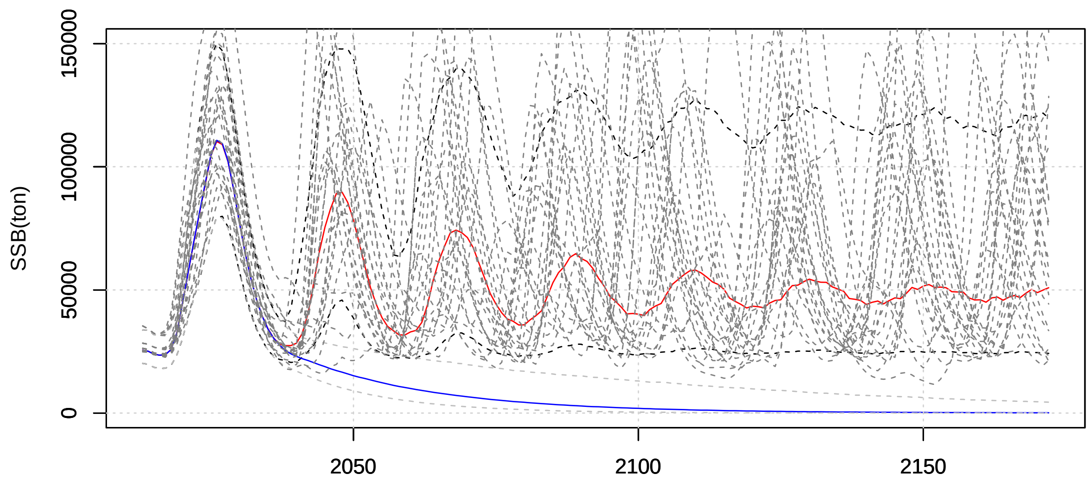

Fig 4 Median (red line) and lower and upper 10 percentile (black dashed lines) of results of simulation 3(harvest control rule; if SSB is above 40,000t, constant F strategy (F0204) is applied. If SSB is below 40,000t, catch reduction applied by scenario 6 of NC9 requests is applied). For comparison of effect of the HCR, median (blue) and lower and upper 10 percentiles (gray dashed lines) of SSB from simulation 2 were also shown. Grey dashed lines represent five individual trajectories of future SSB of randomly picked up from 6000 simulation replications.

Discussion

Can securing safe recruitment level be a criteria to pick up limit reference point?

As is often referenced, UNFSA (UN1995) pointed that the relationship of limit reference point and maximum sustainable yield in ANNEX II as "Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield." UNFSA(UN1995) also stated "Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.” In the case of Pacific bluefin tuna, since decline of average recruitment has been observed at very low SSB level, average recruitment at higher SSB size such as SSB corresponding to the F_{MAX} is not different from the average recruitment when SSB is larger than historical median SSB, it may be possible to set limit or threshold reference point (choice of the term “limit” or “threshold” should be up to required action as HCR when stock reach it and acceptable risk to violate it) corresponding to historical median SSB or close that level to allow to keep safe recruitment level, in particular, which potentially allows to produce maximum sustainable yield, if required. The target level (i.e., TRP) should be able to determine by the communication between managers, stakeholders and scientists after safe recruitment level is recovered.

IATTC’s proposed LRP

Recently IATTC proposed recruitment based limit reference point (Maunder and Deriso 2014). It based on the depletion level corresponding to the 50% of $R_{0,}$ of Beverton-Holt stock recruitment relationship, if steepness is hypothetically set to 0.75 regardless of the best estimates. Fundamental concept to focus on recruitment overfishing is very similar to ours. Preventing recruitment overfishing has a great merit, for the species which has experienced recovery of the stock from very low stock size like Pacific bluefin tuna. This working paper started from similar idea but tried identifying stock size which is likely produce safe level of recruitment to prevent from recruitment overfishing. It is very interesting both approach suggested similar level of spawning stock size to avoid the risk of recruitment overfishing.

“Kobe chart” and Target Reference Points

This working paper focused on Stock Rebuilding Plan/Harvest Control Rule and Limit Reference Points for Pacific bluefin tuna and, in particular, claimed that average recruitment of PBF is likely to be safe enough. Recently several tuna RFMOs including WCPFC, ICCAT and IOTC started discussions for harvest control rule of stocks in their jurisdiction. During the discussions of those RFMOs, there seems some ambiguities with regard to the relationship between Kobe chart and harvest control rule. In particular, usually hinge point (if biomass size is bellow this point, further reduction of fishing mortality and/or catch is required) is situated somewhere left of vertical line going through the origin. If more consistency among harvest control rule, reference points and Kobe chart is needed, an enhanced version of Kobe chart similar to what used in ICES (see Fig 5) may be useful.

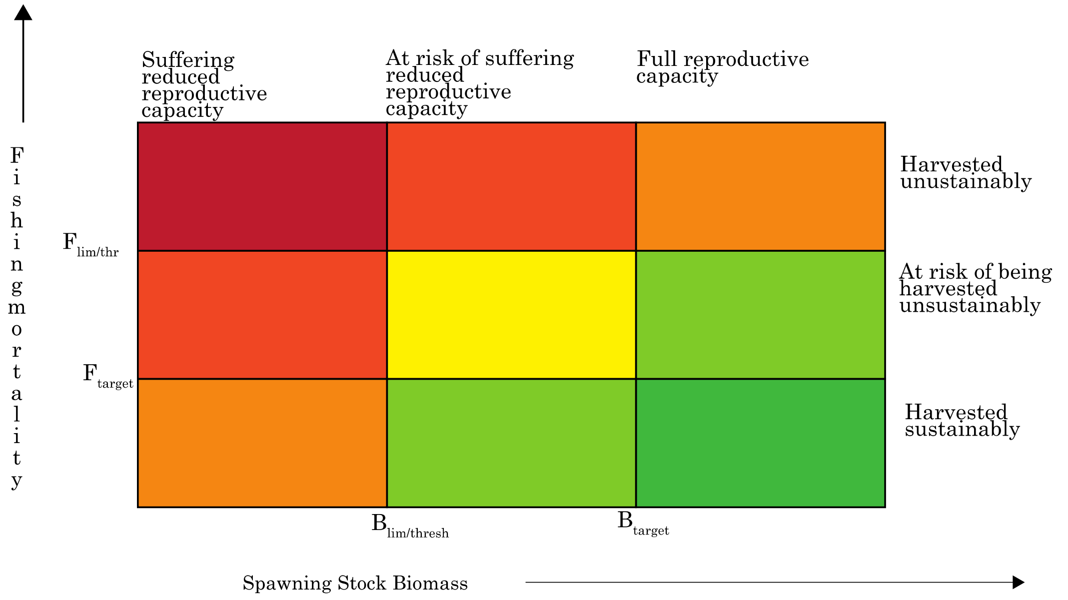

Fig. 5 Reference points for the status of stock for species assessed by ICES. Based on the original figure taken from http://www.marine.ie/NR/rdonlyres/510E2331-F1E6-456C-95C1-FB36CA23302F/0/ICEStheFormofAdvice.pdf necessary changes (F_{lim} and B_{lim} to $F_{lim/thr}$ and $B_{lim/thr}$, F_{PA} and B_{PA} to F_{TARGET} and B_{TARGET}) were made. This chart suggests if biomass size is bellow B_{target} some moderate action is needed while bellow $B_{lim/threshold}$ further severe management action e.g. suggested in this WP is required.

