

Gonadal information and analysis of southern bluefin tuna collected by Taiwanese scientific observer program with updated information

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ABSTRACT

Gonadal samples of SBT were collected by Taiwanese scientific observers aboard longline vessels operating in the Indian Ocean. A total of 1,407 samples were obtained between 2010 and 2024, comprising 664 females and 743 males. The fork lengths of both sexes primarily ranged from 90 to 150 cm. Monthly trends in the gonado-somatic index (GSI) showed that female GSI peaked in April and gradually declined thereafter, with elevated values observed from March to July. In males, GSI peaked in March and then decreased steadily. Overall, the monthly GSI patterns for both sexes were consistent with previous results.

According to the histological observations, we focused on female SBT samples. A total of 566 histological female SBT samples collected between 2010 and 2023 were classified by sexual maturity stage, with an additional 102 individuals from 2023. The majority of these samples were diagnosed as immature status, while approximately 14.9% were identified as mature but reproductively inactive. Most of the mature females were found to be in the regressed or regenerating stage (Stage 7) during the period from April to August.

1. INTRODUCTION

Several studies related to the reproductive biology of the southern bluefin tuna (SBT, *Thunnus maccoyii*) were conducted in the waters of Australia and Indian Ocean. Multiple indices of SBT, such as age-at-first-maturity, gonad index, ovary size-frequency and fecundity, had been investigated in the waters off southeastern and southern Australia (Thorogood, 1986). And Farley and Davis (1998) studied the spawning dynamics of SBT using ovaries obtained from the spawning ground and the

main feeding ground in the Indian Ocean. Furthermore, the maturity of SBT had been investigated using histological observations of the gonad samples collected by Taiwanese observer program in the southwest Indian Ocean (Chen et al., 2013). However, there is no consensus standard for identifying the maturity stages in SBT. Developing the guidelines of the diagnosis maturity stages is essential and helpful for further understanding of the reproductive indices of SBT.

Therefore, developing an independently estimated maturity criteria for SBT was supported by the ESC, and also listed as a high priority in the Scientific Research Plan (SRP) since 2015 (Farley et al., 2013a, 2014). To enhance the integrity of the reproductive studies and ensure the continuity of the project, we processed the scientific biological sample collection of SBT as an essential objective in the Taiwanese scientific observer program annually. Here, we presented the results of GSI analyses and the maturity status of SBT collected by Taiwanese scientific observer program.

2. MATERIALS AND METHODS

GSI calculation

The SBT gonad samples were collected by scientific observers deployed on Taiwanese longline vessels operated in the Indian Ocean. The biological information, including the fork length, body weight, sex, sampling date and location, was recorded for each specimen.

Here, for the calculation of gonado-somatic index (GSI), we adopted a length-based formula for calculating the GSI (Chen et al., 2013):

$$GSI = \frac{GW}{L^3} \times 10^4$$

where *GSI* is the gonado-somatic index, *GW* is the weight (g) of gonad and *L* is the fork length (cm) of each specimen.

Histology Section and Maturity status

Gonad samples were preserved in 10% buffered formalin for subsequent histological analysis. Fixed tissue sections were processed and stained using Harris' hematoxylin and eosin to prepare histological slides. We performed histological classification to identify the maturity stages of the gonad samples.

The criteria for classifying the gonadal developmental stages of SBT require further development; therefore, we adopted the classification criteria proposed by Farley et al. (2013b), originally developed for albacore in the southern Pacific Ocean. This system was applied to categorize the developmental stages of SBT gonads into seven stages:

1. Immature; 2. Developing; 3. Spawning capable; 4. Spawning;

5. Regressing – potentially reproductive; 6. Regressed; 7. Regenerating

Individuals were considered mature if the most advanced oocytes were indicative of stage 3 or higher. Among these, stages 3 and 4 represent reproductively active phases, while stages 1–2 and 5–7 are considered reproductively inactive. The detailed criteria for each stage are presented in Table 1, adapted from Farley et al. (2013b).

3. RESULTS AND DISCUSSION

A total of 1,407 gonad samples of SBT were collected during March to September from 2010 to 2024 including 664 females and 743 males. The sampling area were distributed around 30°E-110°E in longitude and 29°S-42°S in latitude in the south Indian Ocean (Fig. 1). The range of fork length of female and male samples were from 73 to 182 cm and 60 to 194 cm, respectively. The majority of samples' fork length were distributed between 90 and 150 cm in both female and male (Fig. 2).

Gonad weights showed an increasing trend with fork length in females and males, displaying greater variability among larger individuals, particularly those exceeding 150 cm in fork length (Fig. 3). Similarly, the relationship between fork length and the gonadosomatic index (GSI) for both females and males, the pattern was observed that the GSI values generally increasing as fork length increased. However, some individuals exhibited relatively low GSI values that did not follow this trend (Fig. 4). These deviations may be associated with the reproductive maturity status of the samples and warrant further investigation.

To understand monthly variation in GSIs and gonadal maturity status, we calculated the mean monthly GSI values for both sexes. In females, GSI values peaked in April and remained elevated through July, followed by a declining trend that reached the lowest levels in September. For the GSI values of males, the maximum value was revealed in March, and then gradually declined, reaching a minimum in September based on updated data through 2024 (Fig. 5). These monthly patterns in GSI for both sexes were consistent with trends observed in previous years. However, due to the temporal coverage of sample collection limited to March through September, as a result of the seasonal operation of the Taiwanese SBT longline fishery in the Indian Ocean, the annual GSI cycle could not be fully characterized (Fig. 5).

For histological identification of gonadal maturity stages, some samples were excluded due to inadequate preservation, primarily resulting from the challenges associated with processing frozen specimens. Here, we focused on the female samples. Consequently, a total of 566 female gonad samples collected between 2010 and 2023 were successfully processed for histological examination (Fig. 6). Sexual maturity

stages were assigned based on the developmental stage criteria outlined by Farley et al. (2013b). Histological diagnosis revealed that the majority of individuals were classified as being in the immature stage, with a subset identified at the developing stage (Fig. 7). Approximately 14.9% of the samples were classified as mature; however, most of these were in reproductively inactive phases, specifically the regressed or regenerating stages.

