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

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ABSTRACT

A total of 950 gonad samples of southern bluefin tuna was collected during the period of April to September from 2010 to 2021 by the Taiwanese scientific observer program. The range of fork length of females and males samples were concentrated between 90 and 150 cm. For the monthly GSIs, the females' GSI remained in the higher values from April to July than others, and the trend revealed a decline after July. And the monthly males' GSIs showed the higher values from March to May and then decreased gradually. It reached the lowest value in September. According to the results of the histological sections, a total of 792 gonad samples in the collection period of 2010-2020 were analyzed for the sexual maturity stages determination. The majority of these samples were determined as immature stage, and about 11.4% samples designated as mature but at reproductively inactive status. Also, most mature females were identified at regressed or regenerating stages during May to July, and most mature males were also identified at regenerating stages during June to July.

1. INTRODUCTION

Several researches related the reproductive biology of the southern bluefin tuna (SBT, *Thunnus maccoyii*) were conducted among different basins. The reproductive studies 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 identifying the maturity stages in SBT. It is essential for establish the guideline of the determination maturity stages for further understanding of reproductive researches in SBT. In order to improving the integrity of the reproductive research results, it is essential that developing an appropriate histological determination standard to classify the mature and immature females. Therefore, the scientific observation and data collection of SBT including biological samples such as gonads, otoliths, and muscle tissues had been classified 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.

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 individual.

Because there were some data missing of body weight that were not recorded by observers. Here, we adopted a length-based gonado-somatic index (Chen et al., 2013) in this paper:

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

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

The sexual maturity stages were classified by the observations of histological sections of gonad samples. The criteria of histological classification for gonadal developmental stages of SBT were remained no consensus and needed further discussed specifically for SBT. Therefore, we followed the criteria of Farley et al. (2013), which were used for albacore in the southern Pacific Ocean, and adopted to categorize the gonadal developmental stages for SBT in this study. Here, the criteria of developmental stages were classified into seven categories listed 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. 2013.

3. RESULTS AND DISCUSSION

A total of 950 gonad samples of SBT were collected during April to September from 2010 to 2021 including 441 female and 509 male samples. 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 2021 (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 gonad weights and fork lengths showed the obvious variation in larger size specimens especially were over 160 cm in fork length (Fig. 3). The similar patterns of the relationship between GSI and fork length were also found in both females and males, which the GSI showed increasing trend with fork length increased. However, the increasing patterns in the relationship between GSI and fork length were somehow unapparent in some samples (Fig. 4). It might relate the maturity status of different samples and needs to be further investigated.

Also, we analyzed the monthly GSIs in both sexes to understand the relationship of GSIs and gonad maturity status. First, the monthly GSIs of females remained higher values from April to July and then revealed decreasing trends. Generally, the lower values were revealed in March and September; Second, the monthly GSIs of males stayed in higher values from March to May and then decreased gradually reached the lowest value in September with updated data of 2021. 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).

Due to the difficulties of processing frozen samples in the sample preservation, some samples were not qualified for processing the histological sections. A total of 792 gonad samples including 378 females and 414 males were collected from 2010 to 2020 were successfully examined histological sections, and the sexual maturity stages were determined based on the criteria of developmental stages in Farley et al. 2013.

According to the observations of the histological sections of both females and males specimen, the gonadal developmental stages of the majority of samples were identified as immature stage and some samples were determined at developing stage. The majority of the samples were designated as immature. And there were about 11.4% of samples designated as mature but most of these samples were reproductively inactive (regressed or regenerating stages) (Figs. 6-8).

The majority of gonadal samples of females and males were identified as immature specimen in newly updated information in 2020. 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 clear 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, more mature female samples were regressed or regenerating stages during April to August than others, while most of mature male samples were regenerating stages during June to August (Fig. 12). Based on the results of histological sections in this study indicated that mature fishes might migrate to the fishing ground of Taiwanese SBT fishery after reproductive activity. Because the fishing season of Taiwanese SBT longliner fishery was limited, it is helpful to collaborate with others researcher for improving the integrity of sample collection and coverages. And it is essential to develop the criteria of histological classification for gonadal maturity stages for better understanding the reproductive biology of SBT.

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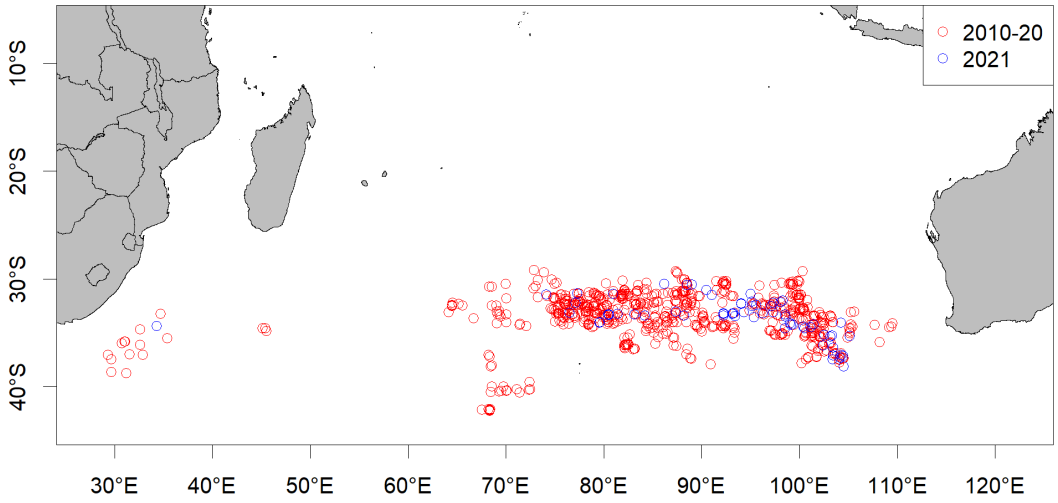


Fig. 1. Sampling locations of SBT gonad samples collected by Taiwanese scientific observer program during 2010-2021.