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2. Progress Report after "Pacific Bluefin Tuna and Albacore Tuna Ageing Workshop" - 1. Annual Age Determination -

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ABSTRACT

The Pacific Bluefin Tuna and North Pacific Albacore Tuna Age Determination Workshop which was held in November 2013, Shimizu, discussed and compiled the current knowledge of the techniques to determine ages of PBF and NPALB and come to consensus to draft the ageing manual. The manuals would be used for standardization of the techniques to obtain comparable results among related-laboratories. This document reports the progress after the workshop that is to apply the newly standardized methods drafted in the manual and compare the results between several researchers in Japan and Taiwan. The results revealed that the reading standards for two Japanese researches were well corresponding. There were still rooms for improvement among the countries; therefore they are discussing continuously to get the more proper consensus.

1.0 INTRODUCTION

Estimates of population abundance, recruitment, and biomass are highly sensitive to growth curve parameters used in the assessment models. In November 2013, the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) convened the Pacific Bluefin Tuna and North Pacific Albacore Tuna Age Determination Workshop. The goals of the workshop were to share information on age determination techniques for NPALB and PBF and to develop standardized protocols to ensure stable and consistent reading of the annual rings to improve the reliability of length-growth relationships used in stock assessments for both species. The meeting was held at the National Research Institute of Far Seas Fisheries (NRIFSF) in Shimizu, Japan. This report documents the progress after the Workshop.

2.0 PROGRESS AFTER THE WS

2.1 Cross checking of the reading between two readers

Fisheries Research Agency of Japan and National Taiwan University have exchanged otolith section photos reading standards for annual rings in each laboratory and the results were cross-checked.

In the ISC age determination workshop, the distance from the core to the 1st and 2nd annual opaque zones on sulcus-side were added as criteria of these annual opaque zone and these criteria increased the certainty of PBF age estimation. Base on the criteria, we re-examined the otoliths for cross-checking the results obtained by two Japanese readers (Fig.1). The results show that the difference between the criteria by two readers are minor. Comparing the results obtained by the previous and the revised criteria, the revised criteria gave a slightly more annual ring counts (Fig.2).

2.2 Cross checking of the reading between Japanese and Taiwanese scientists

Each of 30 otolith samples from Japan and Taiwan was exchanged and examined by the scientists individually. One scientist from Taiwan and two from Japan read annual rings. In the case the reading by two Japanese scientists are different, they discussed each other and select the proper counting.

The result shows that the deviations between Taiwanese and Japanese scientists are larger comparing the ones among the Japanese readers (Fig.3). They would further discuss to get the more proper consensus for each reading until their reading standards meet each other, at least the deviation among Taiwan and Japan come close to that among Japan.

3.0 FUTURE PLANS

Short Term Target

1. As a goal of the WS, ageing criteria would be finalized and standardized to ensure stable and consistent reading of the annual rings,
2. The finalized ageing criteria would be published as ageing manuals,
3. The reference photos of the otolith introducing revised criteria for age determination would be put on the ISC homepages,
4. Remaining otolith samples which were used for the previous age-growth curve studies will be re-determined its ages by the revised criteria by the end of August 2014,
5. The age of otolith samples captured by Taiwanese longline will be re-determined to check the mode observed in the size composition of the longline catch corresponds the 1994 dominant year class by the autumn 2014,
6. The age-length relationships will be revised for the PBFWG meeting in early 2015.

Medium Term Target (5 years ca)

1. A pilot result of age composition by length classes for Japanese and Taiwanese longline catches will be obtained.

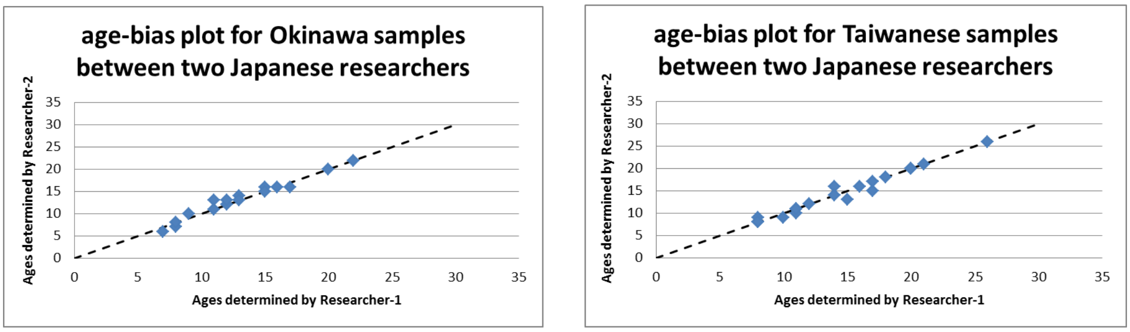

Fig.1 Age-bias plot for Okinawa and Taiwan samples by two readers

1) Okinawa samples; Y=0.9993x +0.1964 (r2=0.9634)

2) Taiwan samples; Y=0.9875x +0.0297 (r^2=0.969)

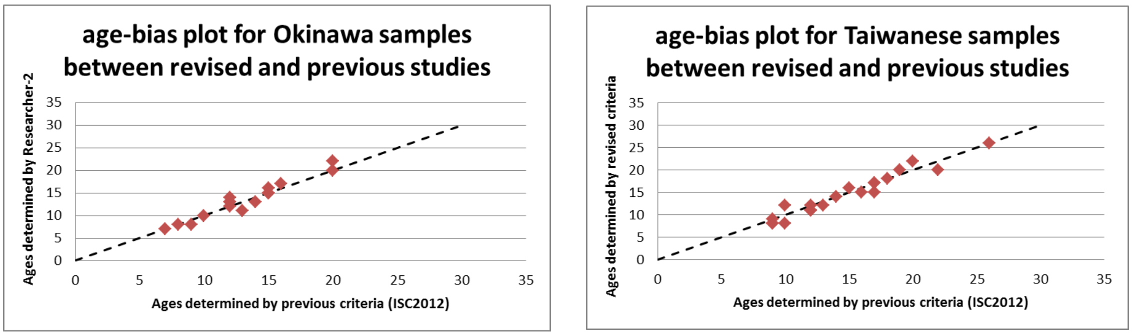

Fig.2 Age-bias plot for Okinawa and Taiwan samples read by the previous (ISC2012) and the revised criteria

1) Okinawa samples; Y=1.0834x +0.8451 (r2=0.9406)

2) Taiwan samples; Y=1.0334x +0.7955 (r2=0.9461)

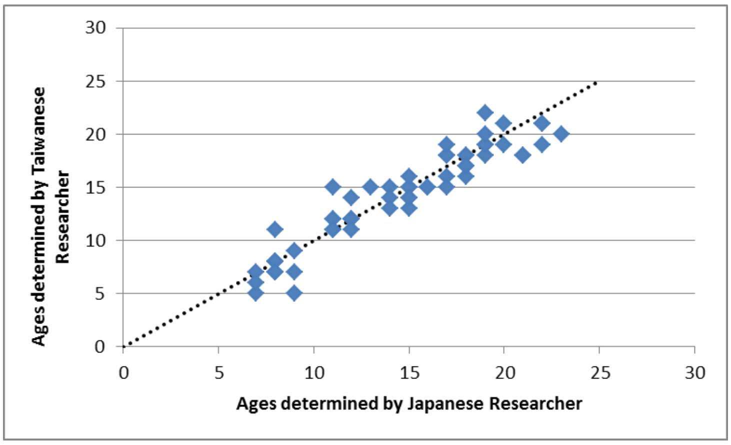

Fig.3 Age-bias plot for mixed samples from Okinawa and Taiwan read by Japanese and Taiwanese scientists using revised criteria Y=0.937x +0.5734 (r2=0.8955)

3. Progress Report after “Pacific Bluefin Tuna and Albacore Tuna Aging Workshop”

- 2. Daily Age Determination -

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ABSTRACT

The Pacific Bluefin Tuna and North Pacific Albacore Tuna Age Determination Workshop which was held in November 2013, Shimizu, discussed and compiled the current knowledge of the techniques to determine ages of PBF and NPALB and come to consensus to draft the ageing manual. The WS suggest validating the first annual ring of Pacific bluefin tuna with annulus counts via the SEM technique, as indirect validation with daily ring counts and marginal increment analysis are often used to determine the time of opaque zone formation. This document reports the progress after the workshop for establishing the working protocols for daily age analysis. Otolith daily increment analysis has been conducting for the Pacific Bluefin tuna (PBF) age-0 fish. Daily age data is used to growth study and estimation of birth month.
The sample preparation method and observation devices for daily increment of PBF were reported in some previous studies. However, we are selected the method that provide both of that number of increments and interval width of increment. The daily increment width will be used for allometric growth study of larva. We reported the otolith structure change depend on fish growth at aging WS, but the identification criteria of daily increment was still unclear. After WS, we decided almost working protocol for PBF age-0 fish.

