Estimation of the length and age compositions of Pacific saury *Cololabis saira* in the Northwest Pacific Ocean during the fishing season in 2018

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Abstract

We collected 462 Pacific sauries from an onboard sampling program by three stick-held dip net fishing vessels of Chinese Taipei operated in the Northwest Pacific Ocean (40° - 50°N, 149° - 166°E) from July to November in 2018. A total of 455 otoliths classified by the otolith types according to the formation of the hyaline zone were used for the age determination. Our results indicated that the Pacific saury exhibits spatial and temporal changes in the size (and age) structure during the fishing season. The smaller fish (< 26 *KnL* cm) were found in July-August while the larger fish (> 32 *KnL* cm) in September-November. The average length of fish caught in the area of 46 °N and 157 °E (mainly from July and August) were generally smaller than those caught in the other areas. The relationship between the fraction of age 1 and body length can be described by a logistic curve with KnL_{50} and KnL_{95} of 26.85 (95% C.I of 26.48 and 27.22) and 28.85 (95% C.I of 28.47 and 29.23) cm, respectively. We found that the fish with small ROAs (< 540 μm) were mainly located in the eastern area (164 - 165 ºE); and with the large ROAs (> 540 μm) occurred in the western area (150 - 155 ºE). We suggest that the length composition data developed in this study could be used as input data of a particular fleet in the integrated stock assessment model for the Pacific saury in the Northwest Pacific Ocean.

1. Introduction

The Pacific saury (*Cololabis saira*) is commercially important in the Northwest Pacific Ocean, targeted by stick-held dip net fisheries from several members, including Japan, Russia, Korea, Chinese Taipei, China, and Vanuatu, of the North Pacific Fisheries Commission (NPFC, 2017). Members of Japan and Russia operate mainly within their exclusive economic zones (EEZ), whereas Chinese Taipei, China, Korea, and Vanuatu operate mainly east of Hokkaido and the Kuril Islands in the Northwestern Pacific. Current stock assessment of the Pacific saury was conducted by using surplus production models (SPMs) that rely only on catch and some indices of abundance. A major criticism of SPMs is that they ignore the stock's size/age structure and therefore fail to account for dynamics in gear selectivity (Wang et al., 2014) and lagged effects of recruitment and mortality (Aalto et al., 2015; Punt and Szuwalski, 2012), which can both lead to biased assessment results.

Estimation of the age-frequency distribution of catch and population in a given year is a critical step in the applications of age-structured stock assessments. However, age information is often costly to obtain. These high costs force scientists to limit the number of fish aged directly, and to rely on age–length keys (ALKs; Fridriksson, 1934) to draw inferences about the age composition of the stock or catch. There are no previous studies have been made about the age structure of Pacific saury caught in the high sea during July-November. The objective of this paper is to give the estimations of the age structure and the age-length key of Pacific saury caught in the Northwest Pacific Ocean by the stick-held dip net fisheries of Chinese Taipei.

2. Materials and methods

2.1 Sample collection

Pacific sauries were collected from an onboard sampling program by three stick-held dip net fishing vessels of Chinese Taipei operated in the north-western Pacific Ocean (40° - 50°N, 149° - 166°E) from July to November in 2018. For each vessel, three fish were randomly collected from the first fishing operation of the daily catches. To consider the potential low effective sample sizes caused by the tendency for sauries caught together to be more similar in age from the same fishing operation than those in the total catch, the number of fish collected from each operation was reduced to three (Aanes and Pennington, 2003). A total of 462 fish were collected in 2018 with the sample size of 36, 114, 114, 126, and 72 from July to November, respectively. The fish were measured for their knob length (the length from the tip of the lower jaw to the posterior end of the muscular knob on the caudal peduncle; Kimura, 1956) and the otoliths were then extracted, washed, dried, and observed by optical microscopy at a magnification of 45× (Suyama et al., 2006).

2.2 Age determination

Fish with no hyaline zone in the otolith and those with hyaline zones are regarded as age 0 and age 1 fish, respectively (Suyama et al., 2006). Otoliths with no hyaline zone were classified as type I, according to the criteria of Suyama and Sakurai (2000). Otoliths with hyaline zones were classified as type II (otolith enclosed by a broad translucent area along its outer edge), type III (otolith with one complete hyaline zone), and type IV (otolith with two hyaline zones) (**Fig. 1**). Fish with otoliths that did not belong to one of these four types were excluded from the age determination. A total of 455 otoliths, with the sample size of 36, 113, 110, 125, and 71 from July to November, respectively, were retained for further analysis.

