Journal of Marine Science and Technology

Volume 23 | Issue 5 Article 27

MATURITY CHARACTERISTICS OF PACIFIC SAURY DURING FISHING SEASON IN THE NORTHWEST PACIFIC

Wen-Bin Huang
Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualien, Taiwan., bruce@mail.ndhu.edu.tw

Yu-Chun Huang
Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualien, Taiwan.

Recommended Citation
Huang, Wen-Bin and Huang, Yu-Chun (2015) "MATURITY CHARACTERISTICS OF PACIFIC SAURY DURING FISHING SEASON IN THE NORTHWEST PACIFIC," *Journal of Marine Science and Technology*: Vol. 23: Iss. 5, Article 27.
DOI: 10.6119/JMST-015-0630-1
Available at: https://jmstt.ntou.edu.tw/journal/vol23/iss5/27

MATURITY CHARACTERISTICS OF PACIFIC SAURY DURING FISHING SEASON IN THE NORTHWEST PACIFIC

Acknowledgements

The authors are grateful to the Council of Agriculture (102AS-11.1.1-FA-F5) and the National Science Council (NSC 98-2313-B-259-003-MY3), R.O.C. for grant support, to the Taiwan Squid Fishery Association for their assisting in the collection of the saury samples, and to the Overseas Fisheries Development Council in Taiwan for their assisting identification of the sampling locations. The authors also wish to thank Mr. G. R. Elle in the National Dong Hwa University for his comments on the manuscript and help with English writing. We also wish to thank anonymous reviews for their constructive comments on the manuscript.

Journal of Marine Science and Technology, Vol. 23, No. 5, pp. 819-826 (2015)
DOI: 10.6119/JMST-015-0630-1

MATURITY CHARACTERISTICS OF PACIFIC SAURY DURING FISHING SEASON IN THE NORTHWEST PACIFIC

Wen-Bin Huang and Yu-Chun Huang

Key words: *Cololabis saira*, ovarian developmental stage, gonadosomatic index (GSI), condition factor (CF), summer fishing season.

ABSTRACT

Pacific saury is a commercially important fish in the Northwest Pacific. This study examined the maturity characteristics, gonadosomatic index (GSI), condition factor (CF), and ovarian developmental stage of the saury stock in three months of the fishing season (from May to December) in the Northwest Pacific. The maturity characteristics of saury varied among these three months (May, July, and October) in 2009. In May, large GSI and CF values with advanced ovarian developmental stages but small knob lengths (KnL) and body weights (BW) were found. Also in this month, the large-sized saury (> 29 cm) possessed large GSI values and the medium- and small-sized saury (≤ 29 cm) possessed large CF values. The GSI and CF values in July were similar to those in October while the KnLs and BWs of the former were larger than those of the latter. Most ovaries of the medium-sized saury (27-29 cm) developed to early cortical alveoli stage (CA1) and late cortical alveoli stage in July and October, respectively. Few individuals (5 samples) possessed GSI values larger than 1.0. Most saury were found at the CA1 stage, comprising 42.5-57.8% of the monthly samples, and the most advanced ovarian developmental stage was the secondary yolk stage and found only in May, comprising 2.0% of samples in May. From the point of view of maturity characteristics and body size for saury during the fishing season, it is suggested that it is better not to harvest saury early in May and that the fishing effort in July should be controlled in order to give the small and immature saury a couple more months to grow and mature for sustainable fishing.

Paper submitted 06/24/14; revised 06/22/15; accepted 06/30/15. Author for correspondence: Wen-Bin Huang (e-mail: bruce@mail.ndhu.edu.tw).
Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualien, Taiwan.