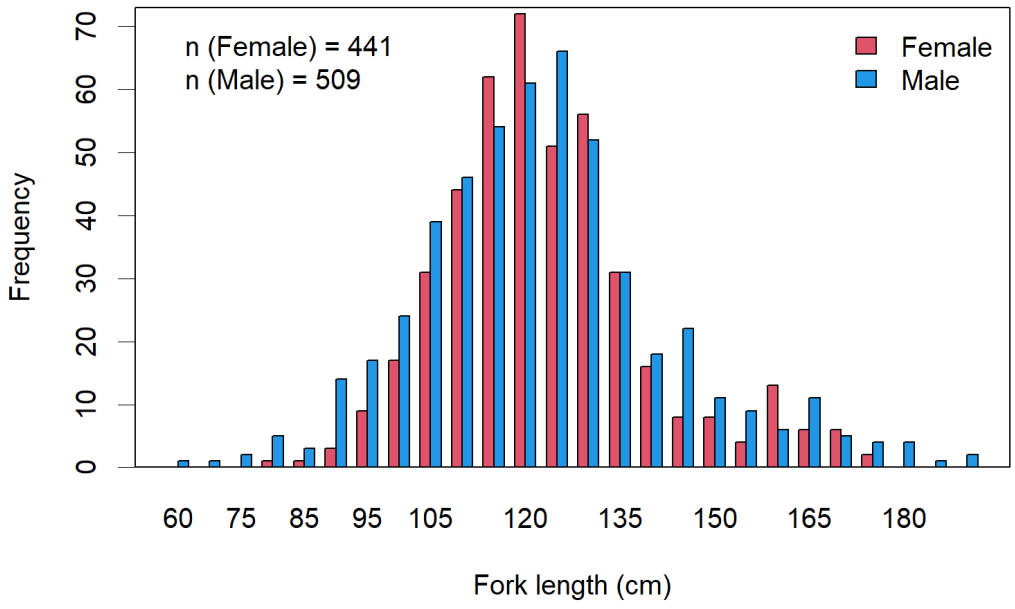


Fig. 2. Length frequency distributions with 5 cm intervals for SBT gonad samples collected by Taiwanese scientific observer program during 2010-2021.

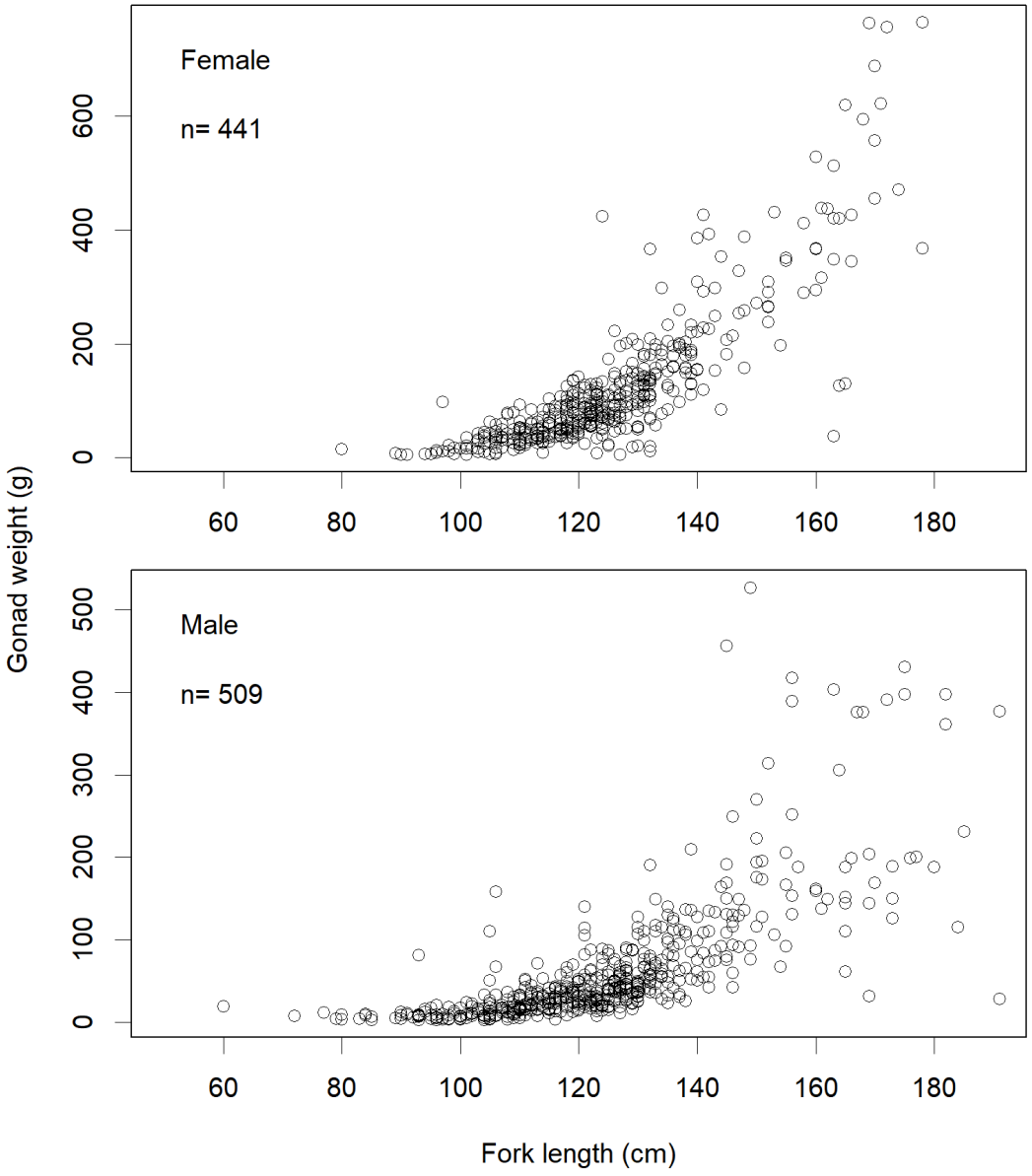


Fig. 3. Relationship between fork length and gonad weight for SBT gonad samples collected by Taiwanese scientific observer program during 2010-2021.