Additionally, the proportion of maturity stages was analyzed across 5 cm fork length intervals (Fig. 8). The majority of female gonadal samples based on data updated through 2023 were classified as immature. The smallest fork lengths recorded for mature individuals were 97 cm for females (Fig. 9). Although gonad weights and GSI generally increased with fork length, no clear threshold could be identified to separate mature from immature individuals. Considerable overlap was observed in fork length, gonad weight, and GSI values between immature and mature specimens. However, individuals with fork lengths less than approximately 90 cm were exclusively immature, with no overlap detected in this size class (Figs. 8-10).

The monthly distribution of gonadal maturity developmental stages from March to September indicated that most mature female individuals were in a reproductively inactive status (Fig. 11), and the immature individuals were distributed throughout the entire SBT fishing season from March to September. The majority of mature individuals were classified as being in regressed (Stage 6) or regenerating (Stage 7) phases, predominantly during April to August. These findings suggest that mature SBT may migrate into the Taiwanese longline fishing grounds in the Indian Ocean after completing reproductive activity elsewhere.

Due to the limited spatial and temporal coverage of the Taiwanese SBT longline fishery, particularly outside of the March-September fishing season, a complete understanding of the annual reproductive cycle remains constrained. To address this, collaborative efforts with other researchers and SRP will be helpful for refining the histological classification criteria for gonadal maturity stages and advancing knowledge of SBT reproductive biology.

REFERENCES

- Chen, M.H., Chen, K.S., Chen, T.C., Sun, C.L., Chen, C.Y. 2013. Notes on the reproductive biology of southern bluefin tuna *Thunnus maccoyii* in the southwestern Indian Ocean. Indian J. Mar. Sci. 42, 419-424.
- Farley, J.H., Davis, T.L.O., 1998. Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. Fish. Bull. 96, 223–236.
- Farley J, Davies C, Hillary R, Eveson P. 2013a Estimating size/age at of southern bluefin tuna. CCSBTESC/1309/41, 18th Meeting of the Scientific Committee, 2-7 September 2013, Canberra, Australia.
- Farley J.H., Williams A.J., Hoyle S.D., Davies C.R., Nicol S.J. 2013b. Reproductive Dynamics and Potential Annual Fecundity of South Pacific Albacore Tuna (*Thunnus alalunga*). PLOS ONE 8(4): e60577. doi.org/10.1371/journal.pone.0060577
- Farley J, Davies C, Nugraha B. 2014 SRP proposal: Estimating size/age at maturity of southern bluefin tuna. CCSBTESC/1409/23, 19th Meeting of the Scientific Committee, 1-6 September 2014, Auckland, New Zealand.
- Farley, J.H., Hoyle, S.D., Eveson, J.P., Williams, A.J., Davis, C.R., Nicol, S.J. 2014. Maturity ogives for south Pacific albacore tuna (*Thunnus alalunga*) that account for spatial and seasonal variation in the distributions of mature and immature Fish. PLoS ONE 9(1): e83017. doi:10.1371/journal.pone.0083017.
- Thorogood, J. 1986. Aspects of the reproductive biology of the southern bluefin tuna (*Thunnus maccoyii*). Fish. Res. 4, 297–315.

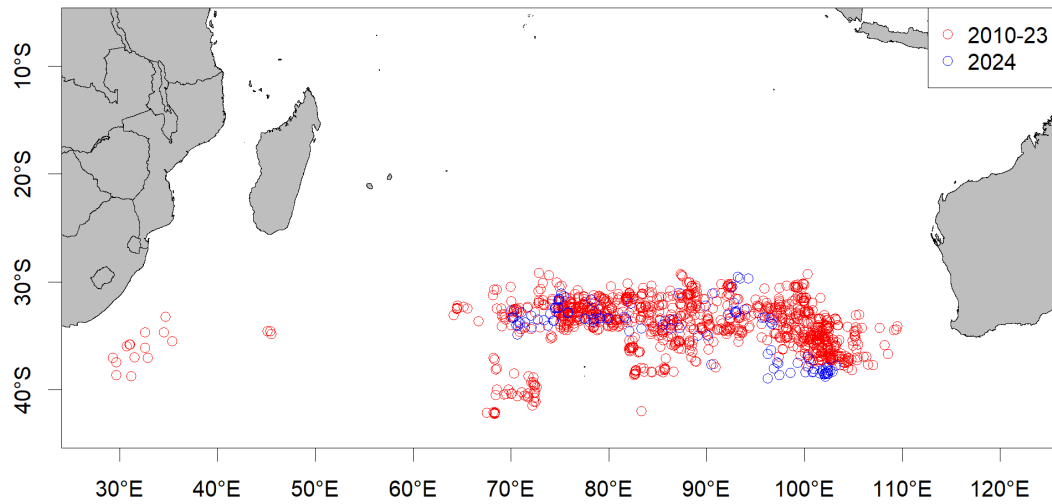


Fig. 1. Sampling locations of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2024.