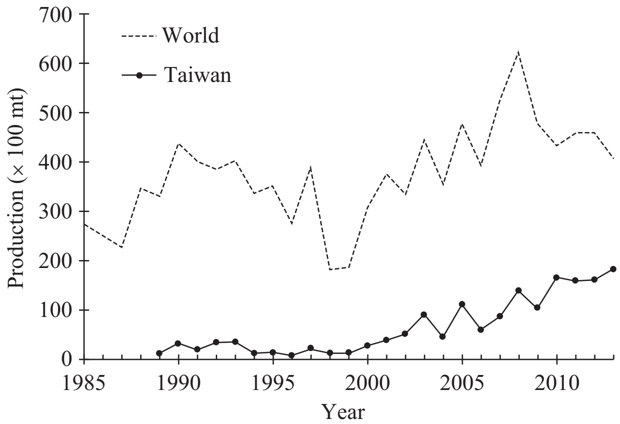

Fig. 1. Variations in annual production of Pacific saury in the world (dotted line) and Taiwan (solid line) from 1985 to 2013 in the North Pacific.

I. INTRODUCTION

Pacific saury, *Cololabis saira* (Brevoort), is a commercially important fish in the Northwest Pacific. In the last decades, annual catches of the saury in the world increased from 180,973 mt in 1988 to 622,119 mt in 2008 and then decreased to 460,961 mt in 2012 (FAO, 2015). Over the same time, the saury catch of Taiwan increased from 12,794 mt in 1988 to 139,514 mt in 2008 and then dramatically increased to 161,514 mt in 2012 (Fig. 1). The saury production of Taiwan is the highest in the world since 2013 with a production of 182,619 mt being larger than Japan, formerly the largest harvester. The Pacific saury fishery in Japan is an inshore fishery since its fishing grounds are generally located within the Exclusive Economic Zone (EEZ) of 200 nautical miles. The Pacific saury in the inshore waters have been well studied and documented since the 1950's (Fukusima, 1958; Hotta, 1962; Fukushima, 1979; Novikov, 1982; Tian et al., 2003; Tian et al., 2004). In contrast, the saury in the offshore waters are mainly exploited by Taiwanese fishing fleets and biological information for the saury stock in this region is limited, particularly the biological parameters sensitive to the ambient environments over life history, such as maturity status during a long distance migration for spawning.

Pacific saury migrates widely between waters of the subarctic and subtropical North Pacific (Hubbs and Wisner, 1980). The physiological longevity of the saury is ca. two years (Suyama et al., 2006). It grows quickly to around 28-30 cm in the first year and reaches 30-33 cm in the second year (Suyama et al., 2006). Differentiation between age-zero and age-one saury is determined by a hyaline zone formed within the otolith during autumn and winter (Hotta, 1960; Suyama et al., 1992; Suyama et al., 1996). The saury migrates extensively between the feeding grounds in the Oyashio waters around Hokkaido and the Kuril Islands in summer and the spawning areas in the Kuroshio waters off southern Japan in winter (Fukushima, 1979; Kosaka, 2000). In addition to maturation and spawning, this annual migratory cycle of the Pacific saury is considered to seek for suitable water temperatures (Odate, 1977) and the optimal utilization of planktonic food resources (Sugisaki and Kurita, 2004) at various developmental stages in the life history. Most of the adults mature and are ready for spawning during their southward migration (Kosaka, 2000; Kurita, 2001). The saury migratory groups were distributed mostly in areas where the sea surface temperature ranged between 10 and 20°C with a high aggregation around 15°C, implying that 15°C is the preferred temperature for saury to aggregate intensively for the spawning migration (Huang et al., 2007).

Spawning season of the saury continues generally from autumn to winter with a major spawning period in winter and extends to spring of the following year (Watanabe and Lo, 1989). The saury generally spawns several times during a single spawning season judging from the asynchronous development of oocytes in its ovary (Hatanaka, 1955; Suyama et al., 1996; Kosaka, 2000; Suyama, 2002). While the saury body lengths at maturation varied with where they were caught (Kurita et al., 2002), the smallest mature fish was 25.3 cm, the majority of the spawning stock was fish of larger than 28.0 cm (Suyama, 2002). Under laboratory conditions, the first spawning was 243 days after hatching and mean knob length (KnL, from tip of lower jaw to posterior end of muscular knob on caudal peduncle) at the beginning of spawning was about 25.0 cm (Nakaya et al., 2009). Development stages of ovarian eggs for saury were defined by histological methods and relationships of the ovarian developmental stages to KnLs, BWs, ovary weights, gonad somatic indices (GSIs), and condition factors (CFs) were documented (Suyama et al., 1996; Kosaka, 2000; Suyama, 2002).