2.3 Radius of annual ring measurement

The radius of otolith annual ring (ROA), defined as the distance from the otolith core to the area where the annual ring begins to form (Suyama et al., 2009; Suyama et al., 2012), was measured in age 1 fish with type II, III or IV otoliths. ROAs were measured using an Olympus DP-22 camera and CellSens software, after calibration against an optical micrometer.

2.4 Data analysis

Monthly distributions of length frequency, otolith type composition and age-length key (i.e., the conditional probability of an age given a particular length category) were examined. Spatial distributions of the average knob length, otolith types, and the average ROA by 1°×1° grid were calculated.

Since the fish consisted of two age groups (Suyama et al., 2006), the probability that the *i*th fish was age 1 (P_i) was modeled with a logistic curve:

$$P_i = 1 \Big/ \left(1 + e^{-\ln(19)\left[(KnL_i - KnL_{50})/(KnL_{50} - KnL_{95})\right]}\right)$$

where KnL_i = the knob length of fish *i*; and KnL_{50} and KnL_{95} = the knob length at which 50% and 95% of the assemblage reached age 1, which were estimated by maximizing a log-likelihood function and by assuming a binomial error distribution with AD Model Builder (Fournier, 2000).

3. Results and discussion

The result of the aggregated length frequency during July-November in 2018 was shown in **figure 2a**. The minimum and maximum lengths of the sampled fish were 24.2 and 32.6 *KnL* cm, respectively. Most of the sampled fish were between 28.7 and 30.2 *KnL* (mean = 29.38 *KnL* cm). Monthly length frequencies were shown in **figure 2b-2f**. The smaller fish (< 26 *KnL* cm) was found in July-August while the larger fish (> 32 *KnL* cm) was found in September-November. The spatial distribution of the Pacific saury length composition was shown in **figure 3**. The fish caught in the area of 46°N and 157°E (mainly from July and August) were generally smaller than those caught in the other areas.

The otolith type composition and the age-length key of the sampled fish during the studied period were shown in **figure 4a**. Among the three otolith types in age 1 fish (n = 413), type II otoliths are dominant during July-November (39%). Type IV (37%) and III (24%) otoliths represented minor proportions of age 1fish. A greater proportion of the type I otolith was found for the fish < 27 *KnL* cm. The proportion of the type IV otolith increases as the body length increases.

Monthly otolith type compositions and the age-length key from July to November were shown **figure 4b-f**. The proportions of age 0 and age 1 fish fluctuated every month. In general, the major proportion of the otolith types has changed gradually from type I to type IV following the progression of the month. More specifically, the type I otolith was the predominant type in July - August, the types II and III otoliths in September, and the type IV otolith in October. It should be noted that a substantial proportion of the type I otolith was found in November for the fish < 27 *KnL* cm compared to that in September and October. The relationship between the fraction of age 1 and body length can be described by a logistic curve with KnL_{50} and KnL_{95} of 26.85 (95% C.I of 26.48 and 27.22) and 28.85 (95% C.I of 28.47 and 29.23) cm, respectively (**Fig. 5**).

The spatial distributions of the otolith types during July-November in 2018 were shown in **figure 6**. The type I otoliths showed a similar spatial distribution pattern compared to the other types of otoliths. However, the sample size of the type I otolith was smaller than the other types. The geographical variation of the ROAs during July-November in 2018 was shown in **figure 7**. We found that the fish with small ROAs (< 540 µm) were mainly located in the eastern area (164° - 165°E); and with the large ROAs (> 540 µm) occurred in the western area (150° - 155 °E). We noted that the sample size of the fish with the small ROA was obviously less than those with the large ROA.