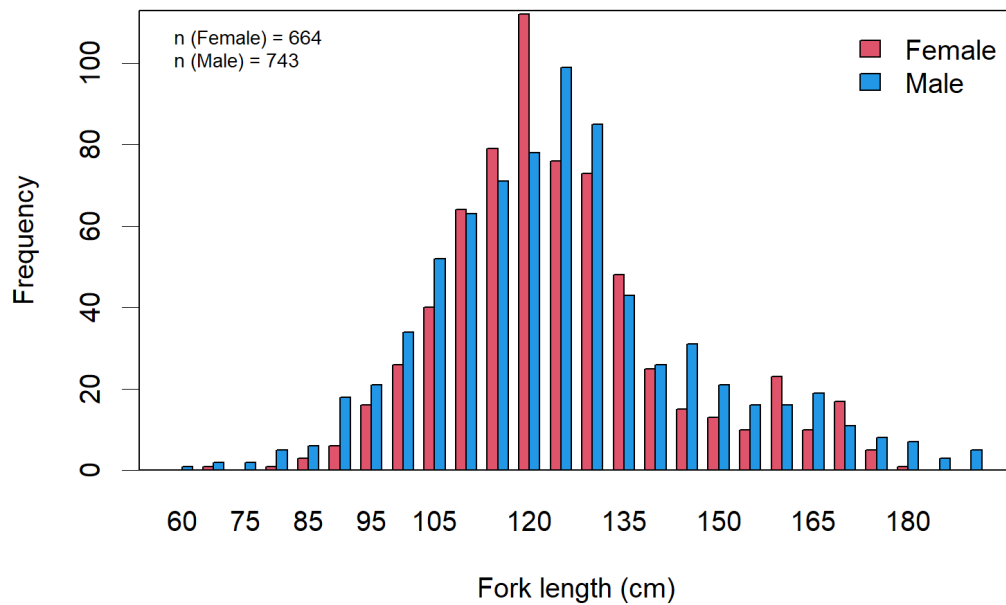


Fig. 2. Length frequency distributions (5 cm intervals) for gonad samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2024.

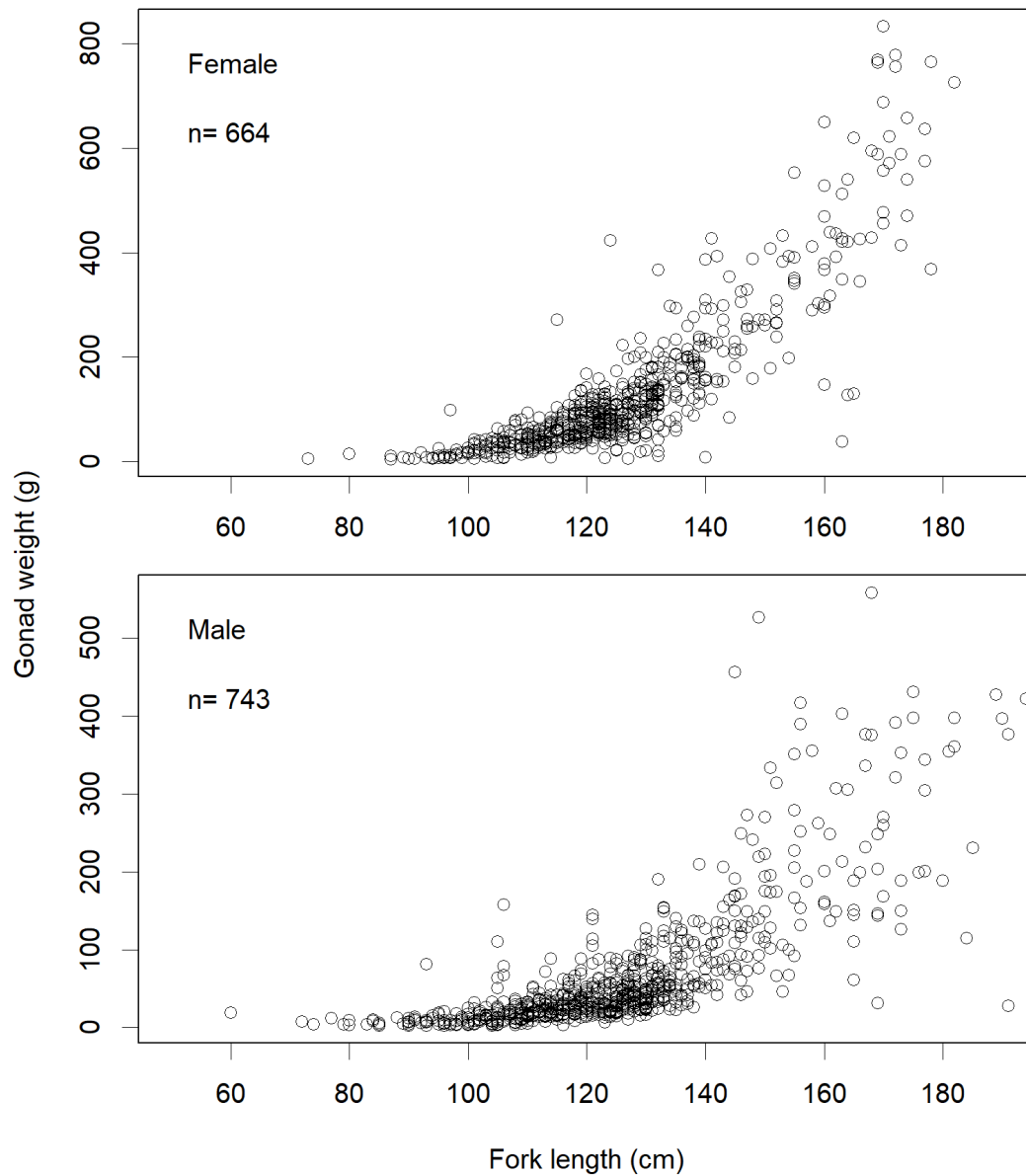


Fig. 3. Relationship between fork length and gonad weight of samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2024.