1 INTRODUCTION

Otolith daily increment analysis have been conducting for the Pacific Bluefin tuna (PBF) age-0 fish. Daily age data is used to growth study and estimation of birth month.

The otolith of tuna species well grow in an anteroposterior direction than vertical direction of body trunk, and otolith will become narrow shape along the body growth (Fig. 1). The sample preparation method and observation devices for daily increment of PBF were reported in some previous studies. The simplest method is surface chemical etching that exposure all of daily increments to distal surface of otolith by using HCL, and observe by SEM. Some other study using transversally sectioned slides for light microscope observation, it is same as annual ling reading. These preparation method is simple and proven but both of method includes shortage point for our research purpose. We are suspected that water temperature affected to the larval relative growth, and temperature difference between two major spawning areas located around Japan can be reflected to some aspect of otolith. Then, we are selected the method can provide the data not only number of increments but interval width of increment from same an otolith sample, and we decided almost working protocol after WS for age-0 fish.

2 SAMPLE PREPARATION AND DAILY INCREMENT READING

Fish samples were caught around Japan by several gears in fishing year 2010. Fork length of fish samples were from 15 to 63 cm. Isolated otolith were cleaned with water and air dried.
Embedding an otolith in epoxy resin block, and cut the resin block by circle cutter (Fig. 2 and Fig. 3). The cutting line obliquely passes from primordium to postrostram of otolith (Fig. 4). The surface of resin piece including primordium is further polished by hand to reduce distance from cutting surface to the primordium (Fig. 5). To exposure the increments, HCL and EDTA were used. The images of increments were took at 250 to 1200-fold magnification with SEM, and spliced together by individual on an image editor (Fig. 7). Spliced image is screened for discrimination of increment appearance, and selected image is used for counting. Three persons read 3 times by each per individual. Personal reading score were averaged and fixed as a personal counting result. Precision of daily ring counting is evaluated by relative standard deviation. If the relative standard deviation of personal reading score for 3 times over 5%, the reader retired counting that individual. Relative standard deviations among personal counting results were also calculated, and it is allowed below 10%. If there is individual showed the relative standard deviation over 10%, traces of counting on image editor were compared all together and reviewed identification criteria of daily increment among all readers until the deviation decrease below 10% (Fig. 8).

3 PROGRESS AFTER AGING WORKSHOP

The working process that consisted from sample preparation method and daily increment counting criteria for PBF age-0 fish is almost fixed after aging WS.
The appearance of daily increment differ according to part of otolith, and increment determination criteria are specified to the feature of each part. The width of interval for first 30 to 60 increments from primordium was most wide and the duplicated increment is very conspicuous. However, daily increments also appear to otolith distal surface, then daily increments can be recognized in this region.

The appearance of daily increments changes after 60 increments, in the earliest case. Width of intervals decrease notably and sub-daily increment became weak. It makes easy to recognize daily and sub-daily increments in this area. More further apart from primordium, width of daily increment interval become much narrower, and few increments gather into one near distal surface of otolith. The appearance and interval width of increments become irregularly. Then, reading line is moved to inside part of otolith (Fig. 9).

The study using tag-recaptured fish otolith suggested that sub-daily increment is almost not existed in this structure. This was one of the progress after aging WS. The feature is correspond to that reported of Foreman (1996) as "narrow microincrements probably do not replicate as well as do wider ones". After this structure, interval of daily increments recover slightly, and sub-daily increment also appear again.

Sequencing change of daily increment width showed some trend by estimated birth month of fish in preliminary study. We are going to conduct more study to confirm this trend.

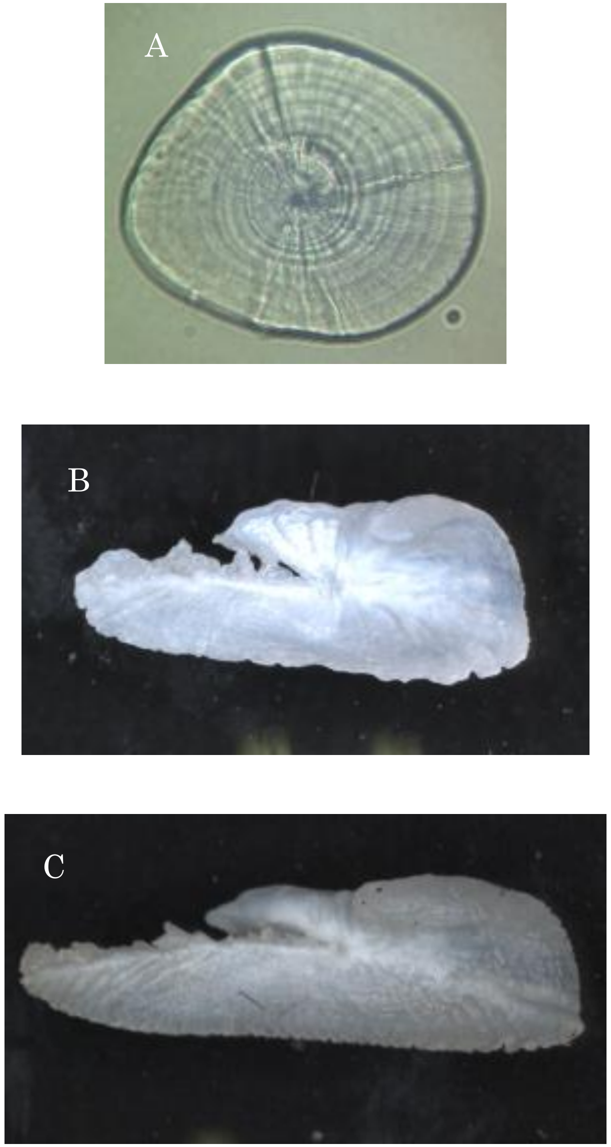
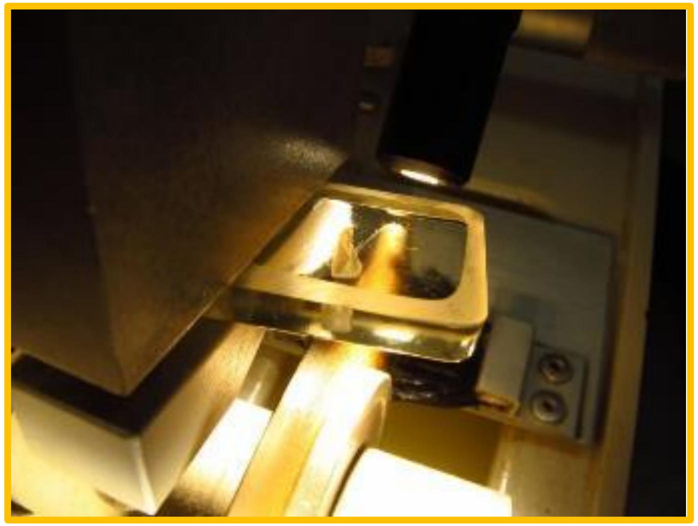


Fig. 1　Otolith growth of PBF from larva to just before age1.
A)　Isolated from larva, B) FL 22.cm, C) FL 50.6cm.
Both of B) and C) is top-down view of distal surface of otolith.