Although type IV otoliths (33.8%) possibly indicated the presence of an age 2 fish, we did not consider that all fish with type IV otoliths had survived for more than 2 years based on the argument of Suyama and Sakurai (2000) that a second hyaline zone may form not only during the winter but also during other seasons. Further, although 3 of 455 otoliths possessed more than three hyaline zones (0.8%), it is not believed that the ages of such fish were more than 3 years because the second and third hyaline zones could not reliably be used as annual rings (Suyama et al., 2006). Therefore, our results revealed that the Pacific saury consists of only two year-classes

(9% of age 0 and 91% of age 1 fish) during the fishing season in the Northwest Pacific Ocean. Our results indicated that the Pacific saury exhibits spatial and temporal changes in the size (or age) structure during the fishing season. We recommend that using the age-length key to estimate the catch-at age composition of the Pacific saury should be considered on a monthly basis.

Previous studies have suggested that using the ROA as a natural tag to document the westward migration of age-1 Pacific saury (Suyama et al., 2012; Miyamotoa et al., 2019). Suyama et al. (2012) indicated that the mean ROA gradually decreased from west (140^{o} E) to east (165^{o} W) during the pre-fishing season, and the monthly mean ROA decreased from August to November during the fishing season (August - November) in the coast waters of Japan. By contrast, we found that fish with relatively small mean ROAs were observed in the July - August rather in September – November in the high seas. Thus, we argued that the hypothesized westward migration route may likely fluctuate annually, being influenced by distribution patterns of prey and oceanographic conditions that also vary every year.

It is now common to fit age-structured models to length-frequency and conditional age-at-length data rather than to age-composition data constructed by multiplying length-frequencies and age-length keys (e.g., Punt et al., 2006). We suggested that the length composition data developed in this study could be used as input data of a particular fleet in the integrated stock assessment model (e.g., Stock Synthesis; Methot and Wetzel, 2013) for the Pacific saury in the Northwest Pacific Ocean.

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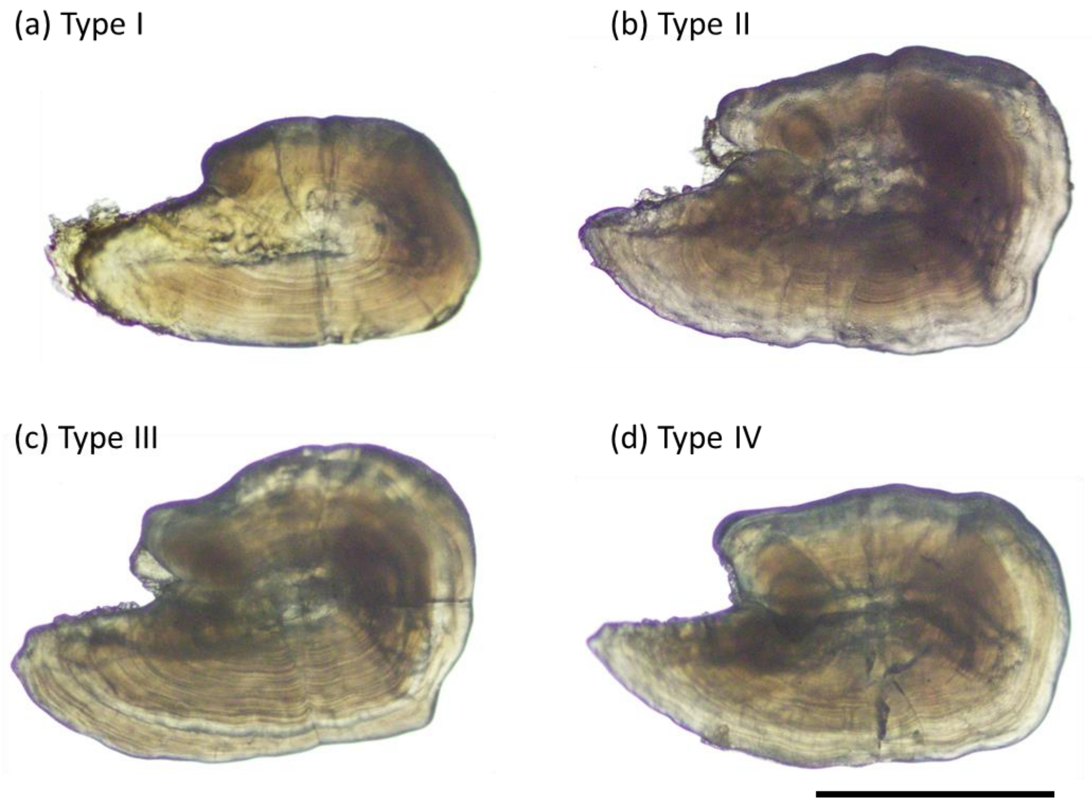

