Updated gonadal information and analysis of southern bluefin tuna collected by Taiwanese scientific observer program

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ABSTRACT

All the samples were collected by scientific observers dispatched on the longline vessels operated in the Indian Ocean. There were 71 gonad samples updated in 2022, and a total of 1021 gonad samples were collected from 2010 to 2022. The range of fork length of females and males samples were concentrated between 90 and 150 cm. Based on the trends of the monthly gonadosomatic index (GSI) analyses, the trend of monthly GSI of females indicated that higher values occurred during April to July and gradually decreased after the peak in April, the second higher valus of GSI was revealed in July. On the other hand, the monthly GSI of males decreased gradually after the maximum value in April. The trends of monthly GSI of both genders showed similar pattern with previous results. There was no dramatically change of the trends of monthly GSI.

According to the results of the histological sections, a total of 869 gonad samples in the collection period of 2010-2021 were analyzed for the sexual maturity stages determination including 424 females and 445 males. The majority of these samples were diagnosed as immature stage, and about 10.5% samples designated as mature but at reproductively inactive status. Also, most mature females were identified at regressed (stage 6) or regenerating (stage 7) stages from April to August, and most mature males were also identified at regenerating (stage 7) stages during June to August.

1. INTRODUCTION

Previous studies related the reproductive biology of the southern bluefin tuna (SBT, *Thunnus maccoyii*) were conducted among different basins. Multiple reproductive index of SBT such as age-at-first-maturity, gonad index, ovary size-frequency and fecundity had been investigated in the waters off the south eastern 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. Also, the study related the sexual maturity of SBT have been conducted and investigated with the information of the morphological and histological observations of the gonad samples collected by Taiwanese observers program in the southwest Indian Ocean (Chen et al., 2013). However, there is no specific standard for determining the maturity stages in SBT. Establishing the guideline of the determination maturity stages is an essential work for further understanding of reproductive researches of SBT.

Therefore, developing an independently estimated maturity criteria and sample collection for maturity studies were supported by the ESC, and also listed as a high priority in the Scientific Research Plan (SRP) since 2015 (Farley et al., 2013a, 2014). For improving the integrity of the reproductive research results, we designed the scientific observation and data collection of SBT including biological samples such as gonads, otoliths, and muscle tissues as essential objectives in the Taiwanese scientific observers program, also it had been conducted for continued program. Here, we presented the updated gonad information of SBT collected by Taiwanese scientific observers deploying on board from 2010 to 2022.

2. MATERIALS AND METHODS

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 were recorded for each specimen.

For the calculation of gonado-somatic index (GSI), we adopted a length-based GSI (Chen et al., 2013) in this study:

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

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

For the histology section, the gonad samples were fixed in 10% buffered formalin for histological processes. And histological sections were processed and stained with Harris' haematoxylin and eosin for the preparation of the histological slides. We conducted the histological classification for diagnosing sexual maturity stages of gonad samples. The criteria of histological classification for gonadal developmental stages of

SBT were needed further discussed specifically. Therefore, here, we followed the criteria of Farley et al. (2013b), which were used for albacore in the southern Pacific Ocean, and adopted to categorize the gonadal developmental stages for SBT. Seven categories of the developmental stages were classified as the (1) immature stage, (2) developing stage, (3) spawning capable stage, (4) spawning stage, (5) regressing - potentially reproductive stage, (6) regressed stage, and (7) regenerating stage. Individuals were designated as mature if the most advanced oocytes were indicative of ≥ stage 3. Stages 3 and 4 are reproductively active stages, and stages1-2 and 5-7 are reproductively inactive stages. The details of the criteria were listed in Table 1. adopted from Farley et al (2013b).

3. RESULTS AND DISCUSSION

A total of 1021 gonad samples of SBT were collected during March to September from 2010 to 2022 including 484 females and 537 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 from 2010 to 2022 (Fig. 1). The range of fork length of female and male samples were from 80 to 178 cm and 60 to 191 cm, respectively. The majority of samples' fork length were distributed between 90 and 150 cm in both female and male (Fig. 2).

The values of gonad weights revealed increasing pattern with the growth of fork lengths obviously in both sexes. Also the relationship between fork lengths and gonad weights showed the clear variation in larger size specimens especially were over 150 cm in fork length (Fig. 3). The similar patterns of the relationship between fork length and GSI were also presented in both females and males, which the GSI showed increasing pattern as fork length increasing. However, in some cases, the GSI were are followed the increasing pattern (Fig. 4). It might be related to the maturity status of those samples and needs to be further investigated.

Also, we calculated the average of GSIs by month in both sexes for understanding of the monthly variation of GSIs and gonad maturity status. First, the monthly GSIs of females revealed highest value in April and remained higher values from April to July. Then it started the decreasing trends after July. Generally, the lower values were revealed in March and September; Second, the monthly GSIs of males revealed the highest value in April. It stayed in higher values from March to May and then decreased gradually reached the lowest value in September with updated data to 2022 (Fig 5). The monthly trends of GSI for females and males showed no obvious changes and remained the similar trends as the past. Because the limited fishing season of Taiwanese SBT

longliner fishery, the collection of samples was also concurred with limitation. The samples were collected only from March to September, monthly trend of GSI would not be explored for the entire year (Fig. 5).

Some samples were not qualified for processing the histological section, due to the difficulties of processing frozen samples in the sample preservation. A total of 869 gonad samples including 424 females and 445 males were collected from 2010 to 2021 were successfully examined histological sections, and the sexual maturity stages were determined based on the criteria of developmental stages in Farley et al (2013b). According to the results of the histological sections of both sexes, the majority of samples were identified as immature stage and some samples were determined at developing stage. And there were about 10.5% of samples designated as mature but most of these samples were reproductively inactive (regressed or regenerating stages) (Figs. 6-8).