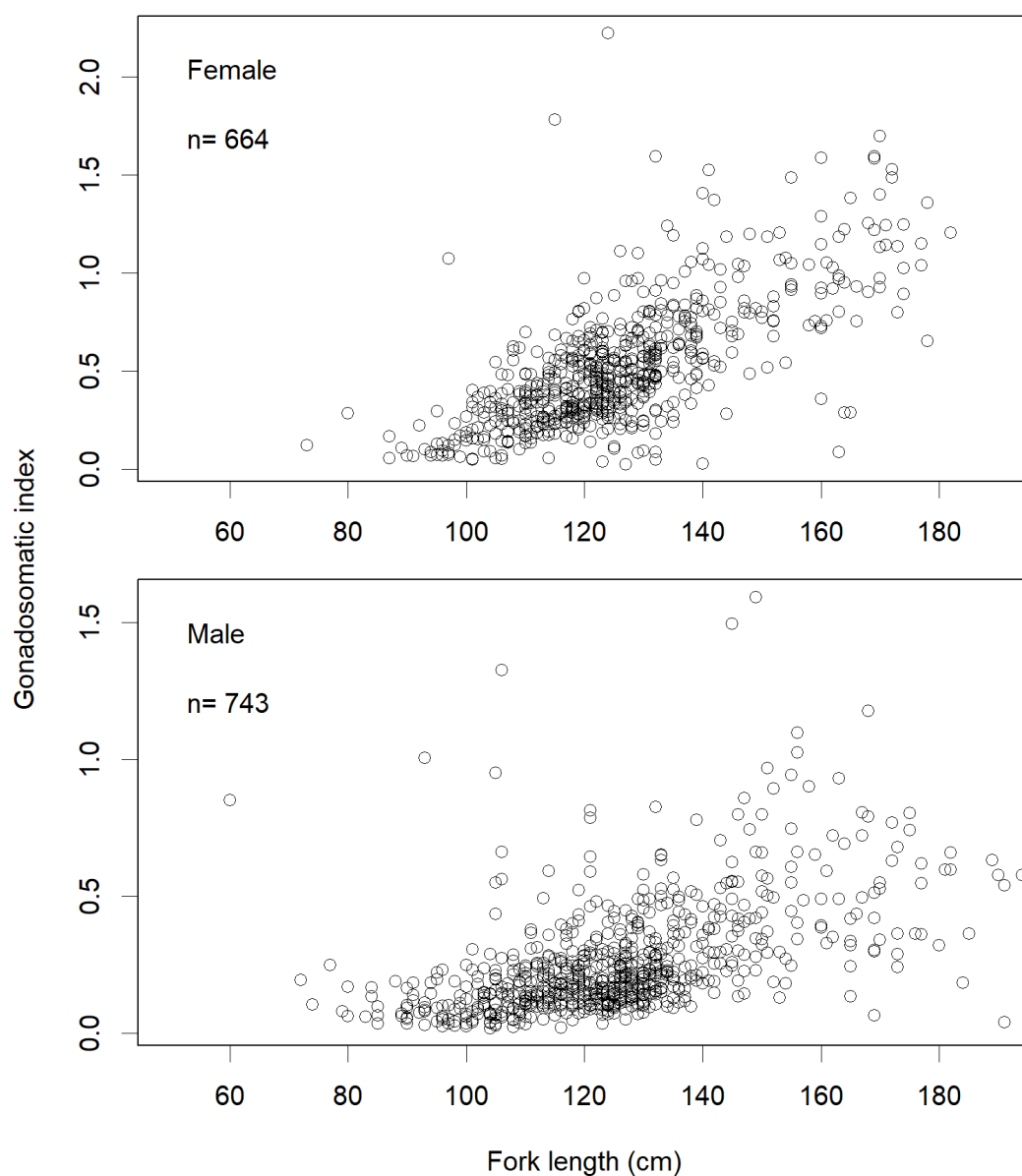


Fig. 4. Relationship between fork length and gonadosomatic index (GSI) of samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2024.