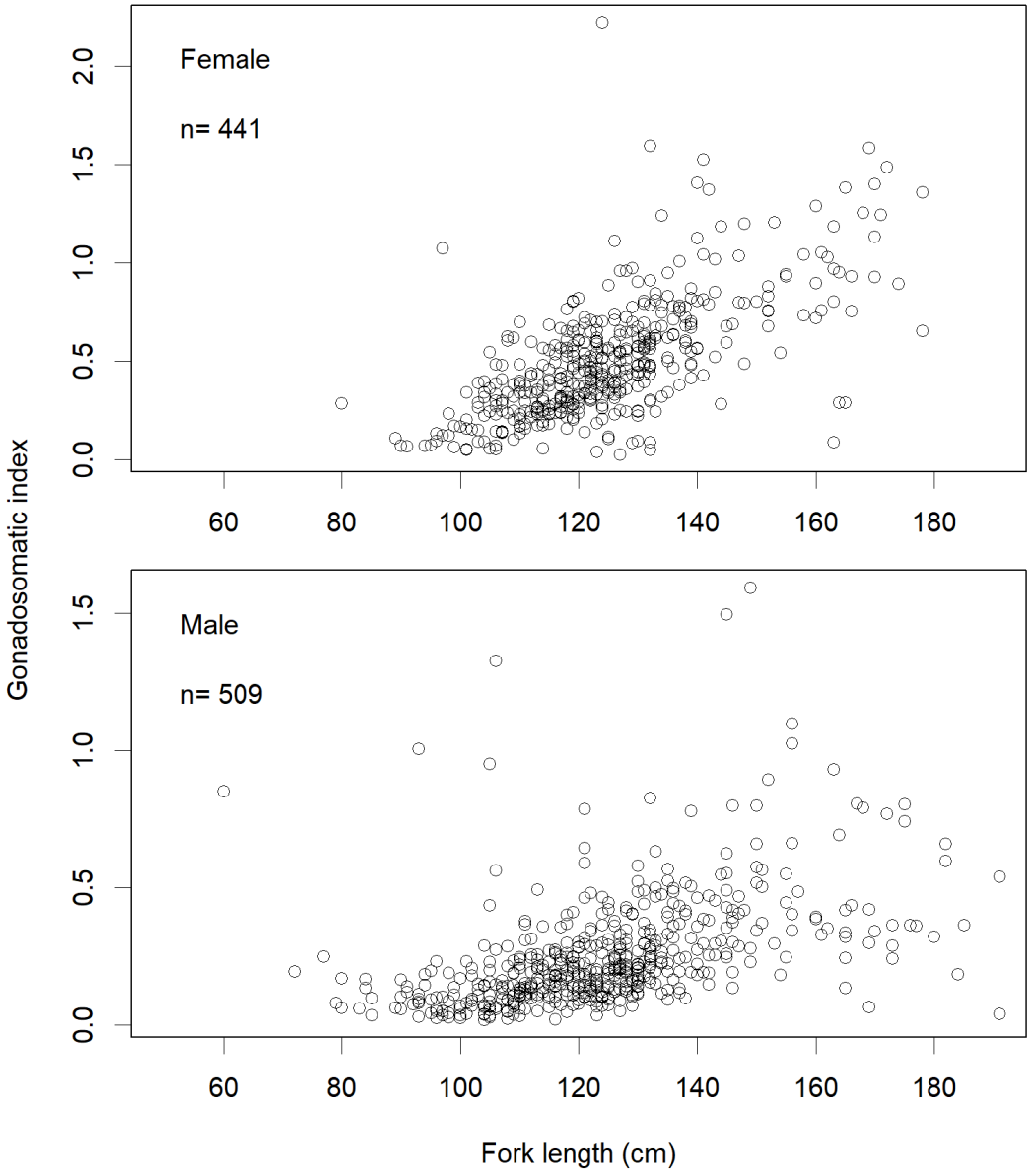


Fig. 4. Relationship between fork length and gonado-somatic index (GSI) for SBT gonad samples collected by Taiwanese scientific observer program during 2010-2021.