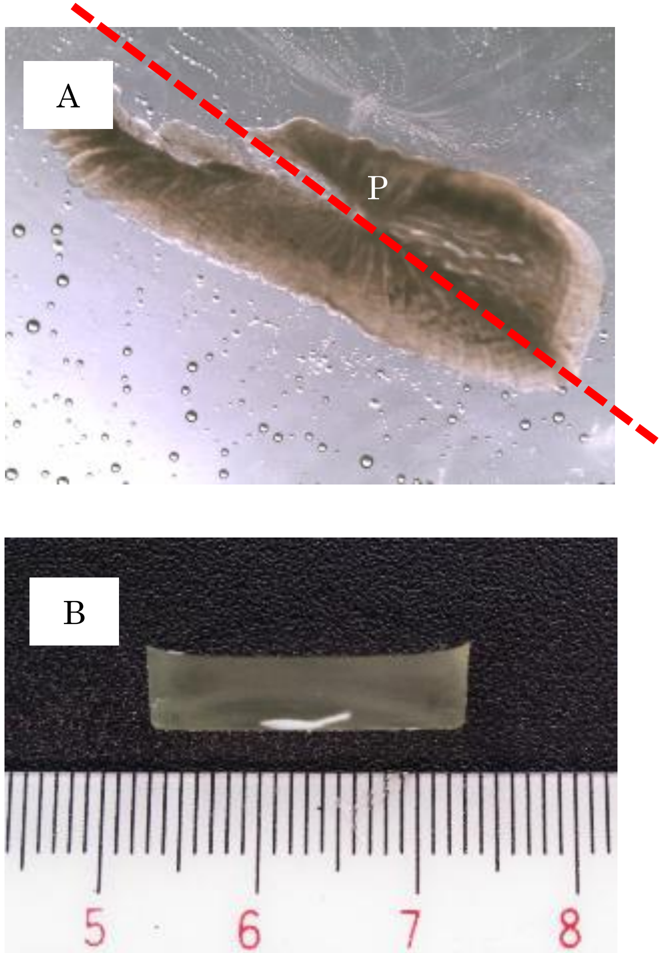


Fig. 4

A) Cutting line indicate cutting line. P: primordium.

B) Cutting surface of resin block. White small part is otolith.

Fig. 5 Hand polishing before chemical etching with polishing paper.

Fig. 6 Scanning electron microscope used in NRIFSF.

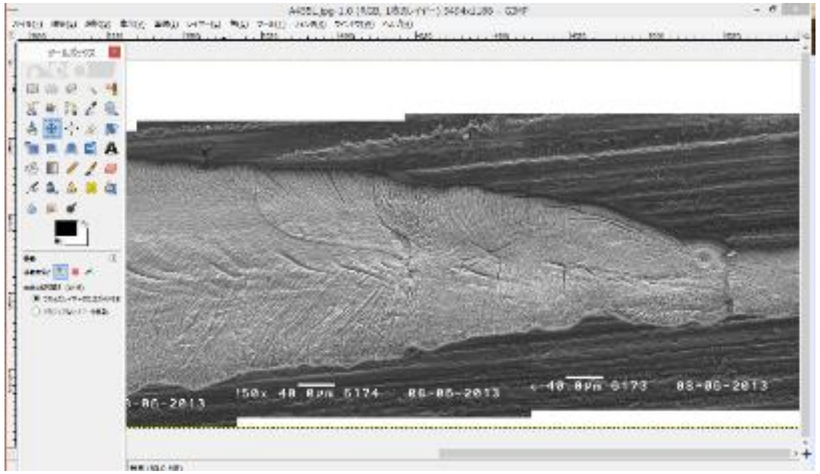


Fig. 7 Splicing the SEM image on image editor.

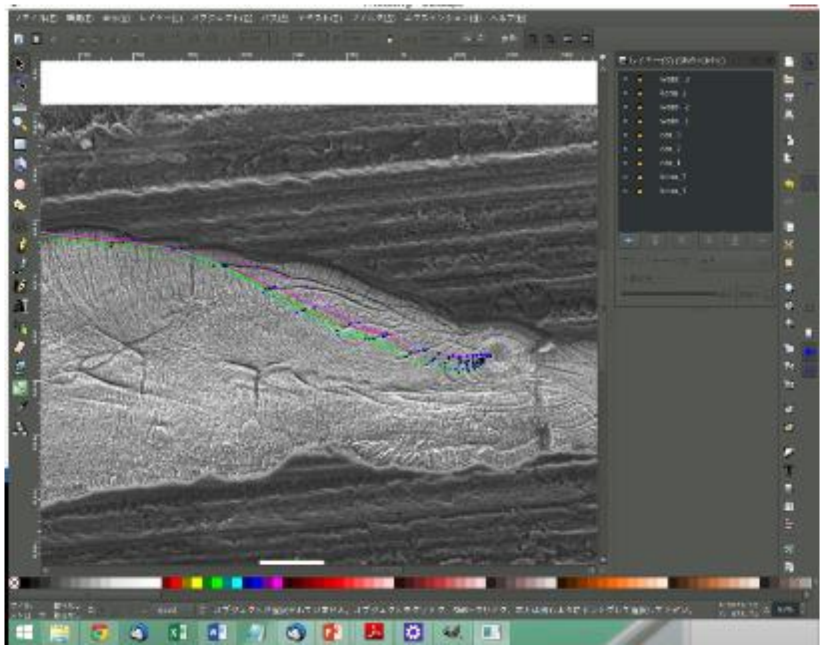


Fig. 8 Trace of reading of daily increments.
Each layer is the proof of personal reading.

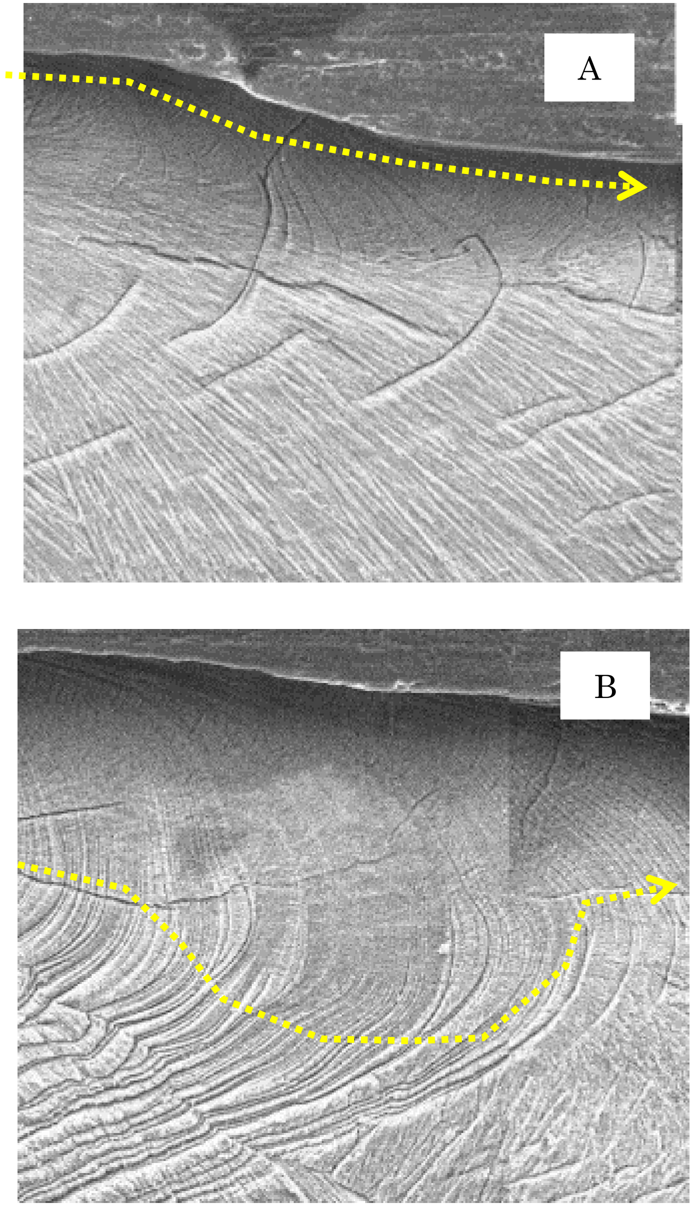


Fig. 9 Example of reading line. Yellow break line shows acceptable reading line in this sample.