Generally, fishing season for saury begins in August and continues through mid-December, coinciding with the southward migration period of saury (Fukushima, 1979; Huang et al., 2007). However, summer fishing season, from May to July, has been practiced exclusively in the offshore waters by the Taiwanese fishing fleets since 2005. There have been some scientific studies examining saury maturity during summer, including the maturation in the Central North Pacific Ocean by Suyama et al. (1996), the reproduction in life history by Kosaka (2000), and the maturation process by Suyama (2002). Among these studies, fishing gear used for specimen collections was not consistent, including gill nets, dip nets, stick-held nets, and set nets. Selectivity of various fishing gears could result in different results of maturity examination for fish. For example, GSI of the saury caught by the torch-light method has been reported to be lower than that caught by gill nets at the same time and waters (Hatanaka et al., 1953). In addition, no document illustrated the reproductive status of the saury in the commercial catch from the offshore waters.

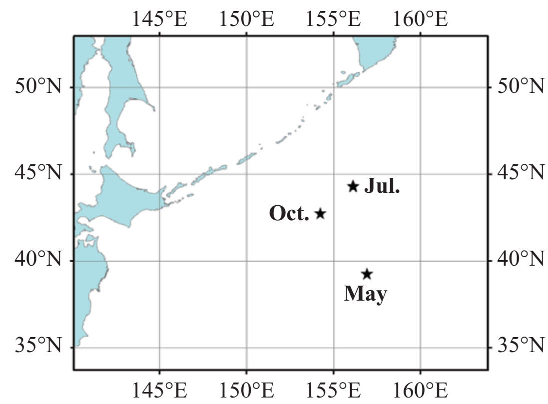

Fig. 2. Map of sampling locations of Pacific saury in May, July and October, 2009 in the Northwest Pacific.

In order to maintain the sustainable utilization of the saury stock under an increased exploitation rate, any new spatial and temporal exploitation of this species resource and its impacts should be carefully scrutinized. Following on the increasing catch of saury in the offshore waters, importance and urgency to understand the reproductive status of the saury from the offshore waters are increasing. In particular, the gap in knowledge of reproductive status for saury in the earlier than customary (autumn) fishing time, the summer fishing season when no saury fishery operated a decade ago, should be filled. Therefore, the objective of this study is to examine and compare the maturity characteristics, GSI, CF, and ovarian development stage (ODS) of the saury stock during the summer fishing season (May-July) and the autumn fishing season (August-December) in the Northwest Pacific.

II. MATERIALS AND METHODS

1. Sample Collection and Treatments

Since the Taiwanese fishing fleet begins fishing saury in May, 180 females were randomly collected from the catch of both May and July and treated as specimens of the summer fishing season. Also, 180 females were collected randomly in October, the month of most abundant saury (Huang, 2010), and treated as specimens of the autumn fishing season. These specimens were caught by a Taiwanese saury fishing vessel with the stick-held net at locations of 157.3°E and 39.3°N, 156.6°E and 44.4°N, and 154.2°E and 42.8°N on 24 May, 16 July, and 15 October, 2009, respectively (Fig. 2). Sea water

Table 1. Sample sizes for maturity estimates and re-sampling size for population simulations of Pacific saury in May, July, and October, 2009 in the Northwest Pacific.