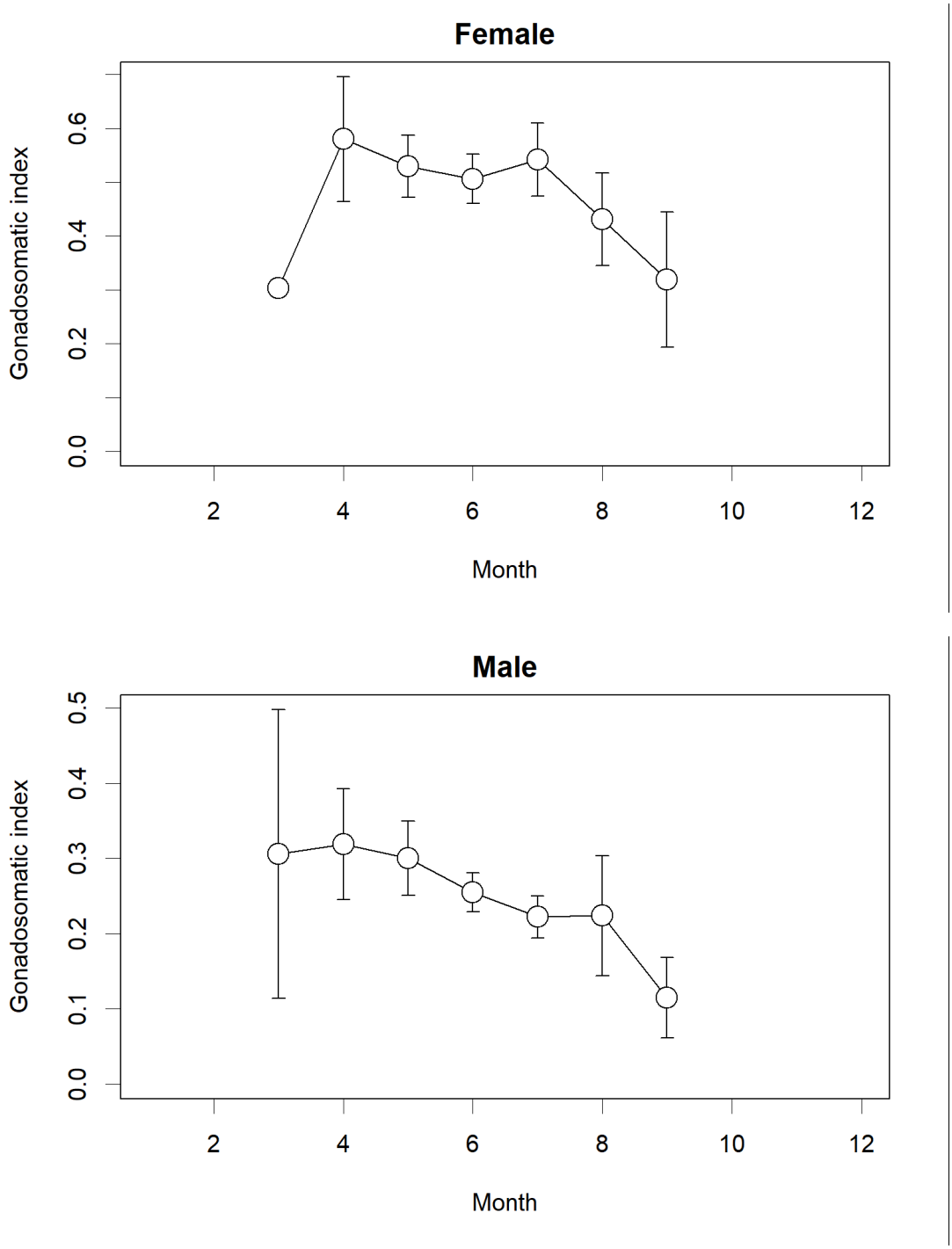


Fig. 5. Monthly trends of gonado-somatic index (GSI) for gonad samples of SBT collected by Taiwanese scientific observer program. Vertical bars represent the 95% confidence interval for means during 2010-2021.

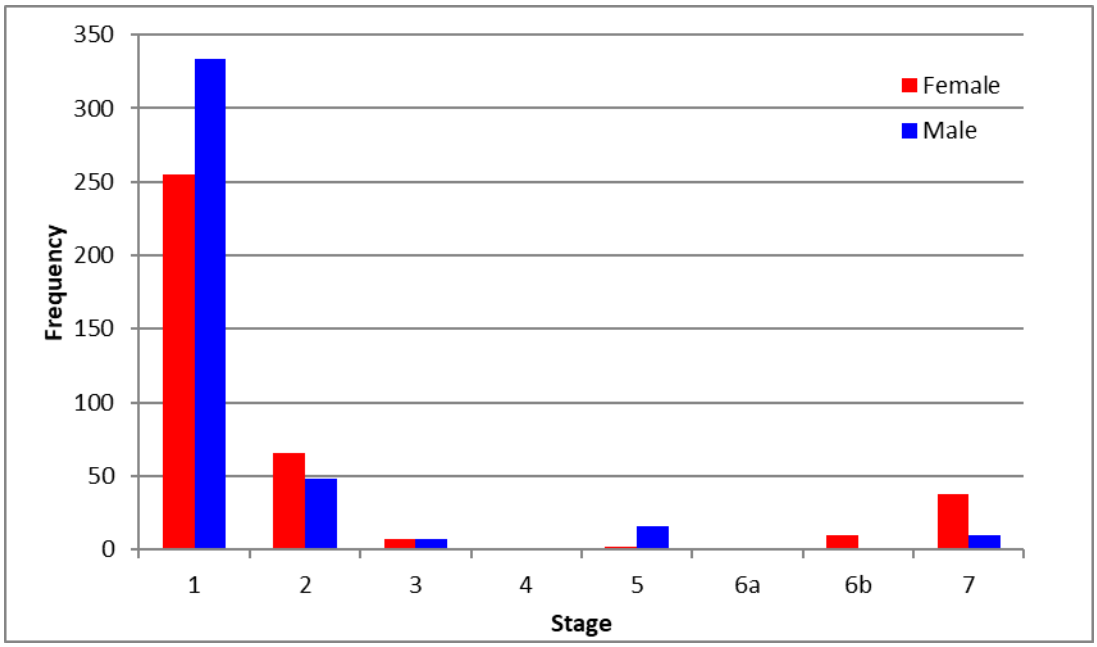
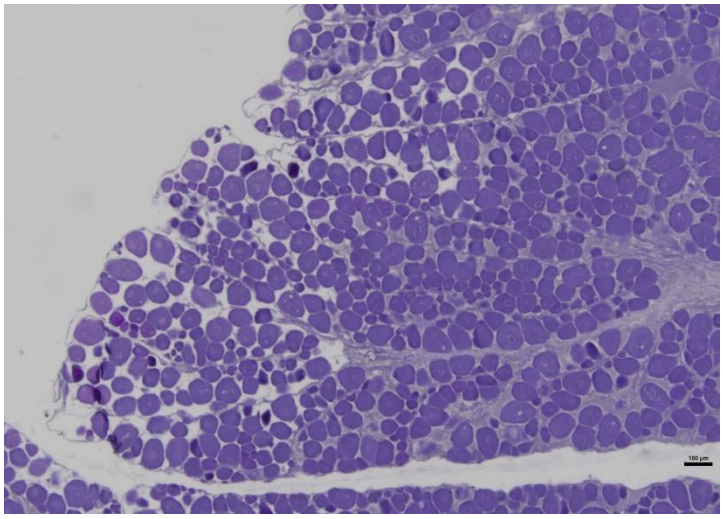
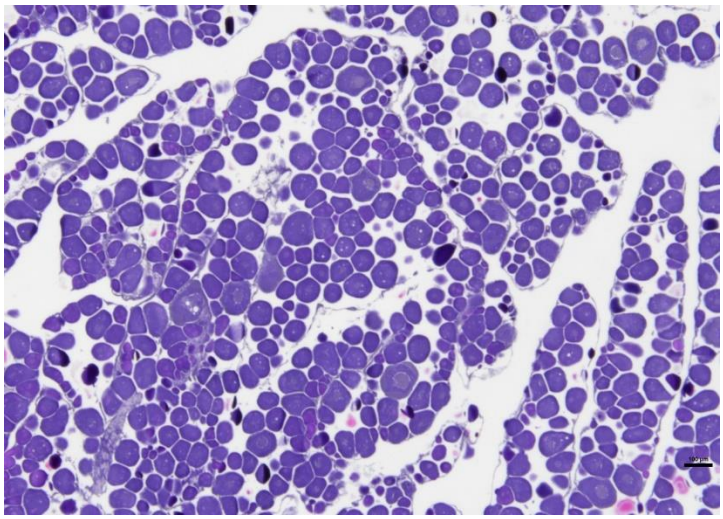