A) In the case of the part where daily increment intervals are regularly and clear area.

B) In the case of the part daily increment interval become very narrow and irregularly area.

4. Current Status of spawning grounds and periods of Pacific Bluefin Tuna

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ABSTRACT

The distribution of PBF larvae were studies from 2011 through 2013 to collect latest information of PBF spawning grounds and periods. The ocean numerical models (JADE and FRA-ROMS) were applied for back-calculation of the larval transportation to estimate the spawned location for every PBF larva captured by the larval surveys. The results reveals the current hot spots in the PBF spawning ground around Nansei Islands (southwest of Yeyama Islands, around Miyako Islands, south of Okinawa Main Island, east of Miyako Islands) and in the Sea of Japan (off Wakasa Bay, from east of Oki Islands to west of Noto Peninsula, around Shin-Oki Bank). The high seasons for spawning were from April to June around Nansei Islands and in July in the Sea of Japan.

1.0 INTRODUCTION

For planning appropriate management measures of the spawning stocks of Pacific Bluefin Tuna (PBF, *Thunnus orientalis*), the latest information of the spawning grounds and periods were collected. PBF is known to spawn from April to June around the Philippines and Nansei Islands areas (Yabe *et al.*, 1966; Bayliff, 1994) and in August in the Sea of Japan (Okiyama, 1974; Nishikawa, 1986). Although there are some reports suggesting PBF spawning partially occurs other than the above areas such as Ogasawara Island (Mori, 1970), there are no reports which suggest spawning of PBF occurs other than the western North Pacific. From 1979 to 1988, Fisheries Agency of Japan conducted the Marine Ranching Project and within the project a large scale larval surveys for PBF were implemented in the Nansei Islands area, Pacific side of Japan Main Island, and in the Sea of Japan (Yonemori, 1989). The Marine Ranching Project reveals a general overview of PBF spawning grounds and periods, however, almost 25 years has been passed since the project. During the quarter century, the spawning stock biomass has been fluctuated dynamically, the circumstances surrounding fisheries has been changed drastically, and even the climate has been changing. To update the PBF spawning grounds and periods, Japan conducted large-scale larval surveys around the Japanese waters from 2011 through 2013.

2.0 MATERIALS AND METHODS

From 2011 through 2013, the large scale larval surveys were conducted by the following 10 research vessels; Shoyo-Maru (FAJ), Shunyo-Maru (FRA), Yoko-Maru (FRA), Tenyo-Maru (NFU), Tonan-Maru (Okinawa Pref.), Kuroshio (Kagoshima Pref.), Kuroshio (Yamaguchi Pref.), Shimane-Maru (Shimane Pref.), Tottori-Maru No.1 (Tottori Pref.), and Hakusan-Maru (Ishikawa Pref.). The methods to collect larval samples were standardized for all R/Vs and a ring net (2m diameter, 7.8m in length) was towed at the sea surface for 10 min with the vessel cruising 1.5 knot. The research cruises were conducted from late April to late July around Nansei Islands and from late June to early September in the Sea of Japan (Fig.1). Totally, 1,651 tows samples were collected and fixed in ethanol for the three years and 637 PBF larvae were identified.

Daily rings appeared on the otolith (sagitta) of the larvae were counted to determine their daily age. The ocean numerical models were used to estimate the spawned location of every PBF larva by simulating larval back transportation for the date of spawned. JADE (JApan sea Data assimilation Experiment; http://jade.dc.affrc.go.jp/jade/) and FRA-ROMS (Fisheries Research Agency-Regional Ocean Modeling System; http://fm.dc.affrc.go.jp/fra-roms/index.html) were used for the Sea of Japan and Pacific Ocean, respectively.

3.0 RESULTS AND DISCUSSION

3.1. Estimated spawning grounds and periods

Fig.2 shows summarized distribution of PBF larvae obtained by research cruises from 2011 through 2013 (May - August). No larva was captured in April and in September. In May, PBF larvae were found around Yaeyama Islands, spreading the distribution to northeast through July. In the Sea of Japan, larvae were captured west of Noto Peninsula, east of Oki Islnds from late June through early August.

The estimated spawning grounds were shown in Fig.3. There are several hot spots could be identified as below;

- Nansei Islands area
  - ✓ southwest of Yeyama Islands,
  - ✓ around Miyako Islands,
  - ✓ south of Okinawa Main Island, east of Miyako Islands,
- Sea of Japan
  - ✓ off Wakasa Bay, from east of Oki Islands to west of Noto Peninsula,
  - ✓ around Shin-Oki Bank.

Seasonal changes of estimated spawning grounds of PBF were shown in Fig.4. Although no larva was captured in April, ones of captured in early May were estimated to be spawned in late April by the daily age analysis. In the same manner, all larva captured in August was estimated to be spawned in late July. Fig.4 shows that PBF starts spawning in late April in the west of Yaeyama Islands, gradually spreads the spawning area to the east, and continues spawning until early July between Yaeyama Islands and Okinawa Main Islands around Nansei Islands. In the Sea of Japan, PBF starts spawning off Wakasa Bay in late June, and spawns around between Oki Islands and Noto Peninsula in July. The size compositions of the spawning stock are different completely; mostly below age-5 in the Sea of Japan and over age-6 around Nansei Islands, suggesting that the spawning stock which spawns around Nansei Islands would not migrate to spawn in the Sea of Japan.

3.2. Comparison with the previous studies

Fig.5 shows the distribution of PBF larvae obtained by larval survey cruises conducted from 1956 to 1989 (Nishikawa et al., 1985). No PBF larva was captured except for the periods from May through August. Although no appropriate oceanographic physical models which can be applied to simulate back transportation of the larvae for the previous studies, comparing the distribution of PBF larvae in the current study with the previous ones may provide some information for the fluctuation of its spawning grounds. The distribution of PBF larvae in May seems to be similar. However in June, fewer larvae were found in the east of Okinawa Main Islands. In July, as actually no survey was conducted in around Nansei Islands and in the Sea of Japan before 1989, so the distribution pattern of PBF larvae around Nansei Islands and in the Sea of Japan in July was new findings. In August, similar pattern of PBF distribution was found but the findings west of Oki Islands seems to be fewer.

PBF is a highly migratory species and may have potential to spawn in the other areas if its condition and circumstances matches. However, considering the wide coverage areas and seasons, this study would provide the information of the latest "core" spawning grounds and periods of PBF. Yonemori (1989) reported that although PBF larvae appeared in 23.9-29.5 degrees centigrade SST, most suitable SST for PBF spawning may range in 25-27 degrees centigrade. In this study also, PBF larvae were captured in SST range of 23.9 to 29.5 degrees centigrade, which is completely same as Yonemori (1989).