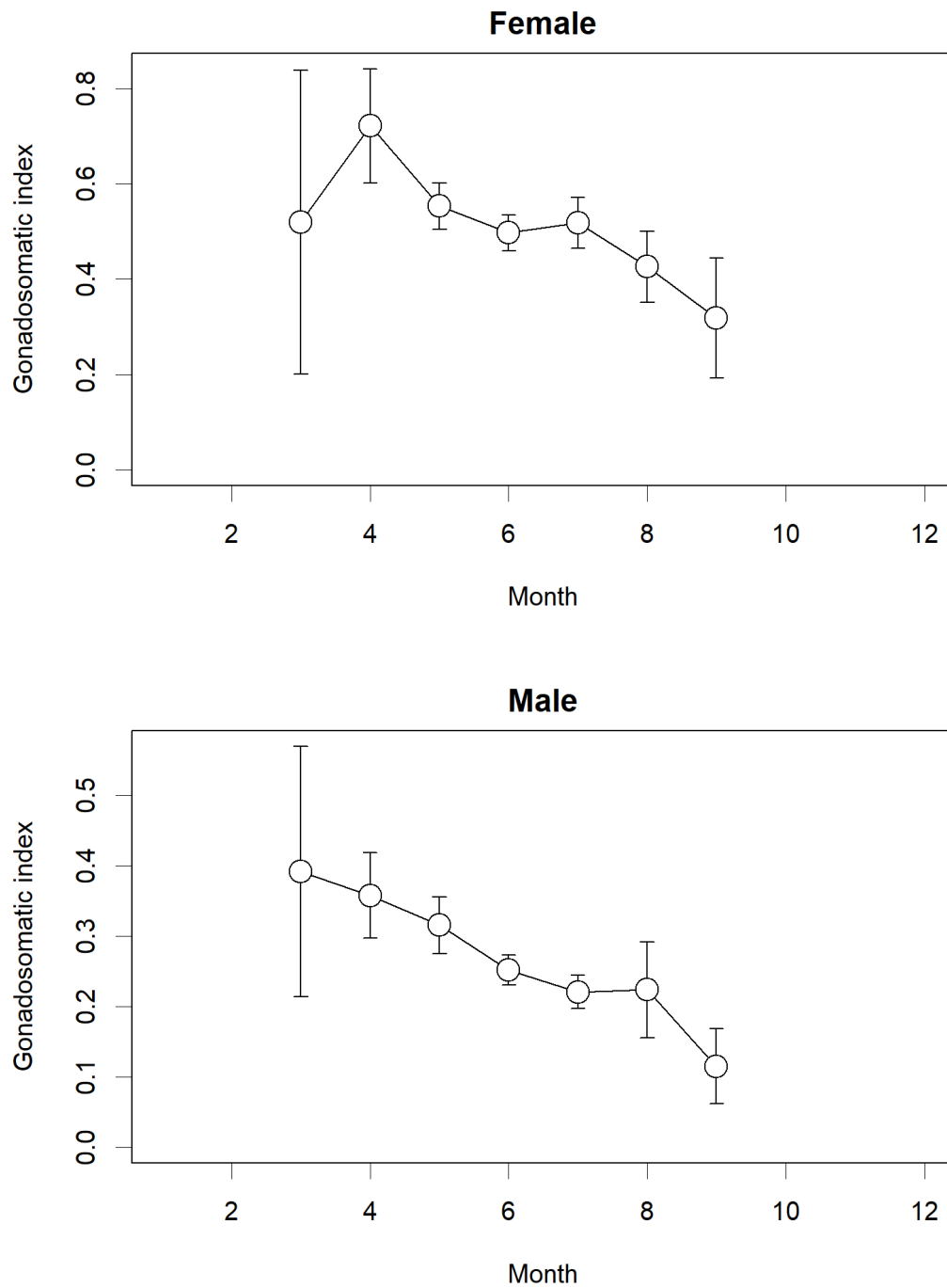
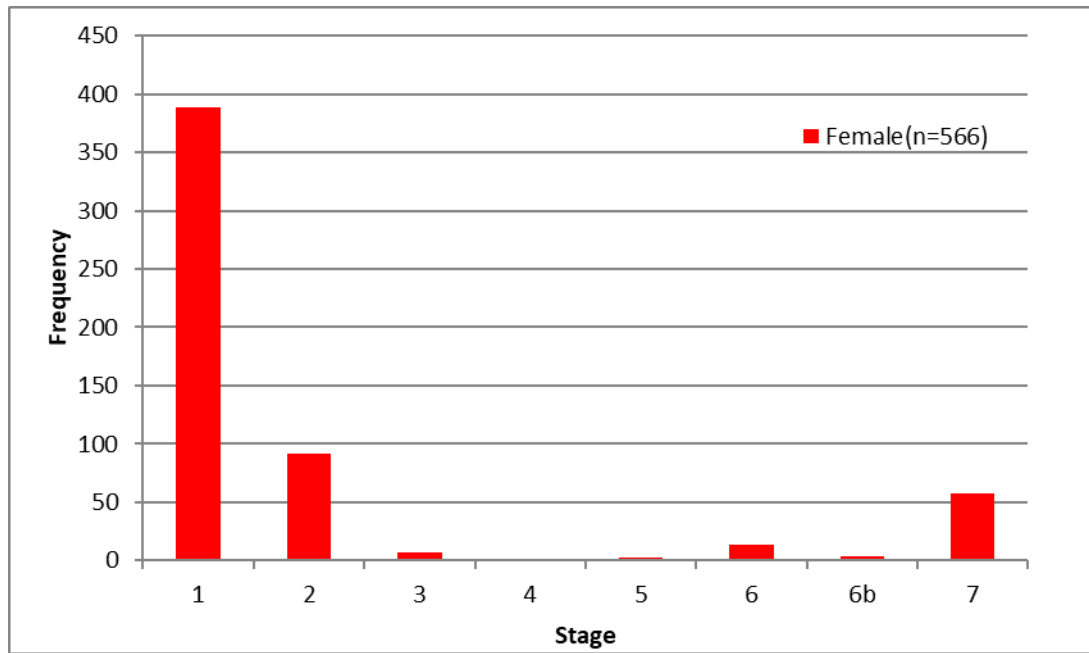


Fig. 5. Monthly trends of gonadosomatic index (GSI) for gonad samples of SBT collected by Taiwanese scientific observer program. Vertical bars represent the 95% confidence interval for means during 2010-2024.

(a)



(b)