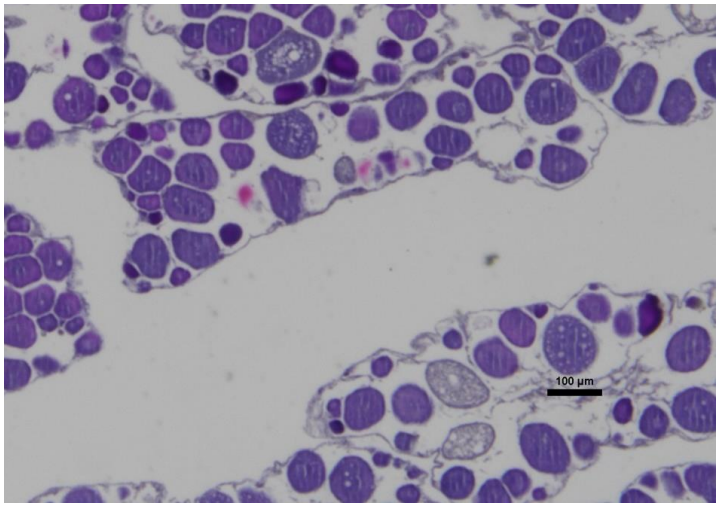
Fig. 6. Number of samples by maturity classes for gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2020.



FL: 127cm, GW: 129.45g (Class 1, immature stage)

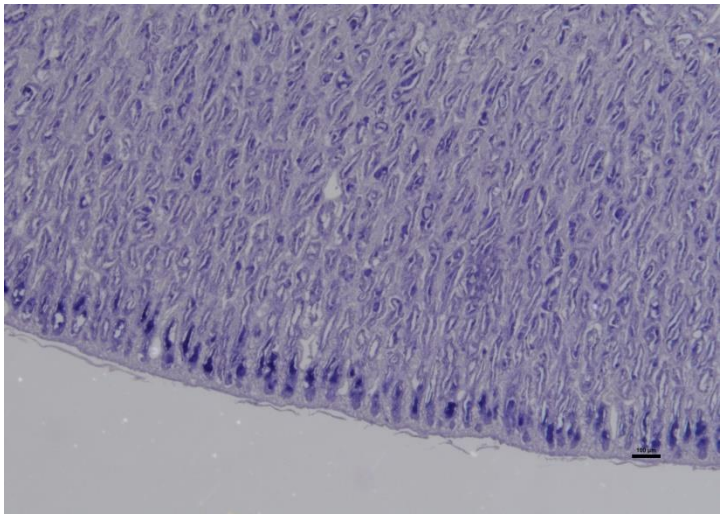


FL: 137cm, GW: 201.08g (Class2, developing stage)

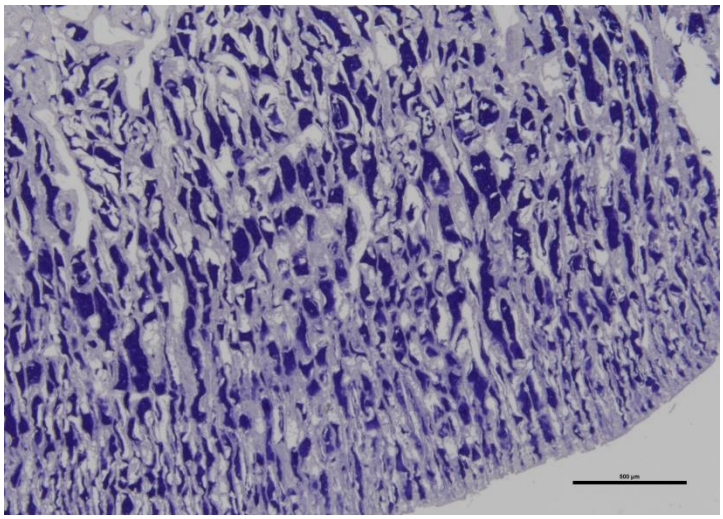


FL172cm, GW756.42 g (Class6, regressed stage)