Figure 1. Light microscope photographs of Pacific saury otoliths. The scale bar is 1 mm. Otoliths with no hyaline zone were classified as type I (a), according to the criteria of Suyama and Sakurai (2000). Otoliths with hyaline zones were classified as type II (b) (otolith enclosed by a broad translucent area along its outer edge), type III (c) (otolith with one complete hyaline zone), and type IV (d) (otolith with two hyaline zones). Fish with no hyaline zone in the otolith and those with hyaline zones are regarded as age 0 and age 1 fish, respectively.

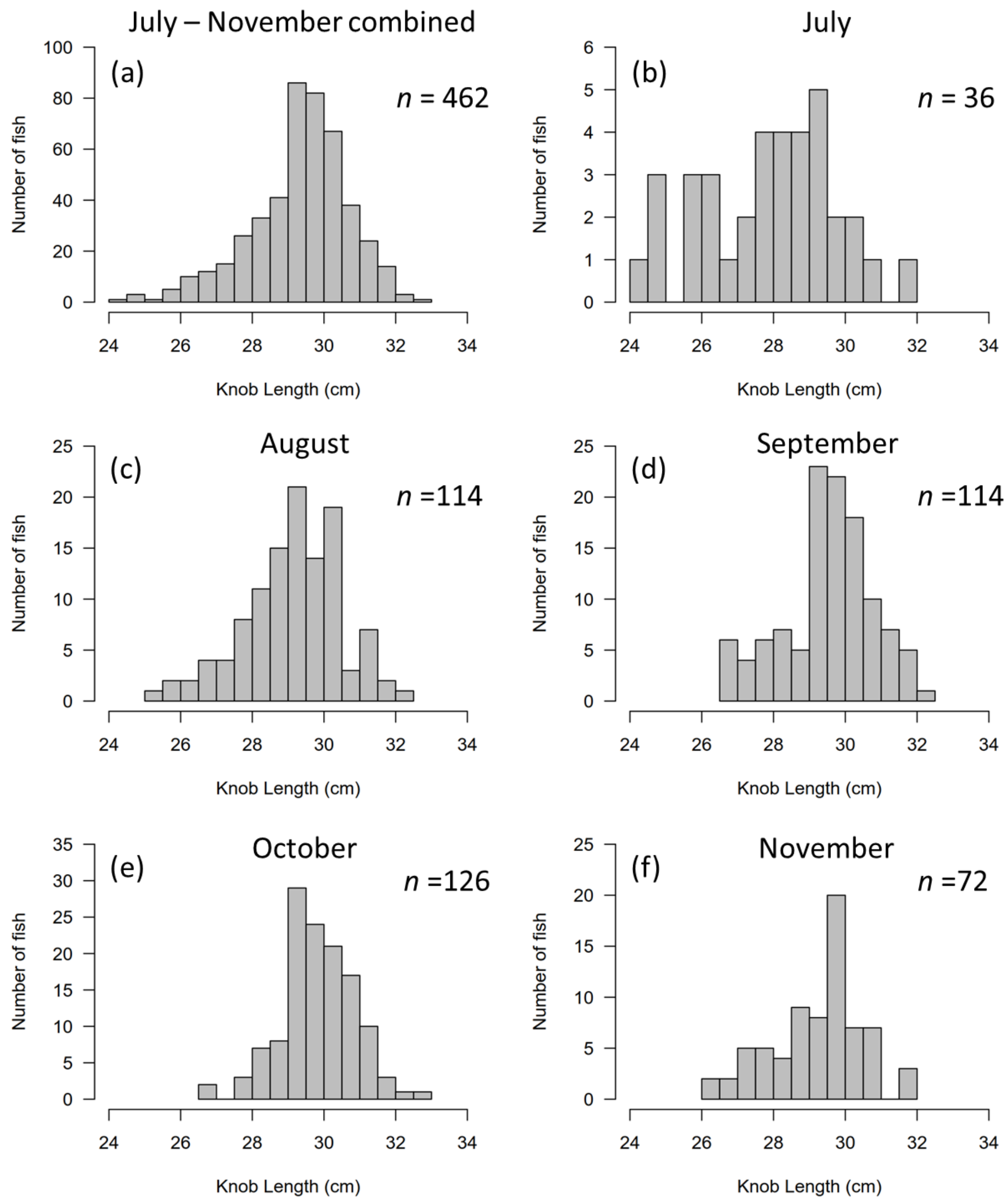

Figure 2. The length-frequency distributions of the Pacific saury collected by three stick-held dip net fishing vessels of Chinese Taipei in the Northwest Pacific Ocean during July-November (a), July (b), August (c), September (d), October (e), and November (f) in 2018.