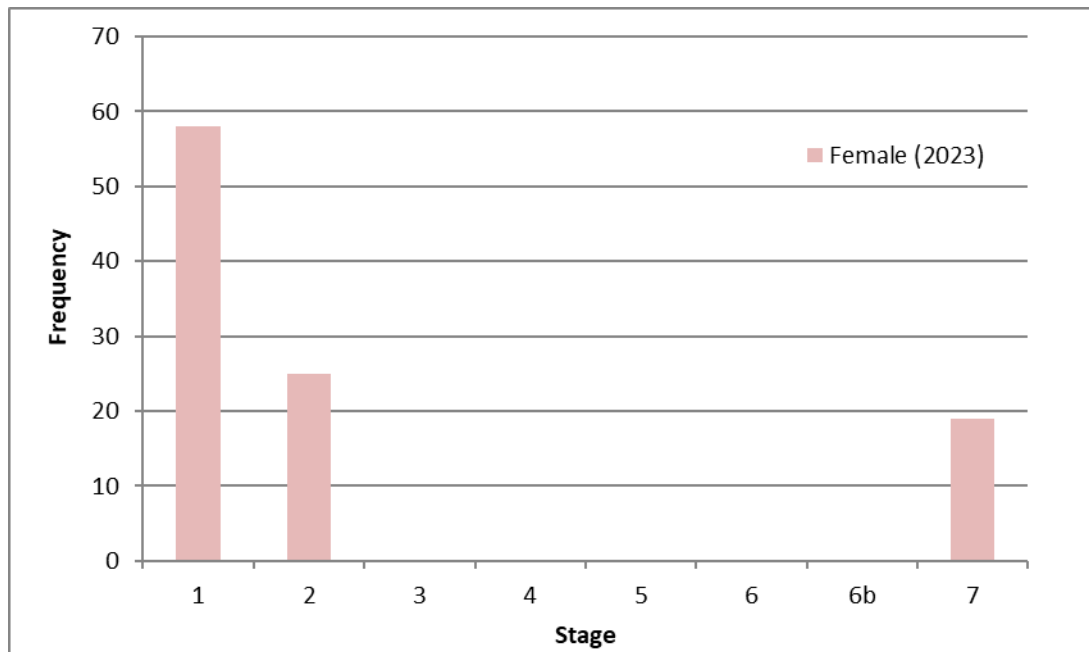
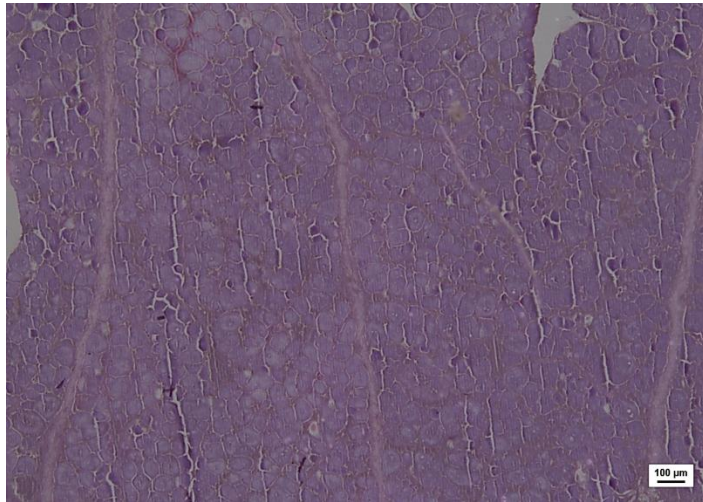
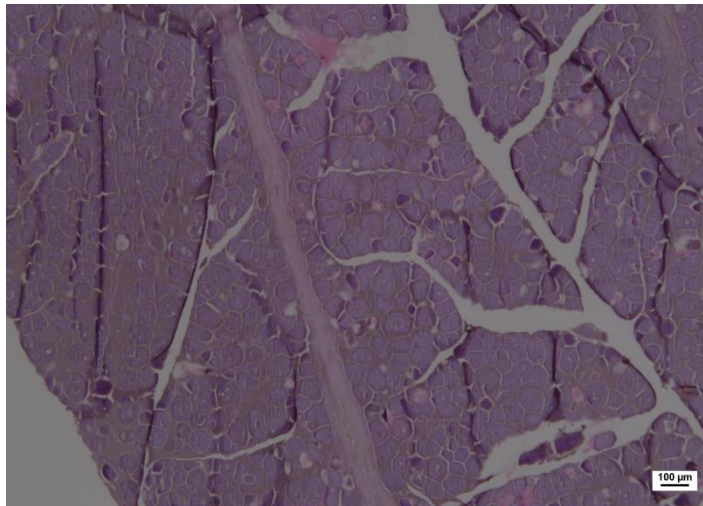


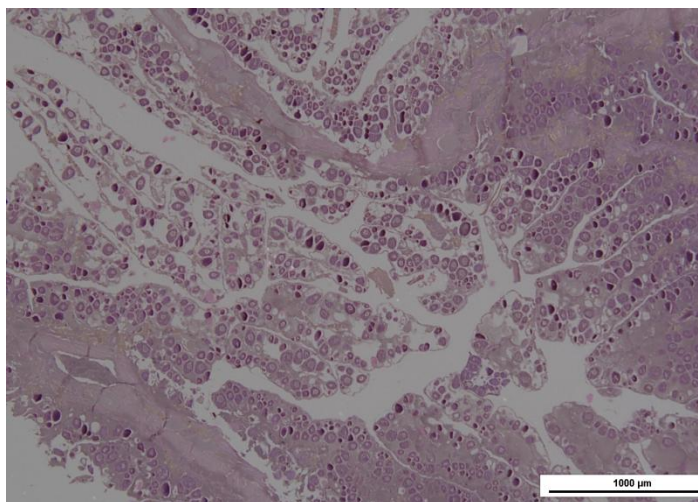
Fig. 6. Number of samples by maturity classes for gonad samples of female SBT collected by the Taiwanese scientific observer program. (a) The collection period was from 2010 to 2023. (b) The histological collection in 2023 (n=102).



FL: 121cm, GW: 87.93 g (Stage 1, immature status)



FL: 143cm, GW: 210.65g (Stage 2, developing status)



FL: 169cm, GW: 588.0 g (Stage 7, Regenerating status)

Fig. 7. Histological sections and measurements of oocytes for gonad samples of female SBT collected by Taiwanese scientific observer program in 2023.