We analyzed the proportion of maturity stages by fork length with 5 cm intervals. The majority of gonadal samples of females and males were identified as immature specimen with the newly updated information to 2021. The smallest fork length of mature females and males were 97 and 93 cm, respectively (Figs. 9-11). Although the gonad weights and GSIs generally increased with the fork lengths, there is no obvious separation boundary between mature and immature individuals. Most immature and mature samples overlapped in the ranges of the fork lengths, gonad weights and GSIs. And there was no overlapped for the samples with fork length less than about 90 cm (Figs. 10 and 11).

According to the proportion of gonadal developmental stages by months (Fig. 12), most mature females which identified as regressed or regenerating stages (stage 6 and stage 7) were found during April to August, and most of mature males were regenerating stages (stage 7) during June to August. Based on the results of histological sections, the monthly variation in the proportion of maturity stages indicated that mature fishes might migrate to the fishing ground of Taiwanese SBT fishery after reproductive activity. Due to the limitation of sample collection and coverages of Taiwanese SBT longliner fishery, it would be essential to collaborate with others researcher for developing the criteria of histological classification for gonadal maturity stages and improving the reproductive biology of SBT.

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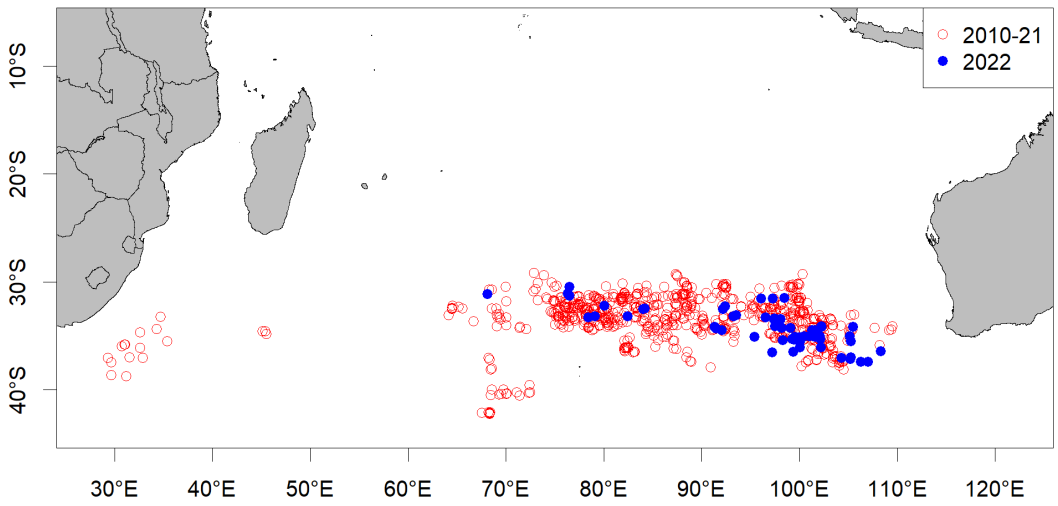


Fig. 1. Sampling locations of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2022.

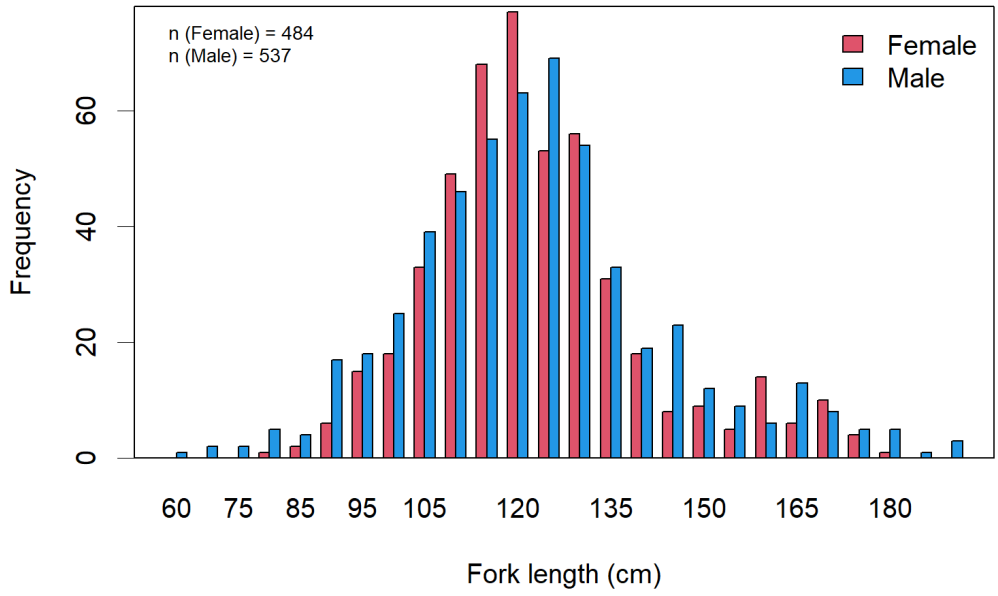


Fig. 2. Length frequency distributions (5 cm intervals) for gonad samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2022.