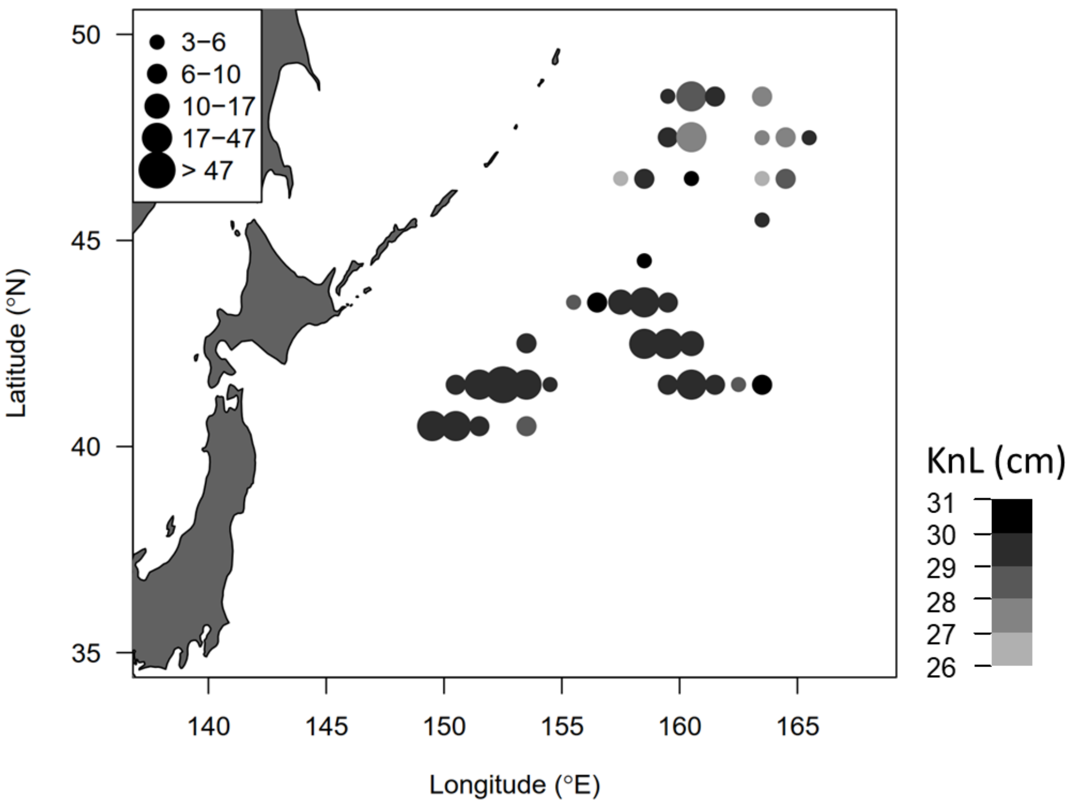

Figure 3. The spatial distribution of average knob length (cm) (by 1°×1° grid) of the Pacific saury collected from July to November in 2018. Colors and sizes of the circles denote the levels of body length and sample size, respectively.