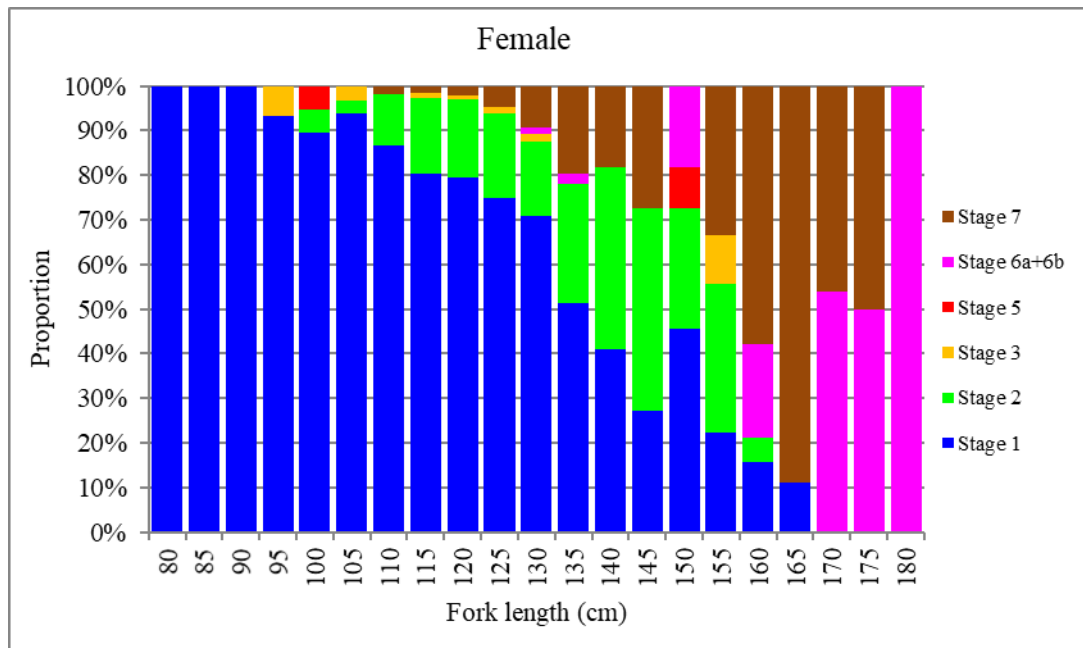


Fig. 81. Proportion of maturity stages by fork lengths with 5 cm intervals for gonad samples of female SBT collected by the Taiwanese scientific observer program from 2010 to 2023.

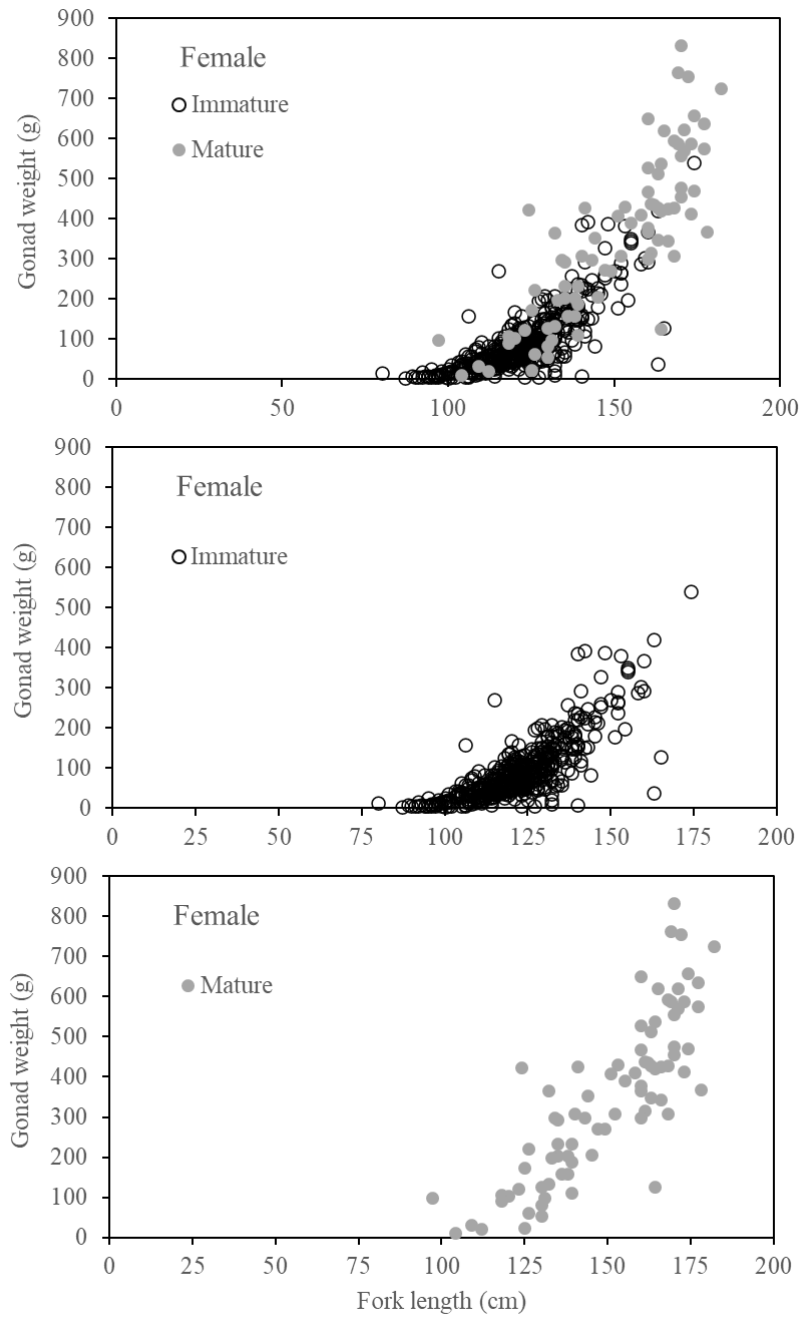


Fig. 9. Relationship between fork length and gonad weight by maturity status for gonad samples of female SBT collected by Taiwanese scientific observer program from 2010 to 2023.