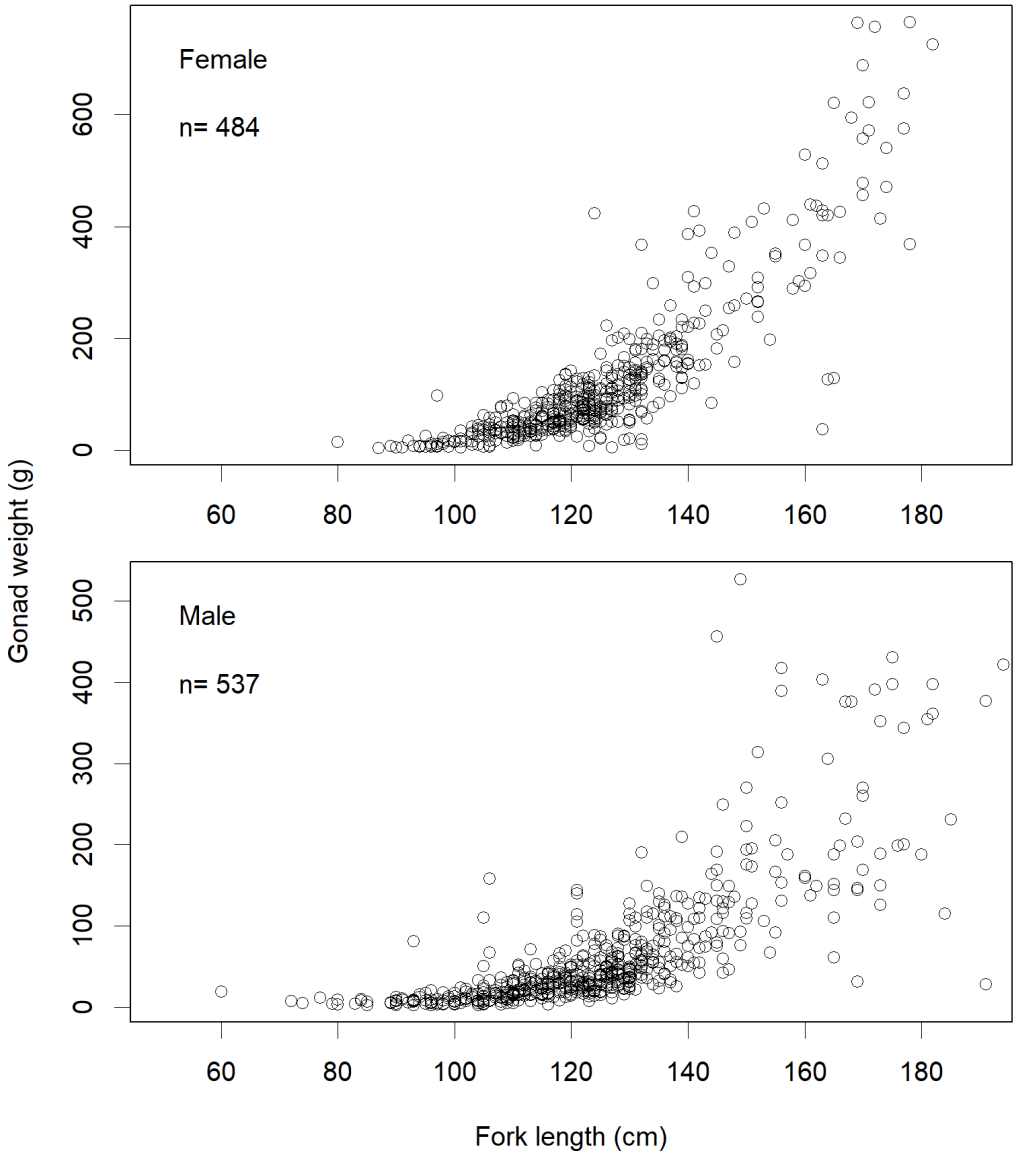


Fig. 3. Relationship between fork length and gonad weight of samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2022.

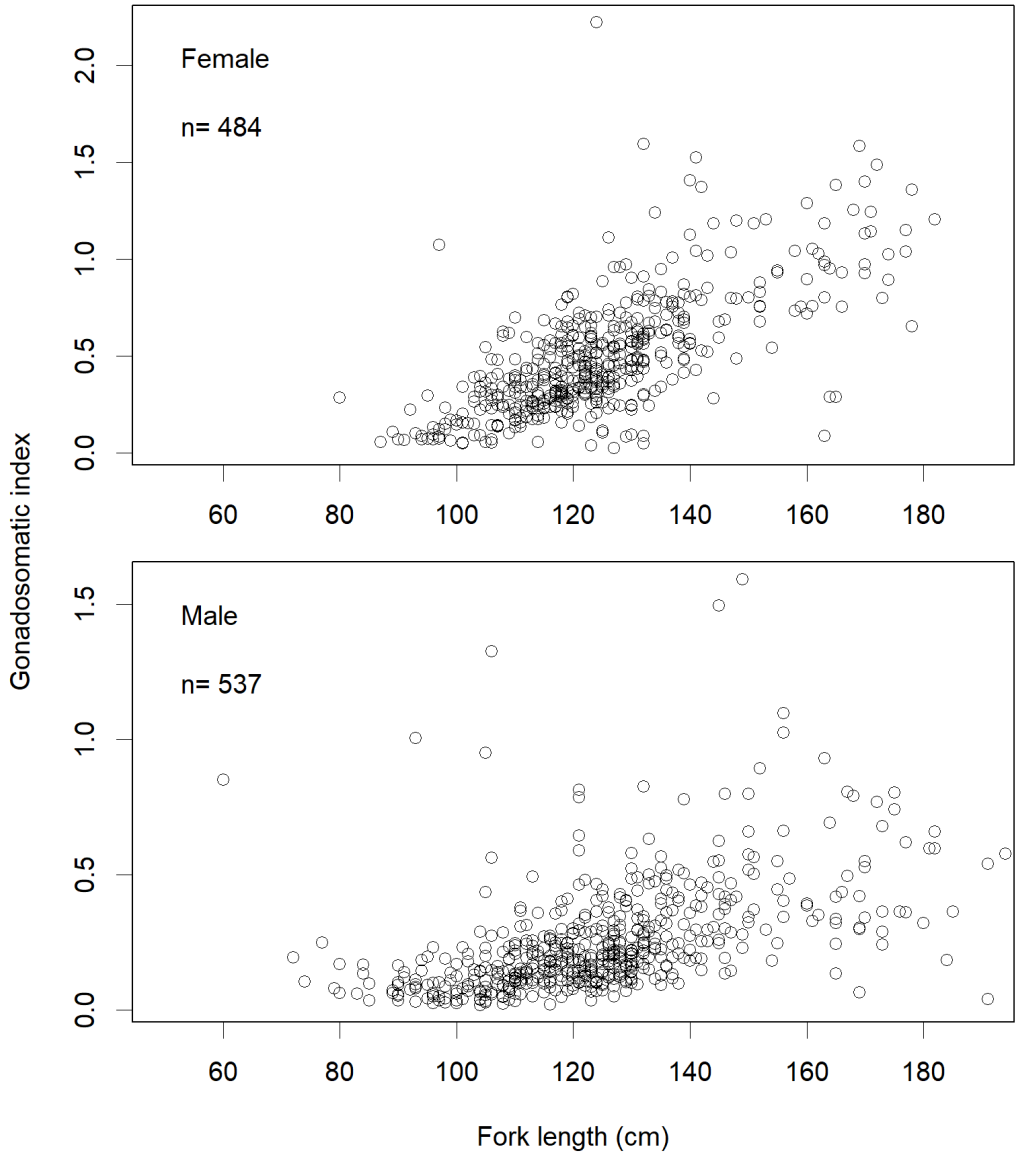


Fig. 4. Relationship between fork length and gonadosomatic index (GSI) of samples of southern bluefin tuna collected by Taiwanese scientific observer program from 2010 to 2022.