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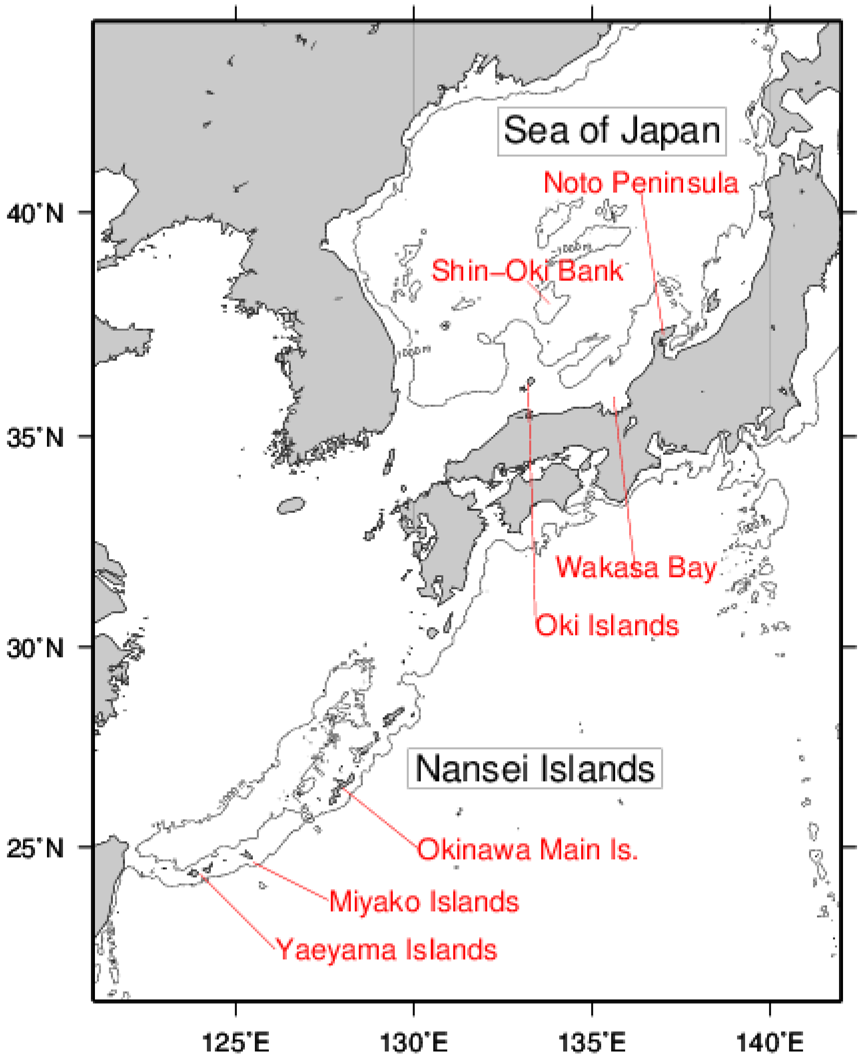

Fig 1 Research area and the related geographical names.

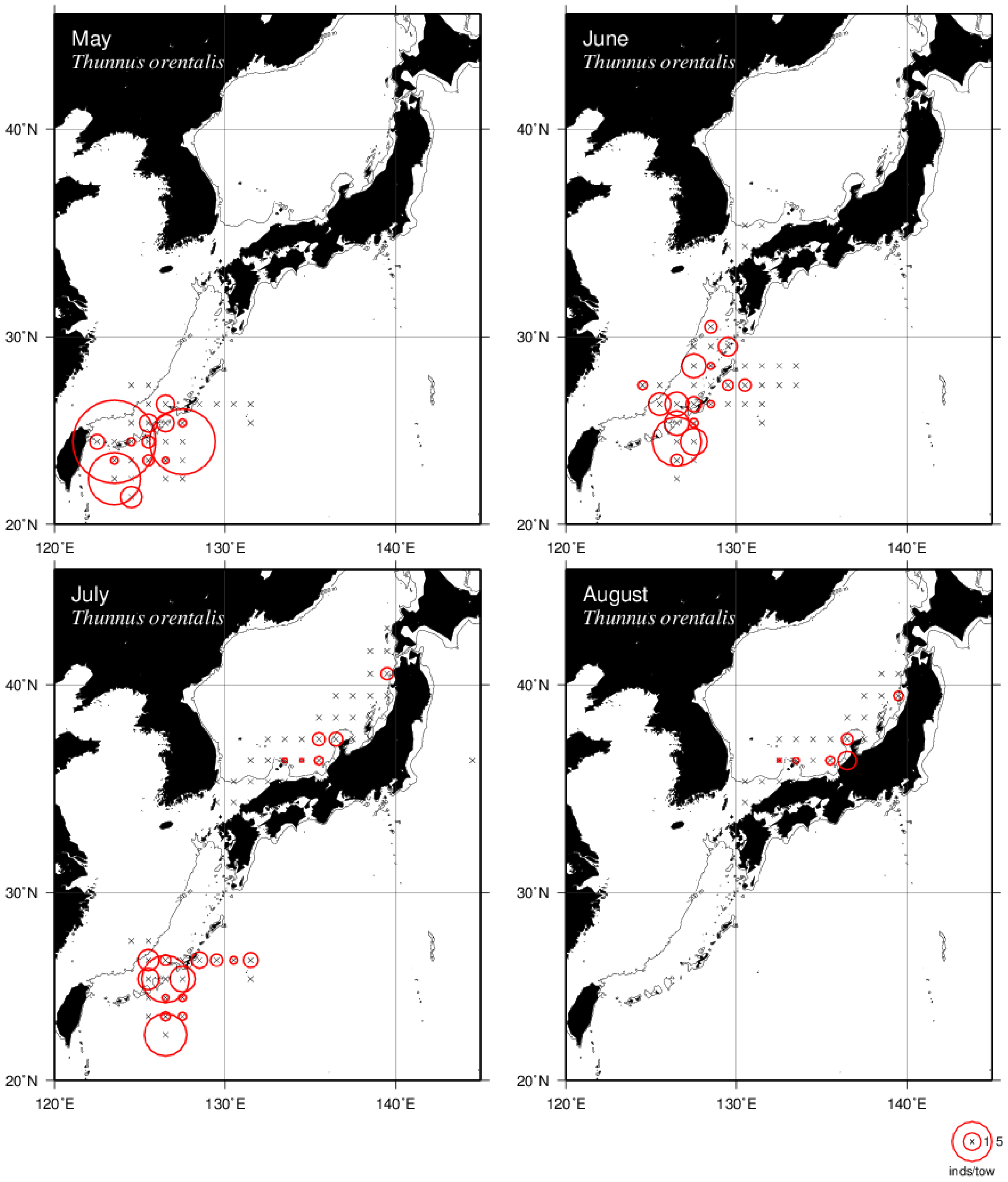

Fig.2 Distribution of PBF larvae obtained by research cruises from 2011 through 2013 (May - August).