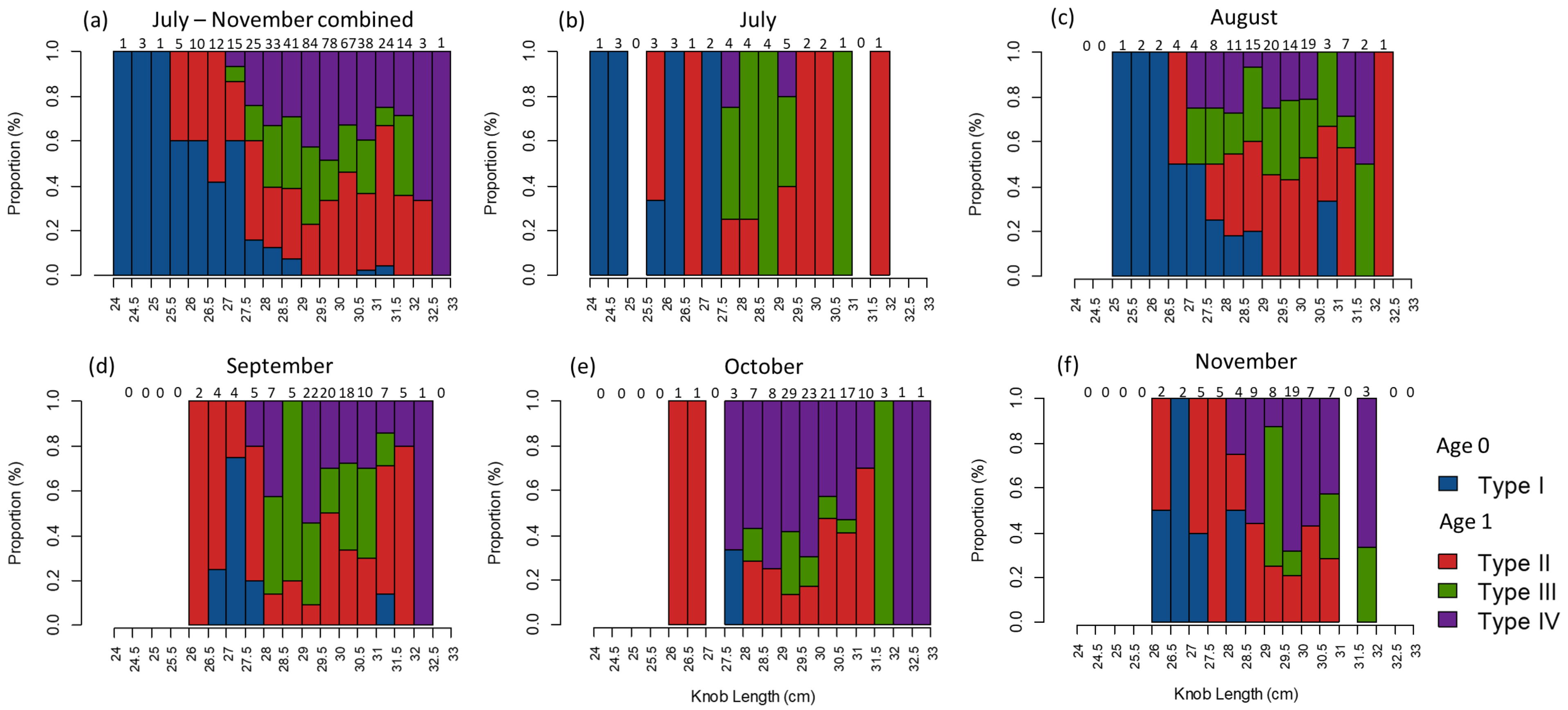

Figure 4. Otolith type compositions and the age-length keys (conditional probability of an age given a particular length category) of the Pacific saury collected by three stick-held dip net fishing vessels of Chinese Taipei in the Northwest Pacific Ocean during July-November (a), July (b), August (c), September (d), October (e), and November (f) in 2018. The number represents the sample size by length class (0.5 cm bin).