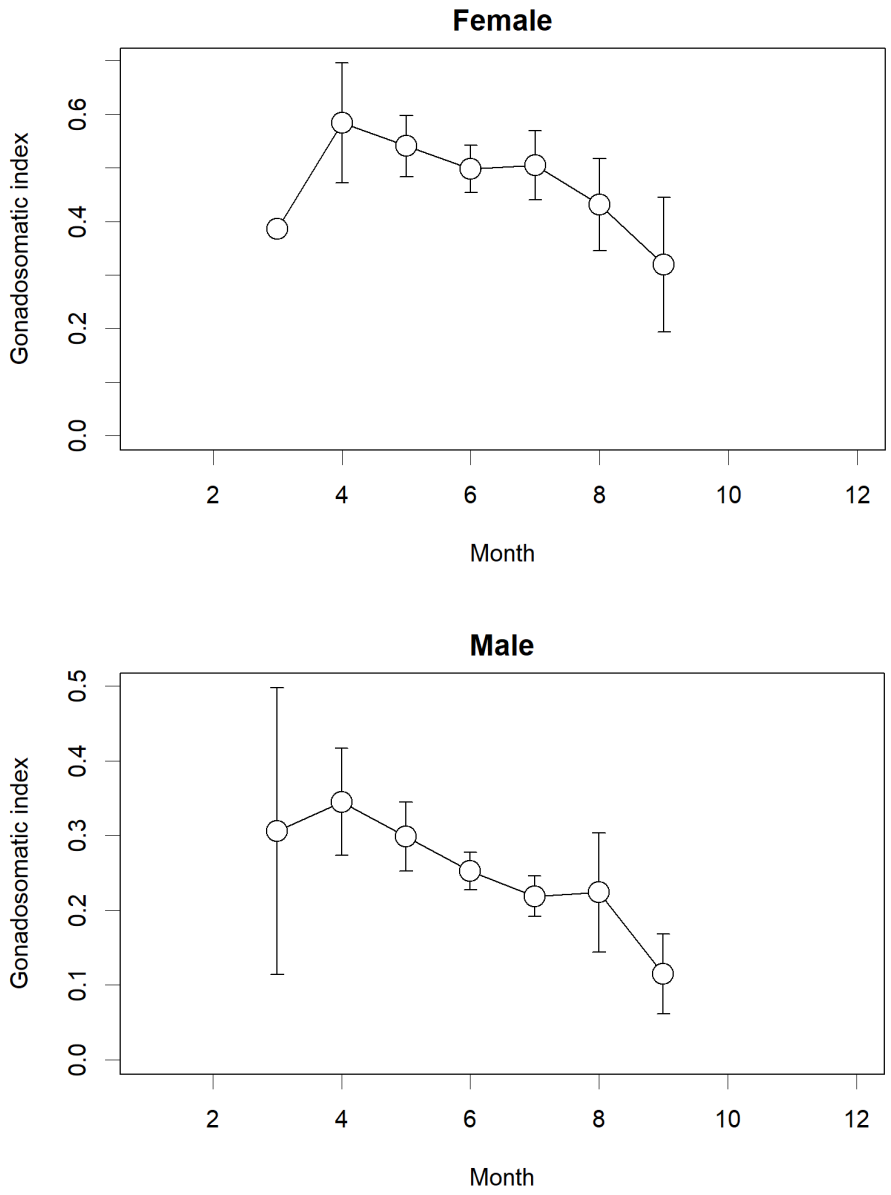


Fig. 5. Monthly trends of gonadosomatic index (GSI) for gonad samples of SBT collected by Taiwanese scientific observer program. Vertical bars represent the 95% confidence interval for means during 2010-2022.