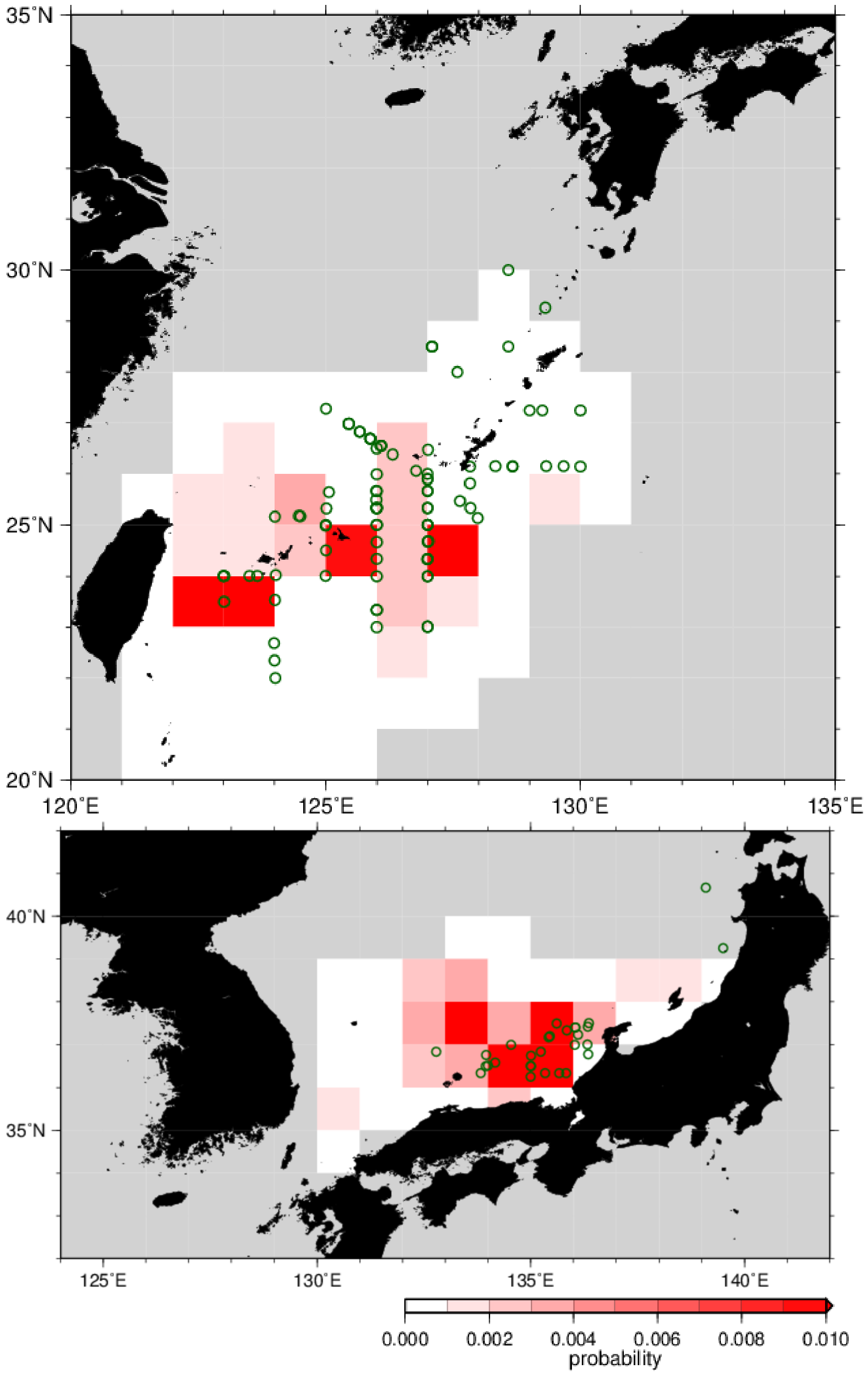

Fig.3 Estimated spawning ground of PBF (upper: Nansei Islands area, lower: Sea of Japan). Data from 2011 through 2013 were compiled. Green circles indicated the locations of PBF larvae were captured. Virtual particles which were set on the sampling locations where PBF larva was captured and simulated backward-transportation for the day of spawned. Summarized probability of the existence of the particles at the days of spawned for all larvae were shown.

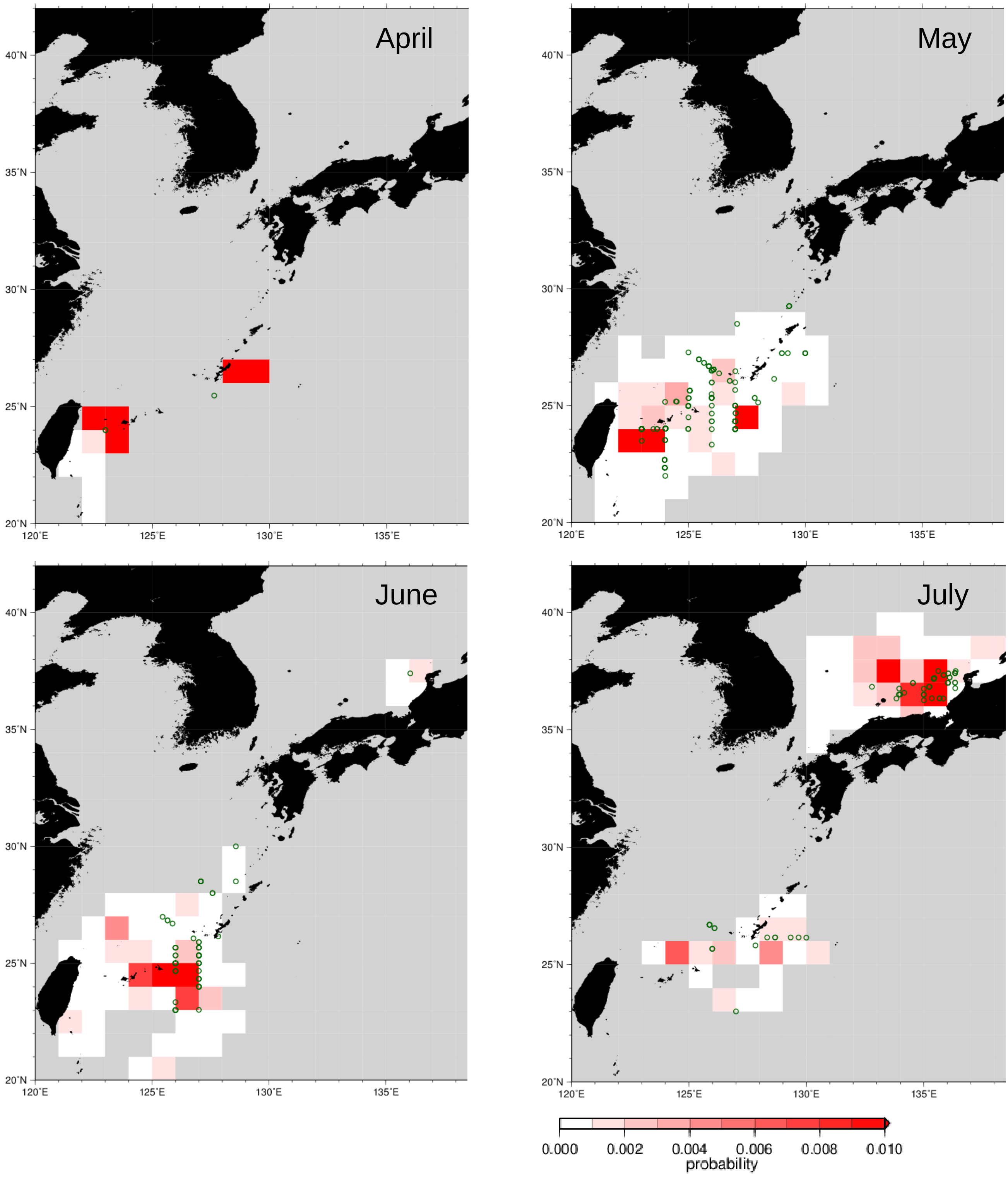

Fig.4　Seasonal changes of estimated spawning grounds of PBF.

Data from 2011 through 2013 were compiled.　Green circles indicated the locations of PBF larvae were captured. Virtual particles which were set on the sampling locations where PBF larva was captured and simulated backward-transportation for the day of spawned. Monthly summarized probability of the existence of the particles at the days of spawned for all larvae were shown.