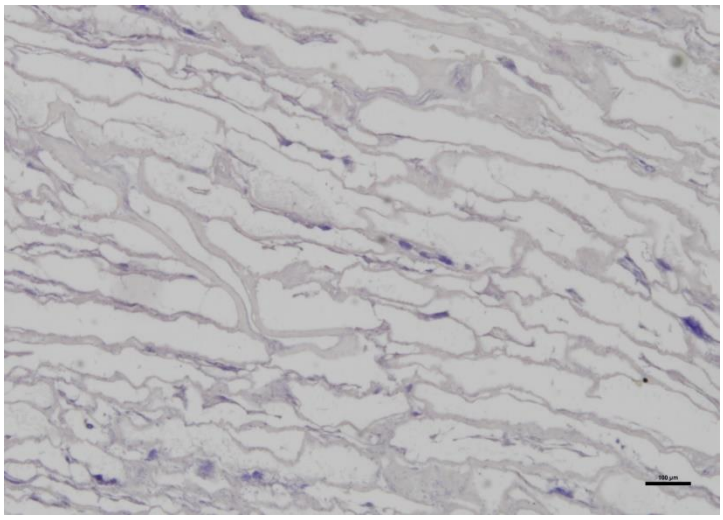
Fig. 7. Histological sections and measurements of oocytes for gonad samples of female SBT collected by Taiwanese scientific observer program during 2010-2020.



FL: 124cm, GW: 88.72g (Class 1, immature stage)



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



FL156cm, GW417.12 g (Class 5, resting stage)

Fig. 8. Histological sections and measurements of oocytes for gonad samples of male SBT collected by Taiwanese scientific observer program during 2010-2020.

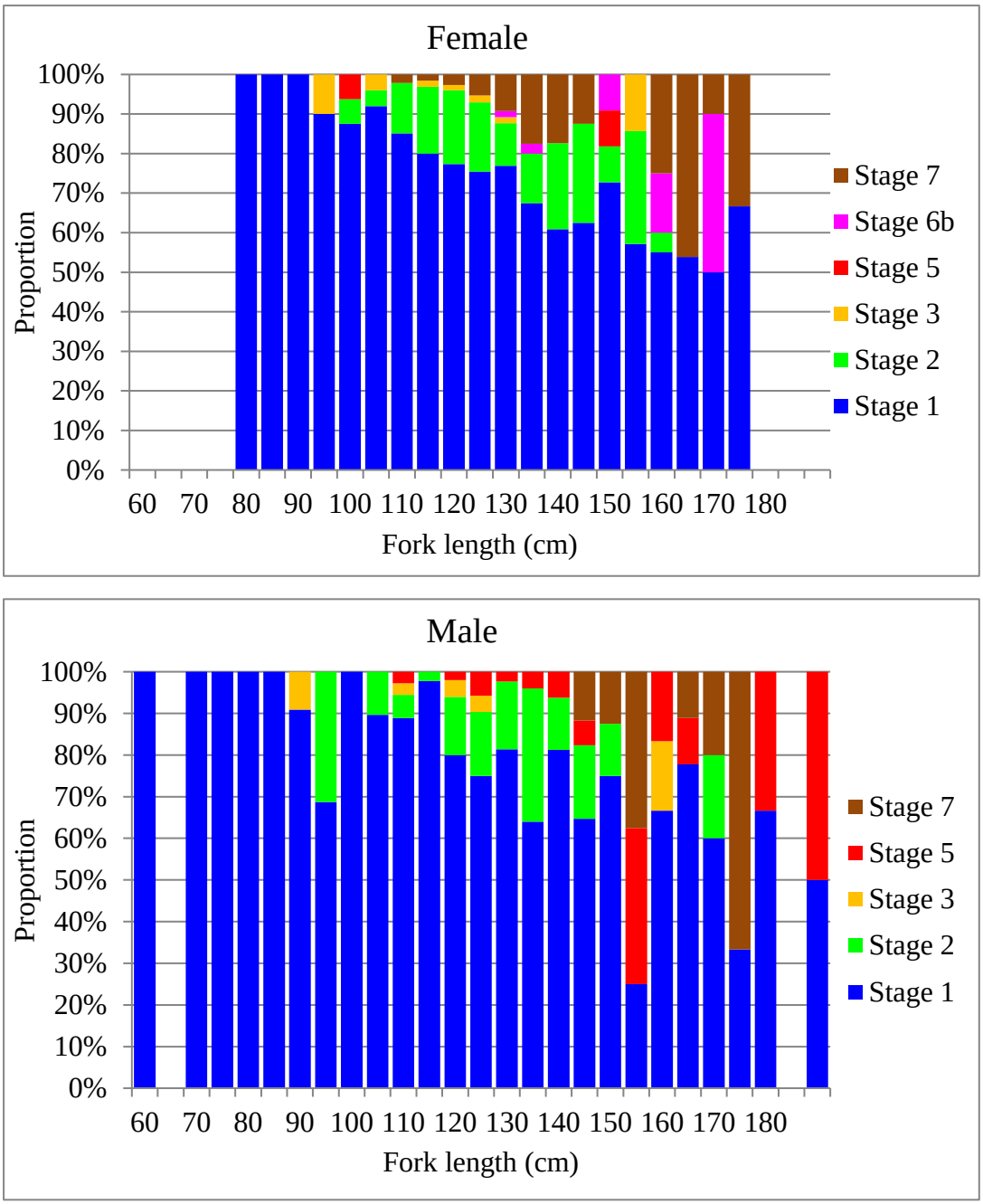


Fig. 91. Proportion of maturity stages by fork lengths with 5 cm intervals for gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2020.