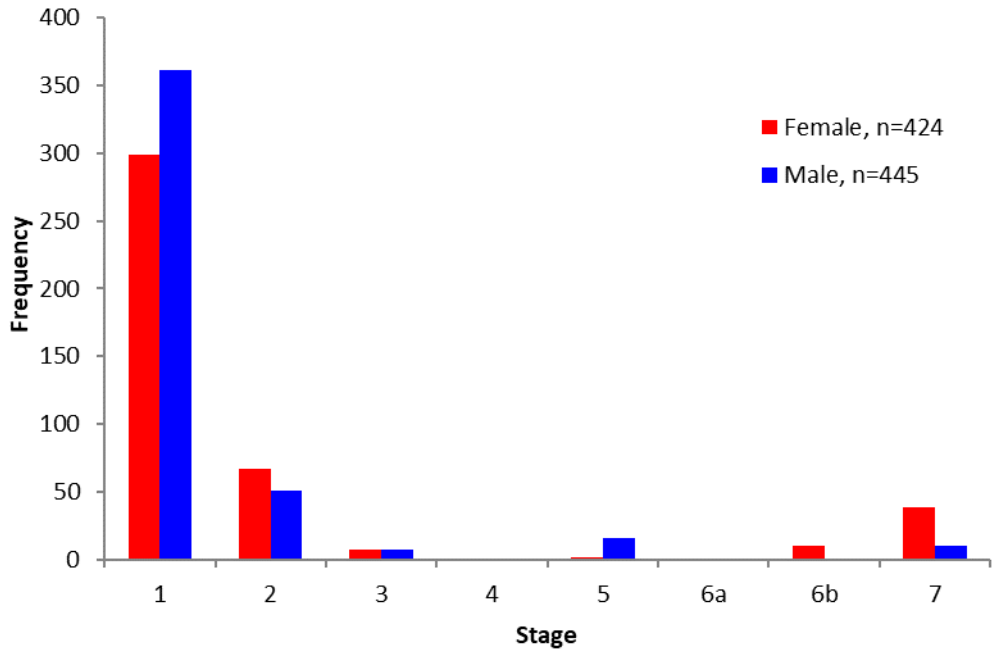
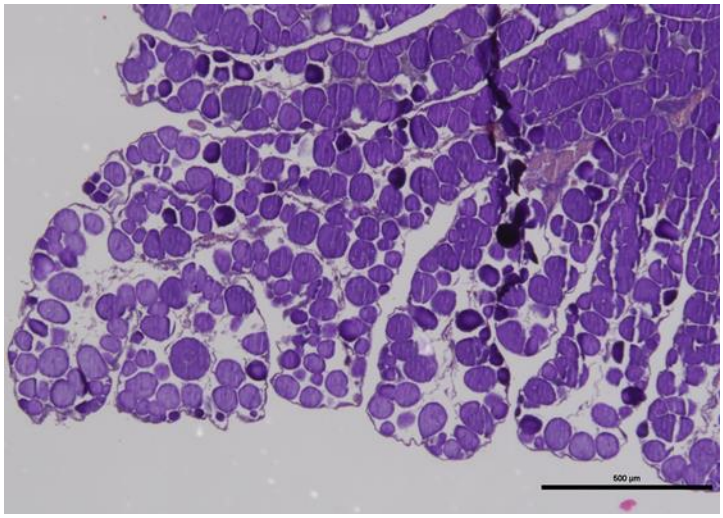
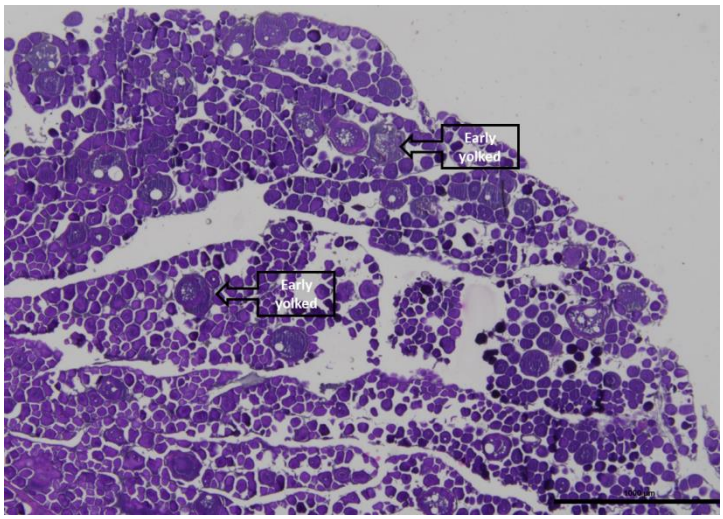


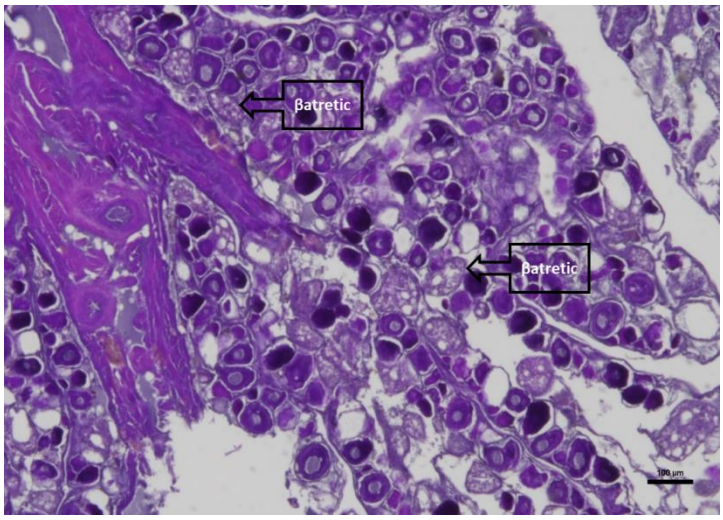
Fig. 6. Number of samples by maturity classes for gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2021.



FL140cm, GW155.26 g (Class 1, immature stage)

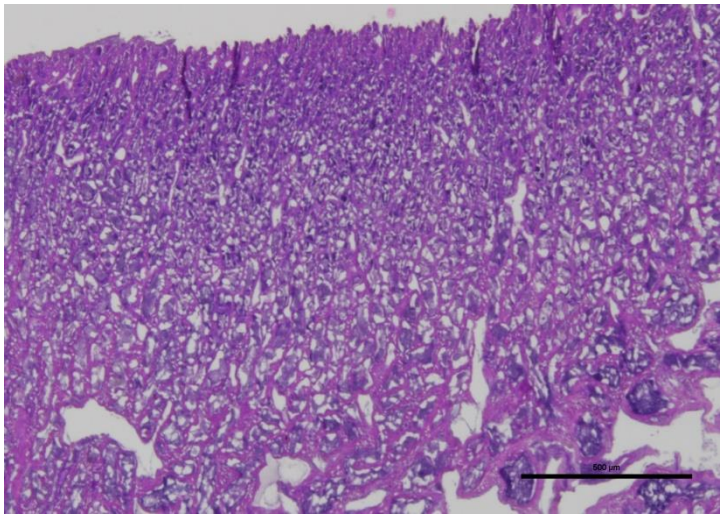


FL: 140cm, GW: 220.71g (Class 2, developing stage)