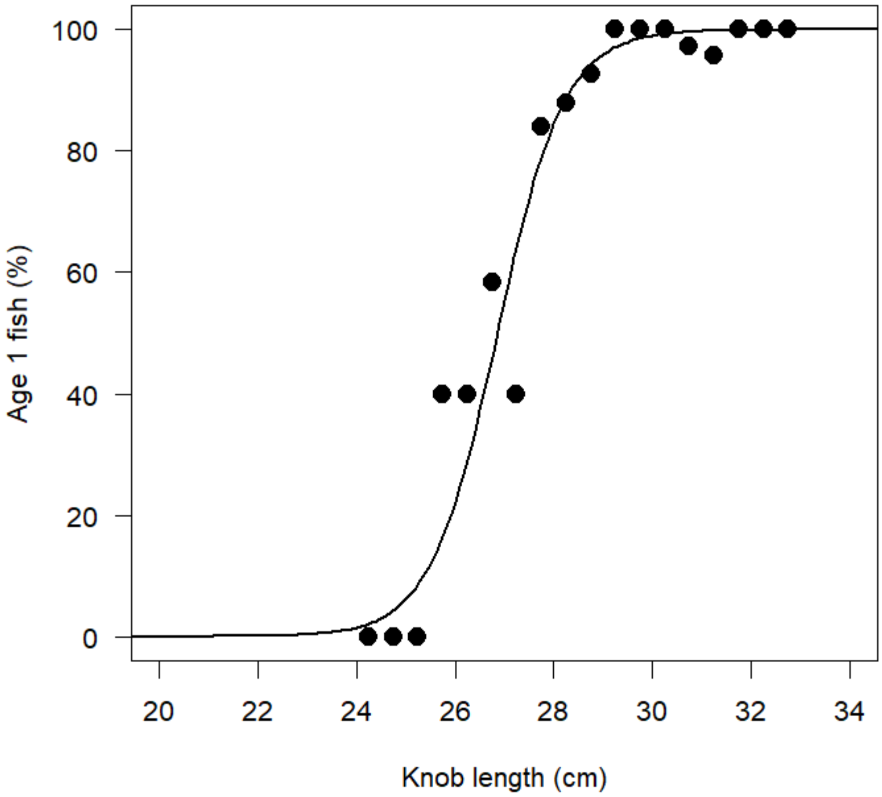

Figure 5. The relationship between the proportion of age 1 fish and the knob length (cm) of the Pacific saury in the Northwest Pacific Ocean. The solid circles represent the observed proportions of age 1 fish by length classes (aggregated to 0.5 cm intervals).