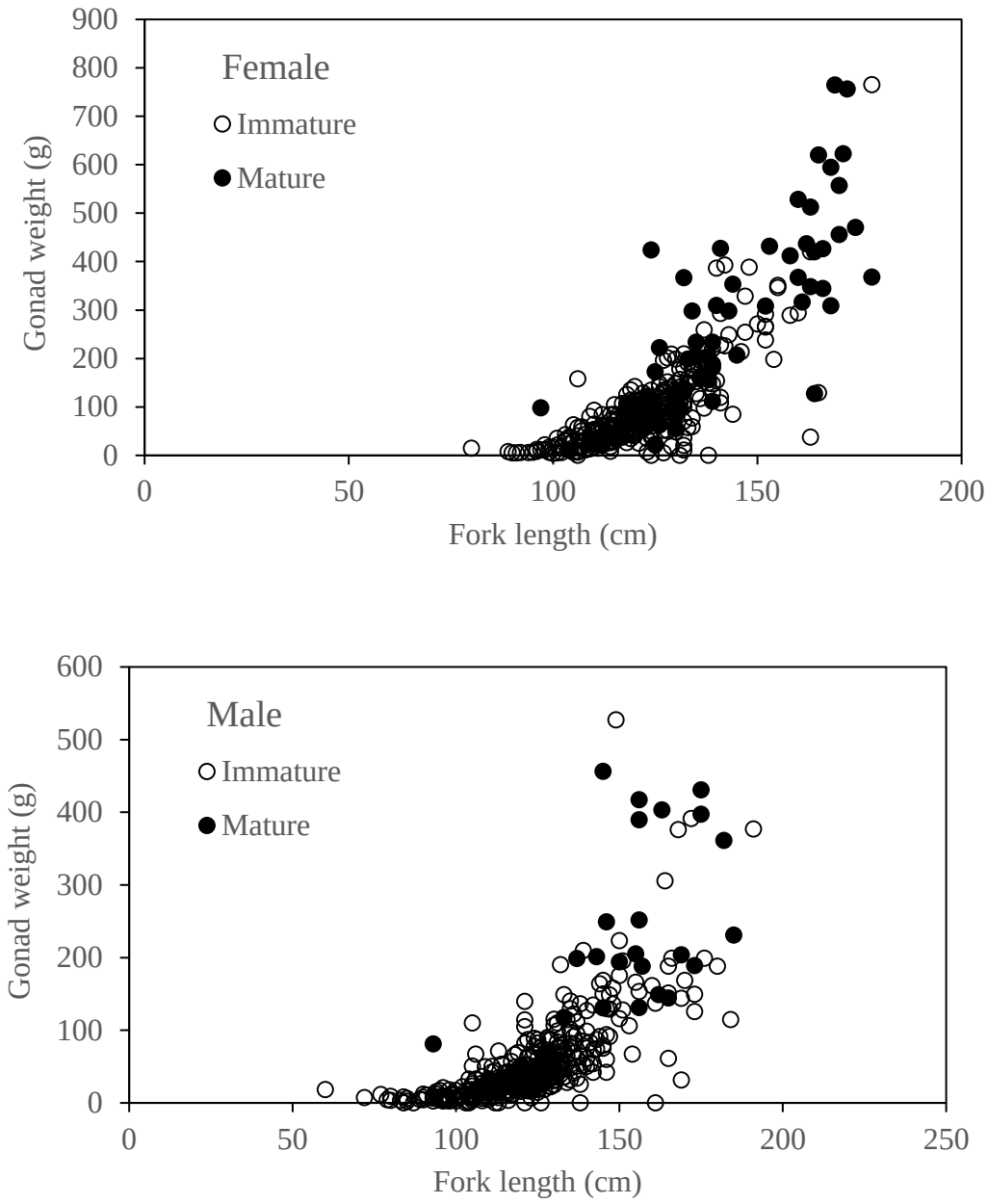


Fig. 10. Relationship between fork length and gonad weight by mature status for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2020.