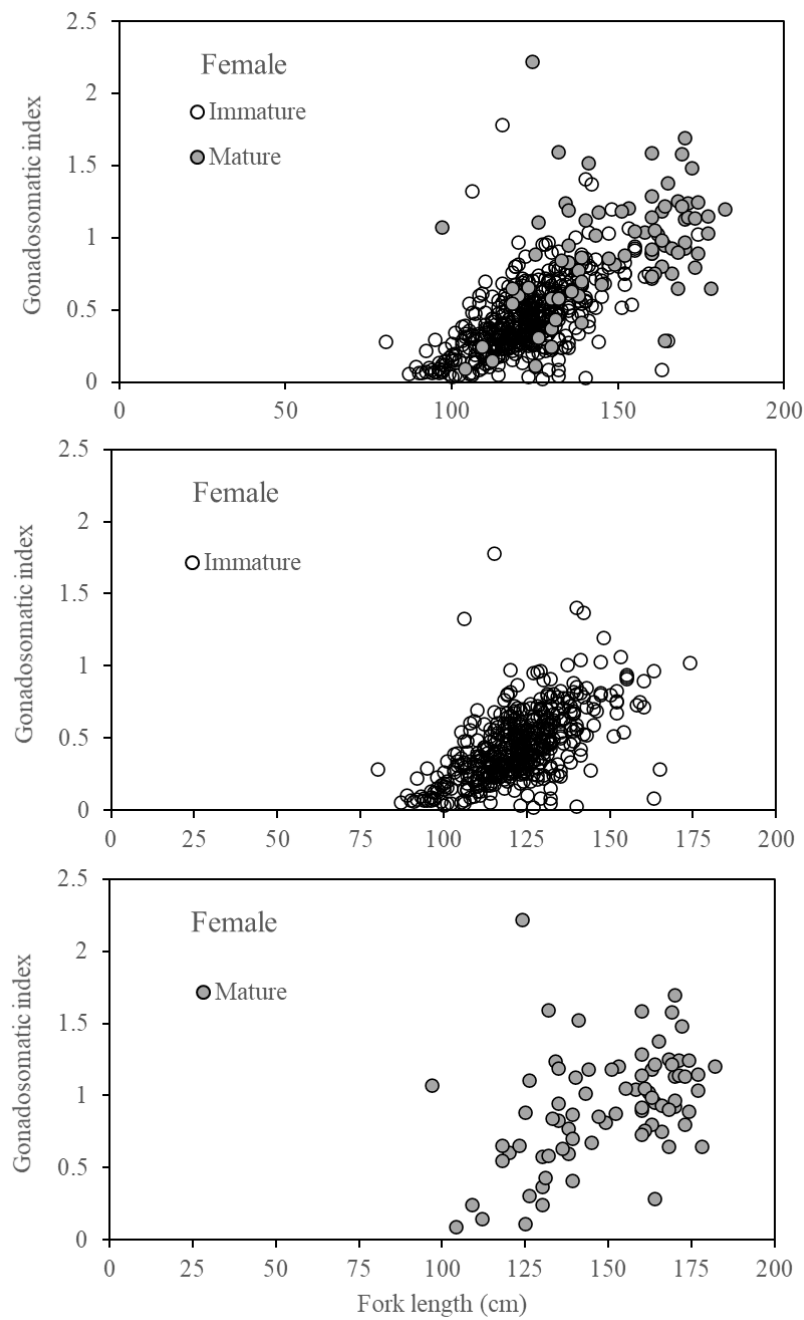


Fig. 10. Relationship between fork length and gonado-somatic index (GSI) by maturity status for gonad samples of female SBT collected by Taiwanese scientific observer program from 2010 to 2023.

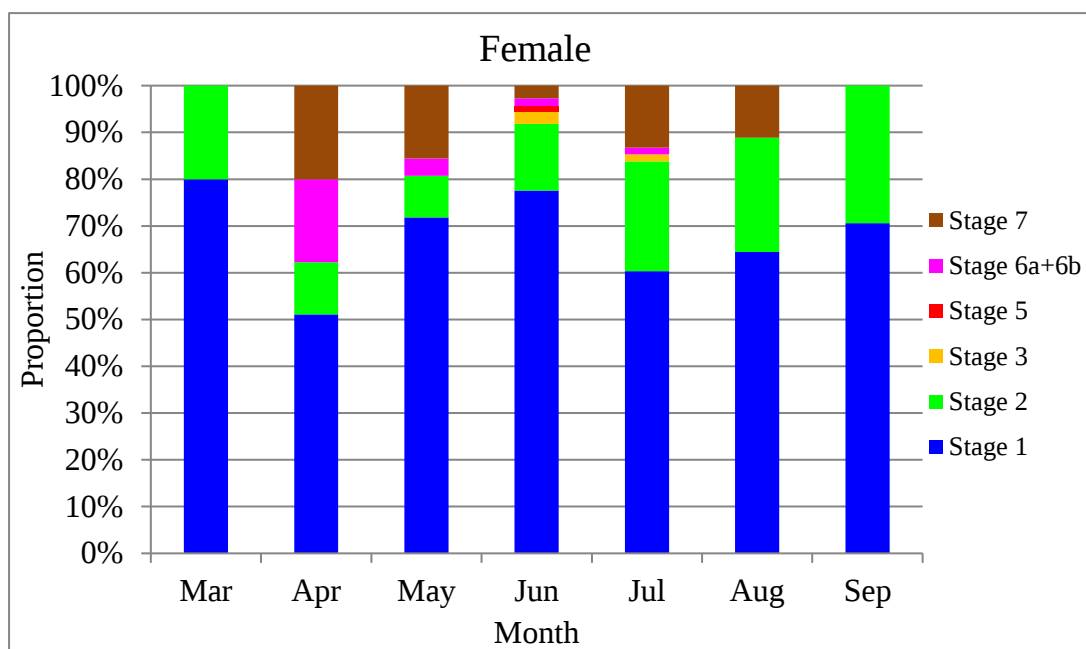


Fig. 11. Proportion of maturity stages by monthly category for gonad samples of female SBT collected by Taiwanese scientific observer program from 2010 to 2023.

Table 1. The criteria of gonadal developmental stages for albacore in the south Pacific Ocean (Adopted from Farley et al., 2013b).

Class	Maturity status	Activity	Development class	MAGO and POF stage	α and β atresia of yolked oocytes
1	Immature	Inactive	Immature	Unyolked,no POFs	Absent
2	Immature	Inactive	Developing	Early yolked,no POFs	Absent
3	Mature	Active	Spawning capable	Advanced yolked,no POFs	<50% α and β atresia may be present
4	Mature	Active	Spawning	Migratory nucleus or hydrated and/or POFs	<50% α and β atresia may be present
5	Mature	Inactive	Regressing-potentially reproductive	Advanced yolked,no POFs	$\geq$ 50% α and β atresia present
6a	Mature	Inactive	Regressed 1	Unyolked or early yolked, no POFs	100% α and β atresia may be present
6b	Mature	Inactive	Regressed 2	Unyolked or early yolked, no POFs	No α and β atresia present
7	Mature	Inactive	Regenerating	Unyolked or early yolked, no POFs	Absent