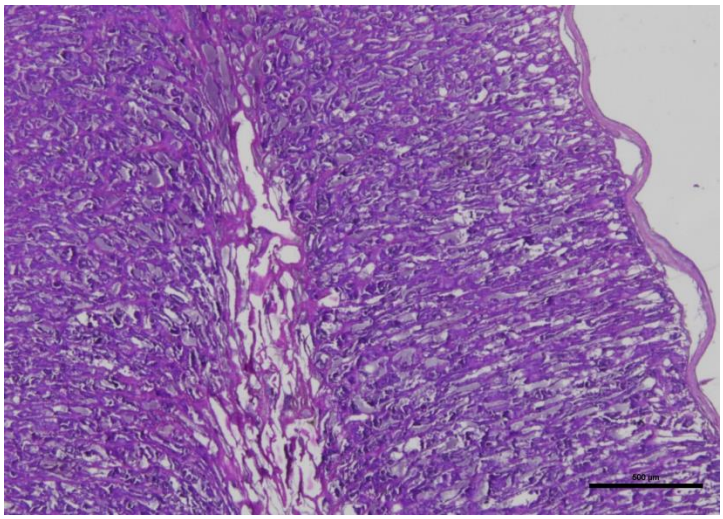


FL161cm, GW438.57 g (Class7, regressed stage)

Fig. 7. Histological sections and measurements of oocytes for gonad samples of female SBT collected by Taiwanese scientific observer program during 2010-2021.



FL: 133cm, GW: 98.32g (Class 1, immature stage)



FL134cm, GW114.68 g (Class 2, developing stage)

Fig. 8. Histological sections and measurements of oocytes for gonad samples of male SBT collected by Taiwanese scientific observer program during 2010-2021.

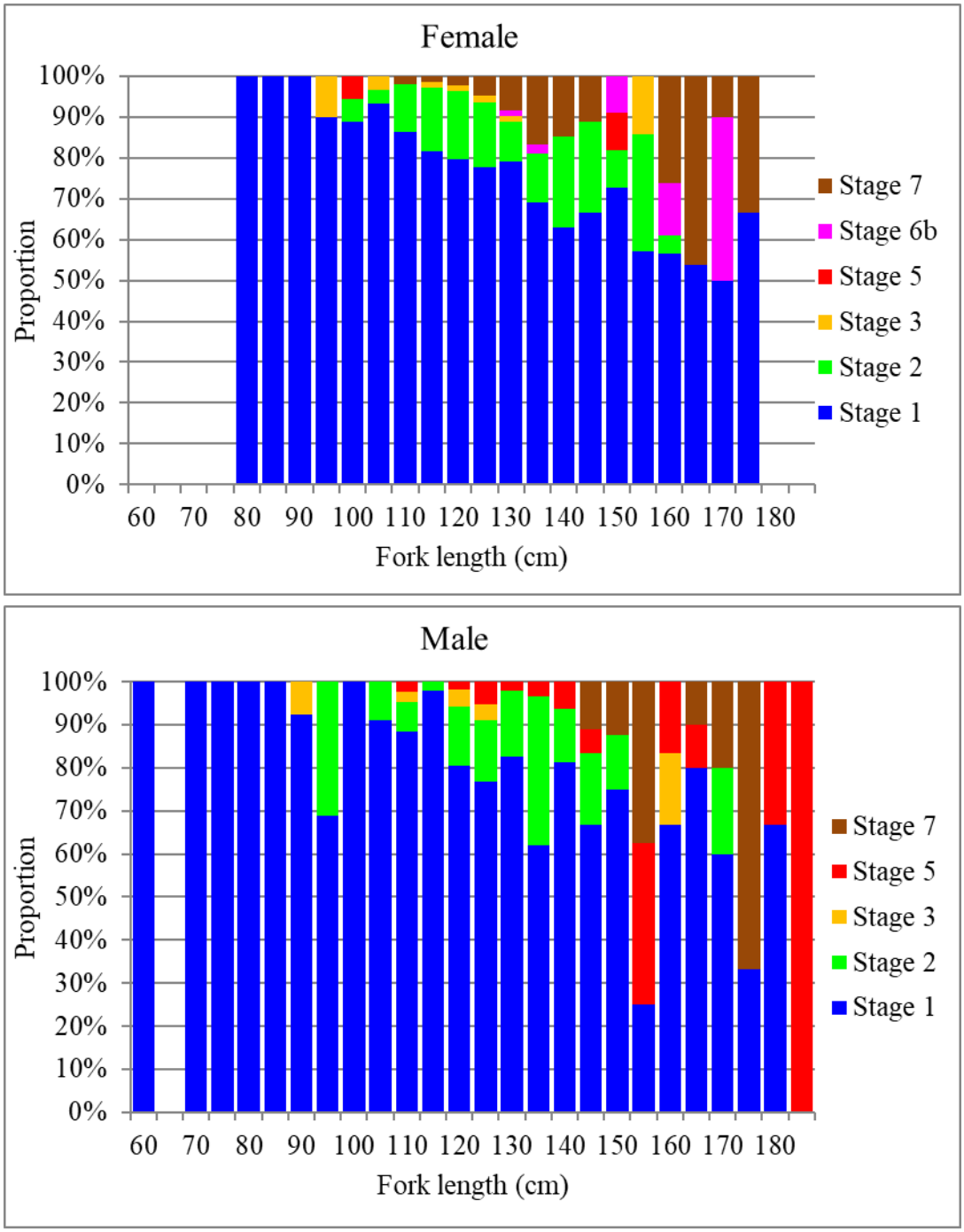


Fig. 91. Proportion of maturity stages by fork lengths with 5 cm intervals for gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2021.