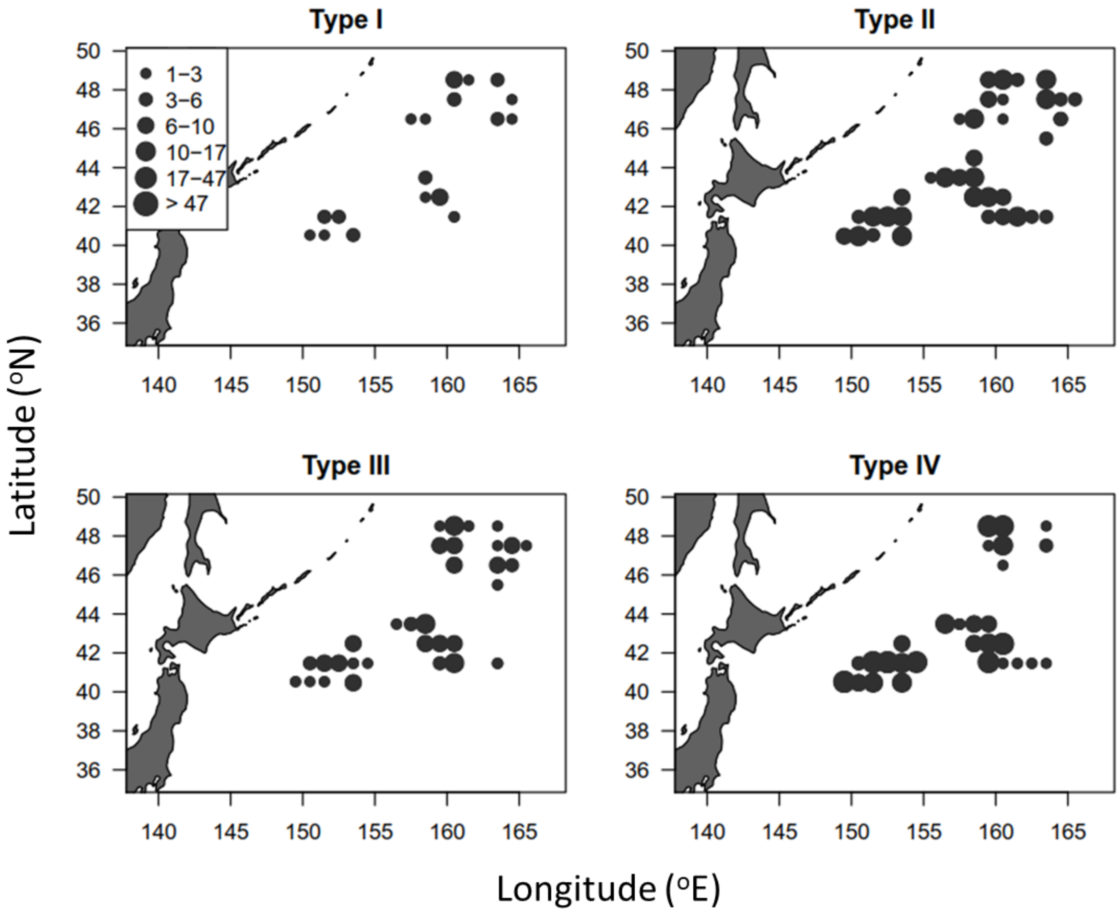

Figure 6. Spatial distributions of the Pacific saury by otolith types: (a) type I; (b) type II; (c) type III; and (d) type IV collected by three stick-held dip net fishing vessels of Chinese Taipei in the Northwest Pacific Ocean during July-November. The sizes of the circles denote the levels of sample size.

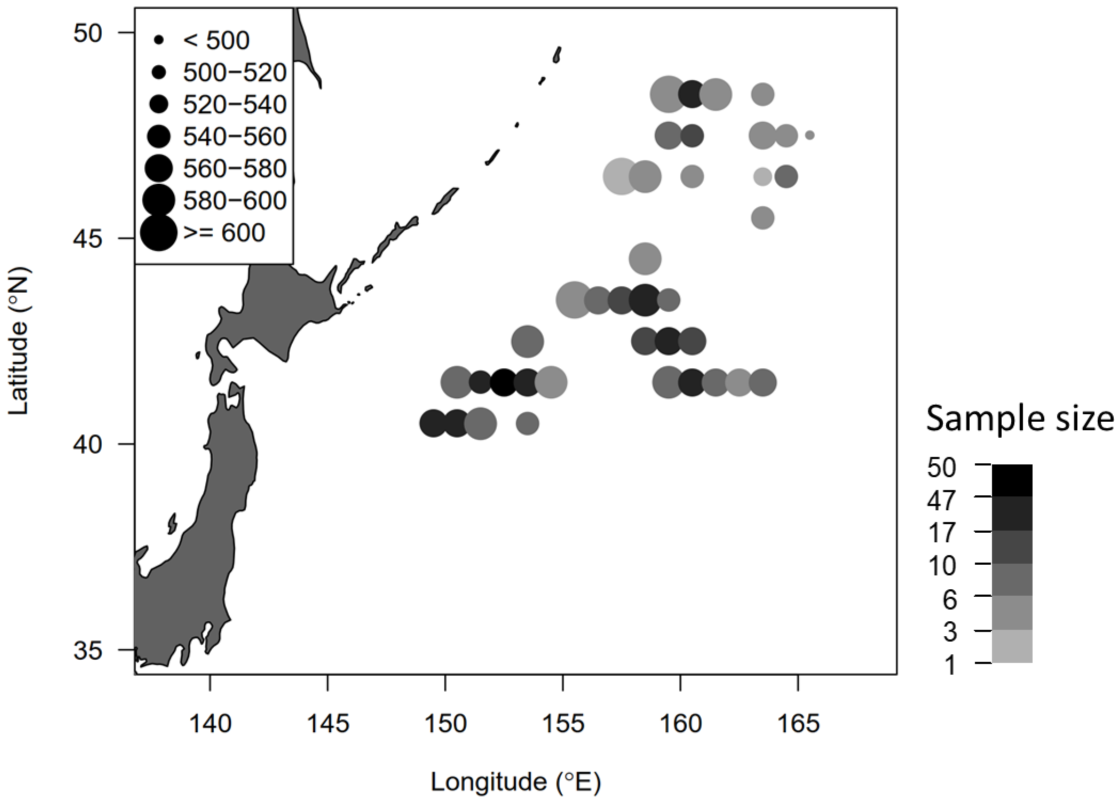

Figure 7. The spatial distribution of the average ROA (by 1°×1° grid) of the Pacific saury collected from July to November in 2018. The sizes and colors of the circles denote the levels of ROA and sample size, respectively.