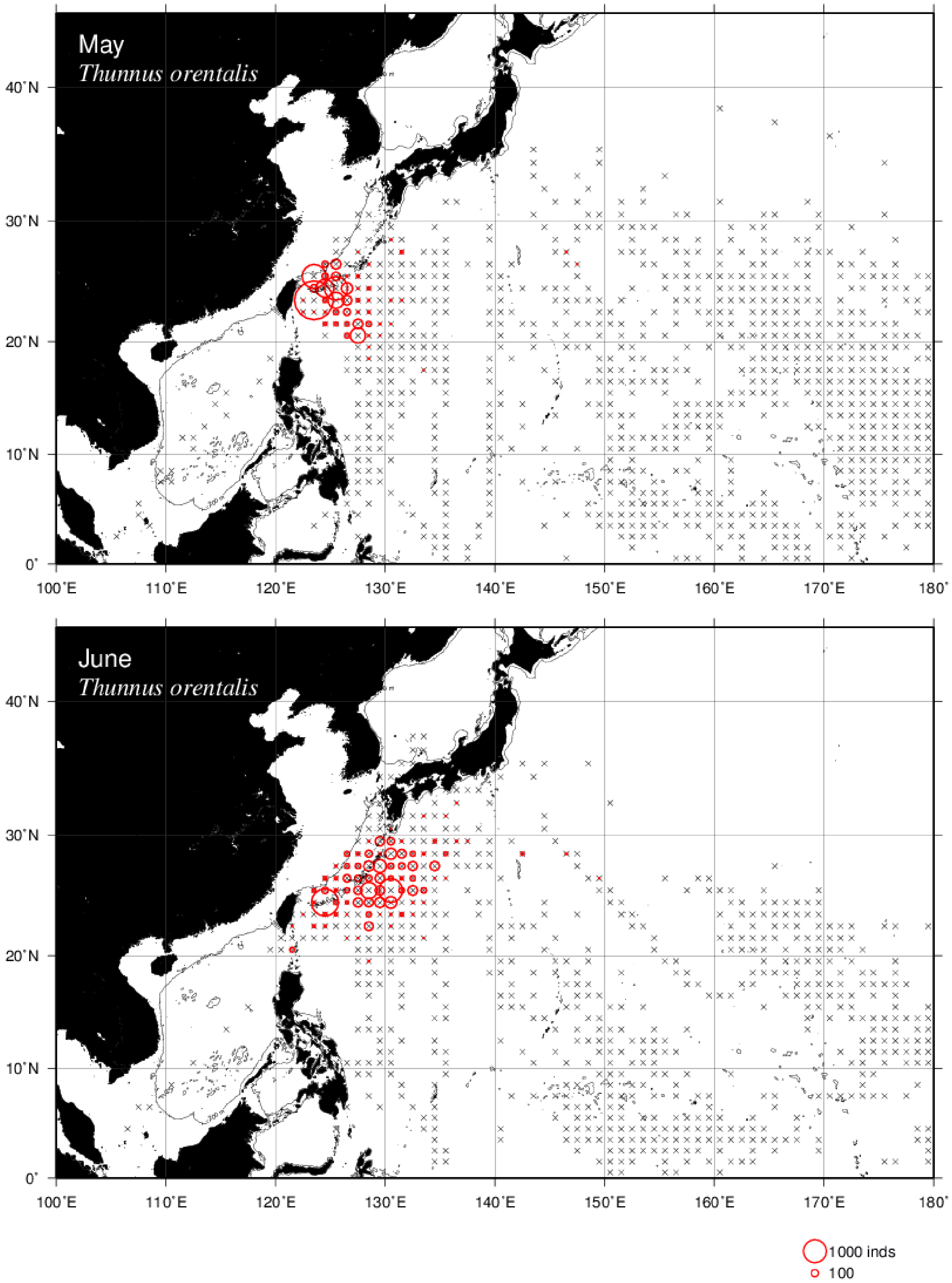

Fig.5 Distribution of PBF larvae obtained by larval survey cruises conducted from 1956 to 1989 (Nishikawa *et al.*, 1985) (May - June).

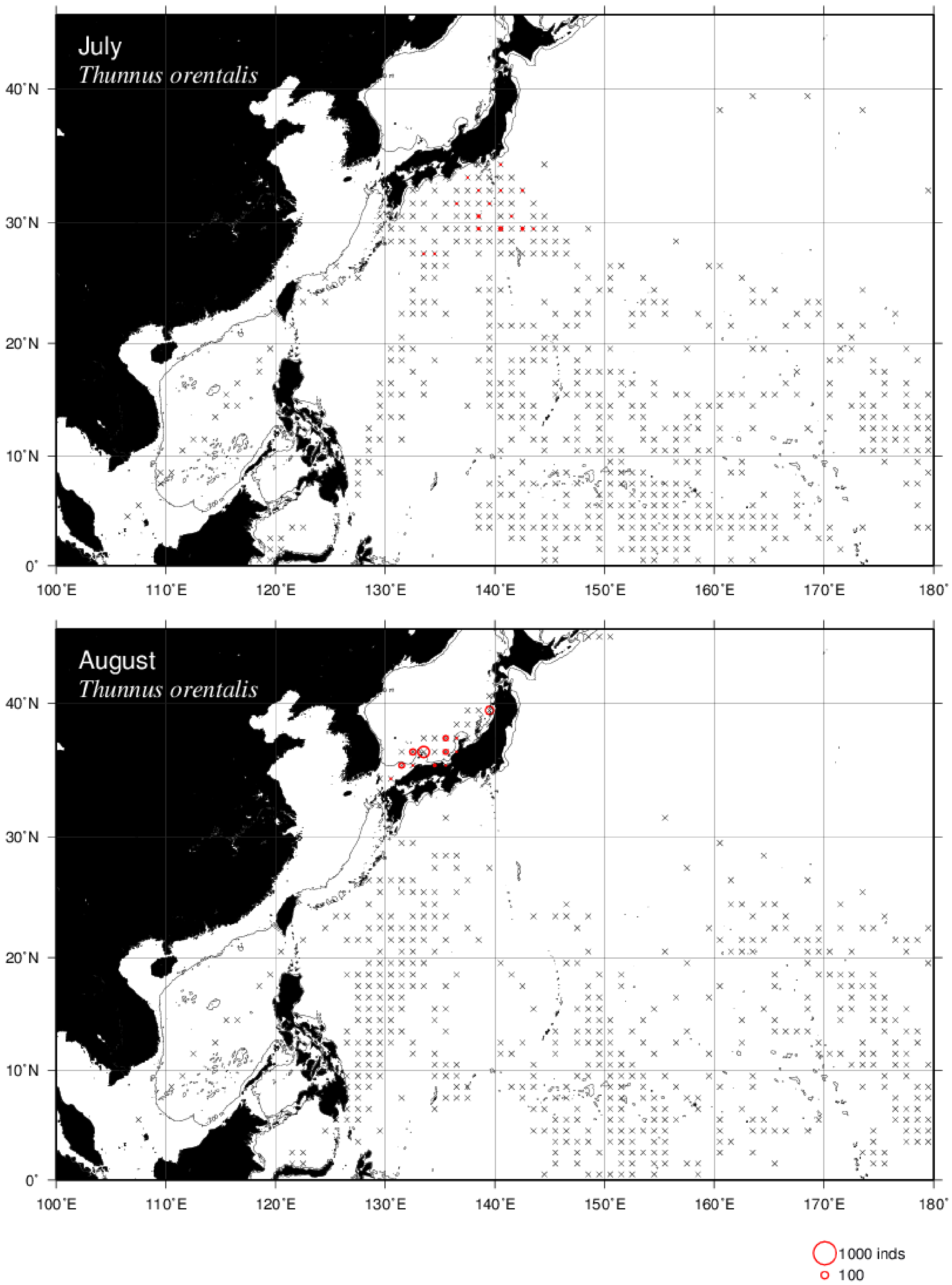

Fig.5 (cont.) (July - August).