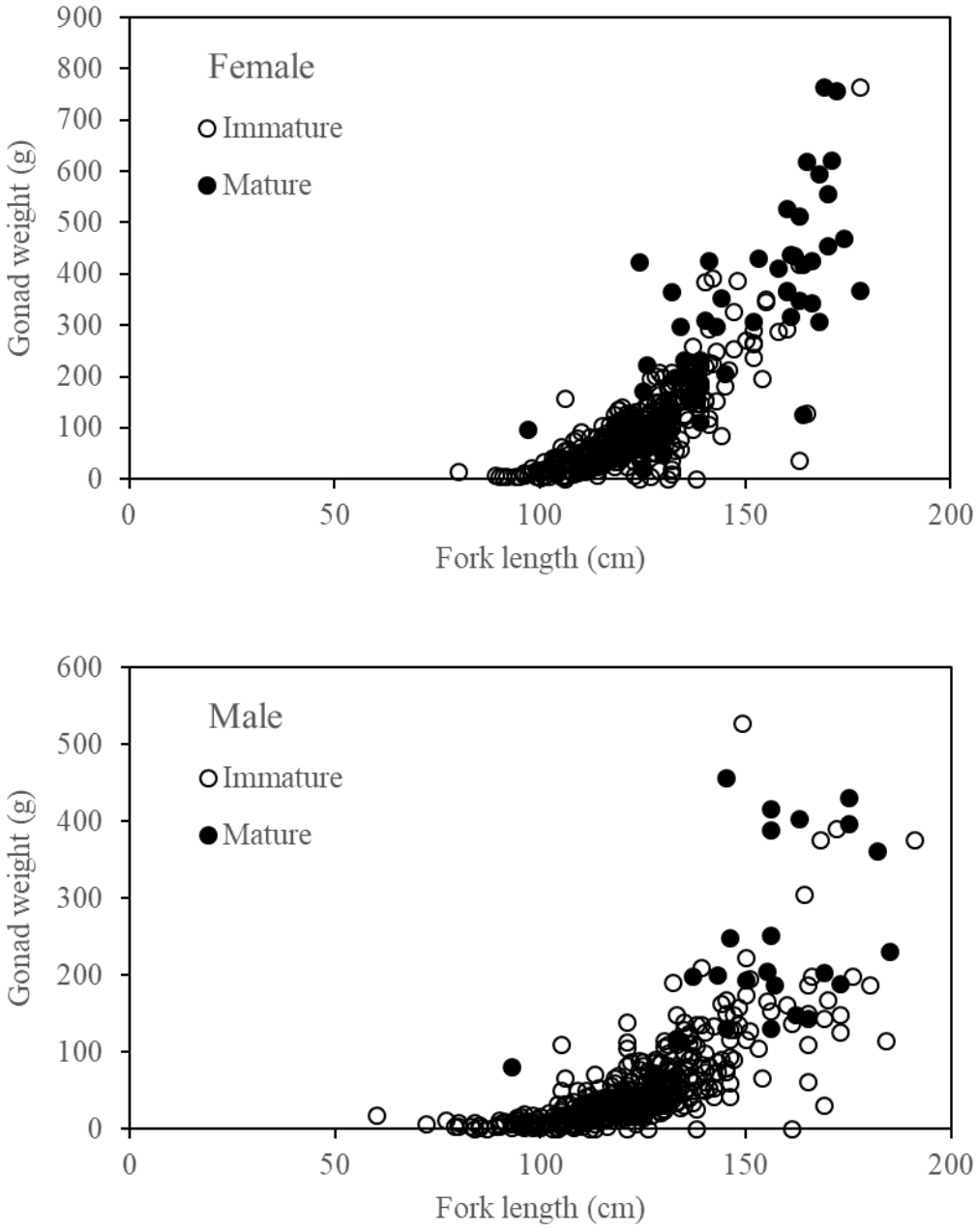


Fig. 10. Relationship between fork length and gonad weight by mature status for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2021.