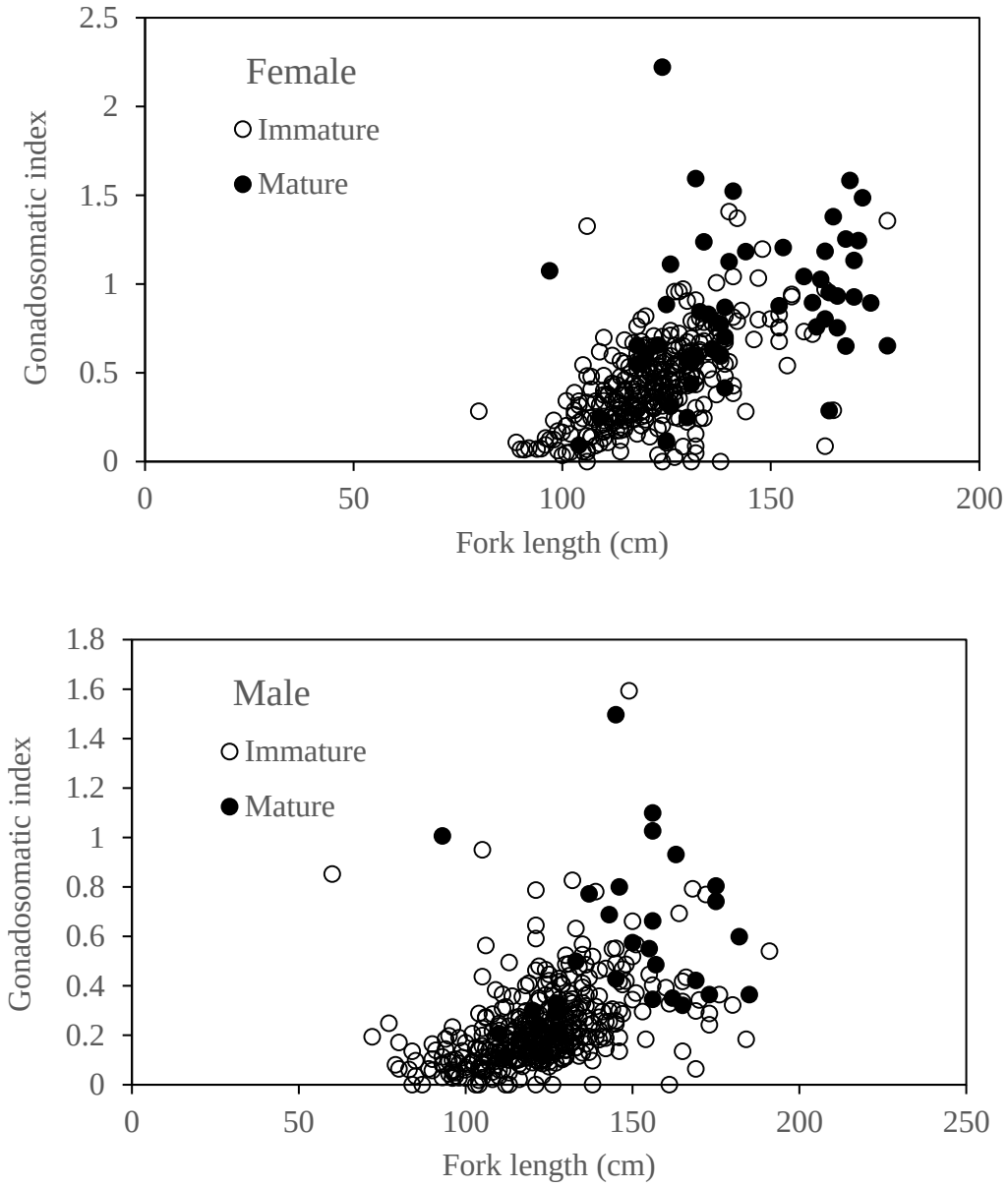


Fig. 11. Relationship between fork length and gonado-somatic index (GSI) by mature status for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2020.

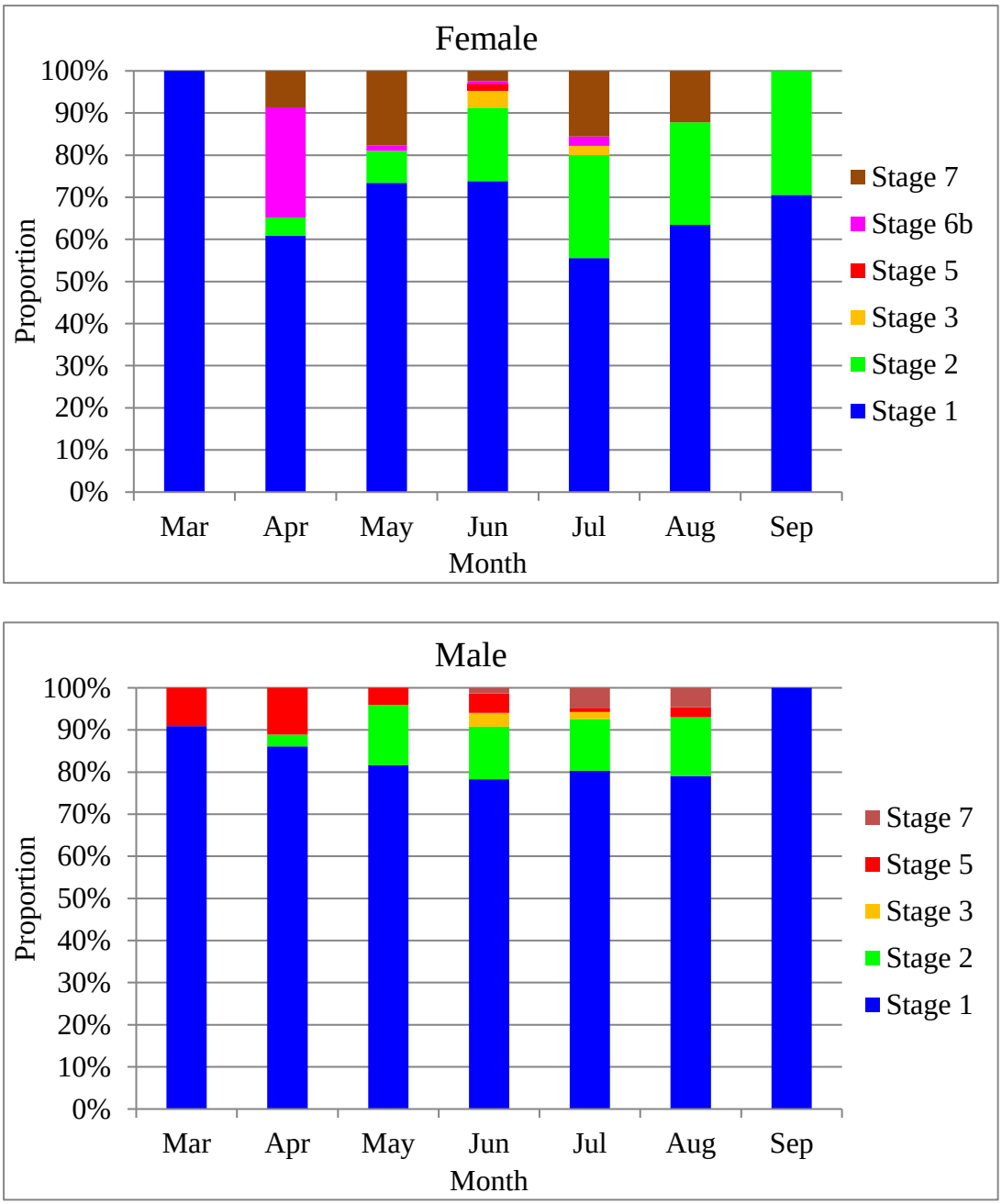


Fig. 12. Proportion of maturity stages by monthly category for female and male gonad samples of SBT collected by Taiwanese scientific observer program during 2010-2020.

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

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