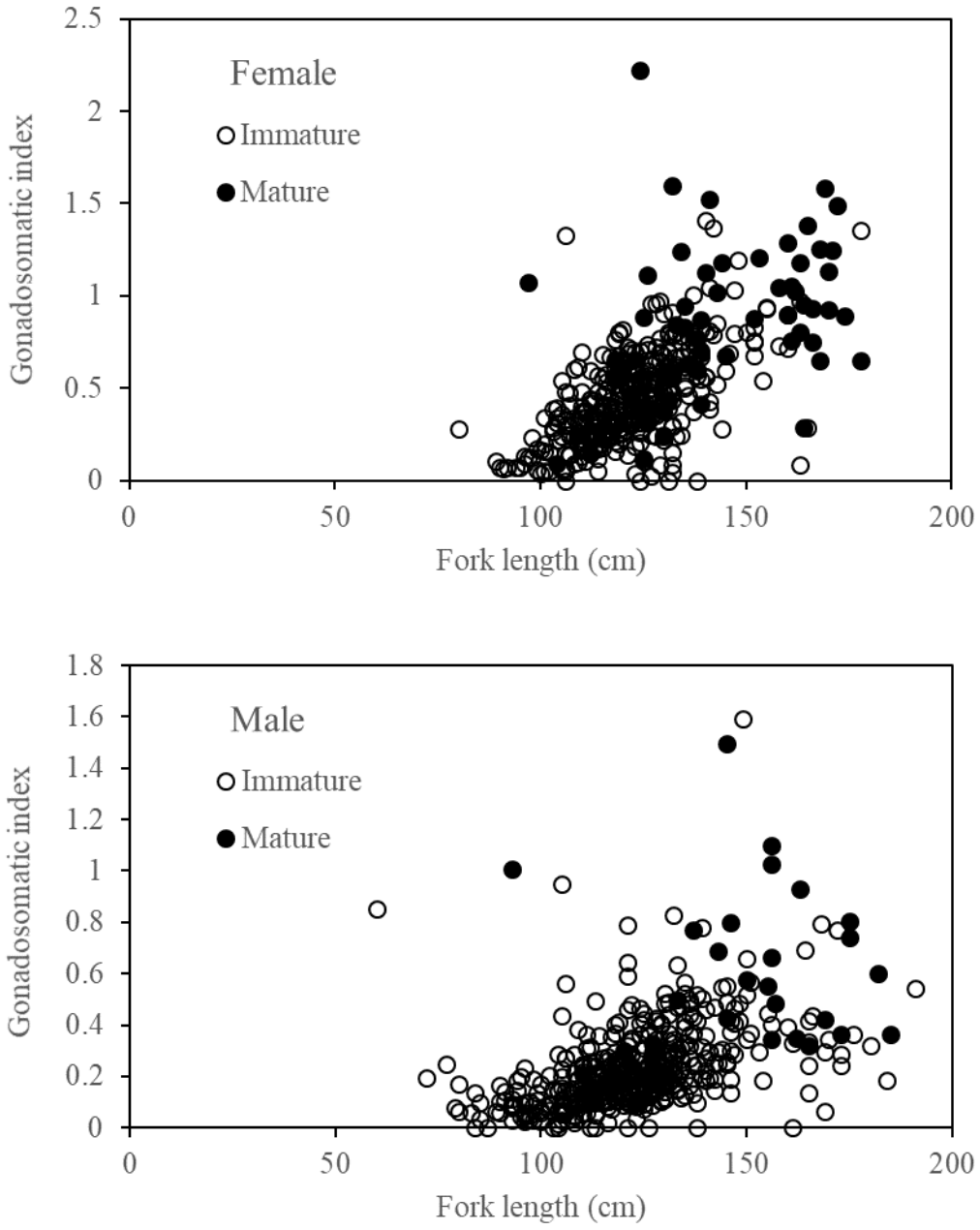


Fig. 11. Relationship between fork length and gonadosomatic index (GSI) by mature status for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2021.

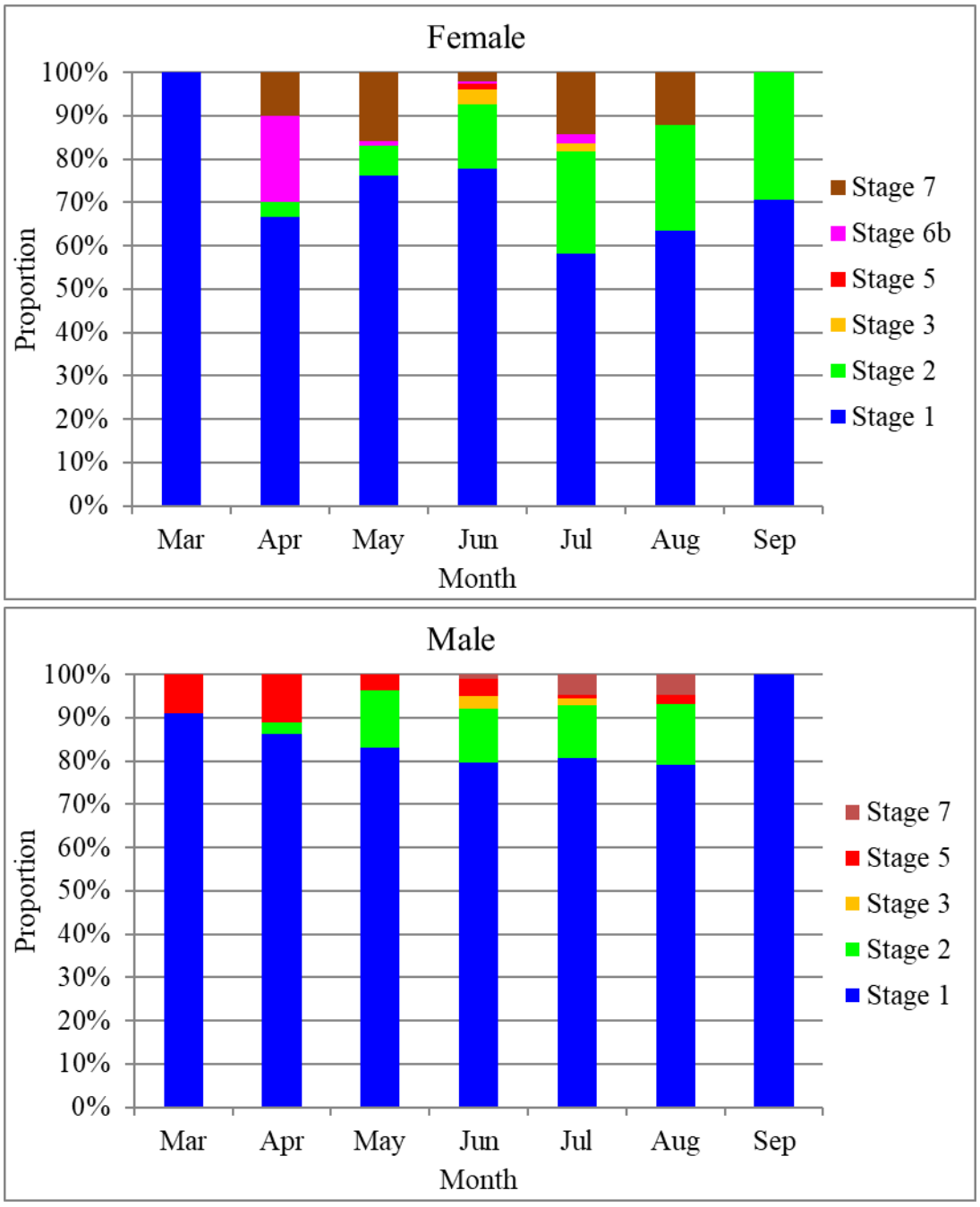


Fig. 12. Proportion of maturity stages by monthly category for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2021.

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 βatresia of yolked oocytes
1	Immature	lnactive	Immature	Unyolked,no POFs	Absent
2	Immature	lnactive	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 nucieus or hydrated and/or POFs	<50% α and β atresia may be present
5	Mature	lnactive	Regressing-potentially reproductive	Advanced yolked,no POFs	≧50% α and β atresia present
6a	Mature	lnactive	Regressed 1	Unyolked or early yolked, no POFs	100% α and β atresia may be present
6b	Mature	lnactive	Regressed 2	Unyolked or early yolked, no POFs	No α and β atresia present
7	Mature	lnactive	Regenerating	Unyolked or early yolked, no POFs	Absent