	Intervals of the knob length (cm)																
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	Total
May																	
Sample size for maturity estimates	0	1	6	5	5	6	6	4	6	6	6	6	5	2	0	0	64
Percentage (%) in the monthly catch*	0	0.9	3.1	8.5	16.0	15.8	13.3	5.4	6.7	10.7	10.5	6.2	2.6	0.4	0	0	100
Re-sampling size for population simulations	0	1	2	5	10	10	8	3	4	7	7	4	2	1	0	0	64
July																	
Sample size for maturity estimates	0	2	1	4	5	5	5	6	6	6	6	6	6	4	0	0	66
Percentage (%) in monthly catch*	0	0.6	1.1	6.0	13.4	10.1	6.2	8.0	11.0	13.8	12.8	9.3	4.5	2.4	0	0	100
Re-sampling size for population simulations	0	1	1	4	9	7	4	5	7	9	8	6	3	2	0	0	67
October																	
Sample size for maturity estimates	0	3	5	5	6	6	6	6	6	6	6	6	6	2	0	0	70
Percentage (%) in monthly catch*	0	2.0	3.5	4.4	7.6	16.6	18.2	13.6	2.9	5.0	5.7	10.7	7.5	1.8	0	0	100
Re-sampling size for population simulations	0	1	2	3	5	12	13	10	2	4	4	8	5	1	0	0	71

*, data from the Taiwanese Saury Fisheries Data Center of the National Dong Hwa University.

temperature, measured by a thermometer under the vessel when fishing was underway, was 13.6, 13.8, and 14.2°C at these 3 locations, respectively. In order to present the maturity information of the largest and smallest saury specimens in the limited samples for histological examination, maximum of 6 individuals were re-sampled randomly at an interval of 1 cm in the KnL range from 21 to 34 cm. If the number of specimens at intervals of 1 cm was lesser than 6, all fish specimens were used for ovarian examination. This method minimized the limitation of low probability for the largest or smallest fish specimens being selected randomly from a theoretically normal distribution population. Therefore, a total of 64, 66, and 70 specimens in May, July, and October were used for ovarian examination and body size measurements, respectively (Table 1). In addition, composition percentages of the KnL distribution (in 1 cm interval from 20 to 35 cm) for the entire Taiwanese catch in May, July, and October 2009, obtained from the Taiwanese Saury Fisheries Data Center, National Dong Hwa University, are shown in Table 1.

BWs, gutted body weights (GBWs, BWs after removing viscera), and gonad weights (GWs) of the females were measured to the nearest 0.01 g and their KnLs were measured to 0.1 cm. After weighing, the ovaries were fixed and preserved in Bouin's solution and 10% formalin, respectively. A transverse ovarian tissue specimen was sampled exclusively from the middle portion of the ovary, though no difference in the ovarian developmental stage was found among the tip, middle, and end portions of saury ovary in the study of Kosaka (2000). These tissue samples were embedded in paraffin, sectioned at 6 μm, and stained with Mayer's hematoxylin and eosin using the histological procedure from Presnell and Schreibman (1997).

The ODS was determined by the most advanced developmental stage of the oocytes in the ovary (Kosaka, 2000; Suyama, 2002). Eight oocyte developmental stages were also defined in these two studies and were referred in this study, including peri-nucleolus stage (Pn), early cortical alveoli stage (CA1), late cortical alveoli stage (CA2), primary yolk stage (YF1), secondary yolk stage (YF2), tertiary yolk stage (YF3), maturation stage (M), and ripe stage (R).

2. Data Analysis

The GSI and CF were estimated by GW/GBW × 10^2 and BW/KnL^3 × 10^3, respectively. A simulated data set of the entire Taiwanese saury catch in the analysis month was made using the sample fish data and a re-sampling size in 1 cm intervals. The size of re-sampling with replacement within each 1 cm interval was an integer that was rounded from the total sample size multiplied by the corresponding percentage of the 1 cm interval in the monthly catch (Table 1). If the integer was 0, the re-sampling size in the interval was assigned to be 1 for keeping the observed specimen information in the simulation. Therefore, a total re-sampling number of 64, 67, and 71 were applied for the simulation in May, July, and

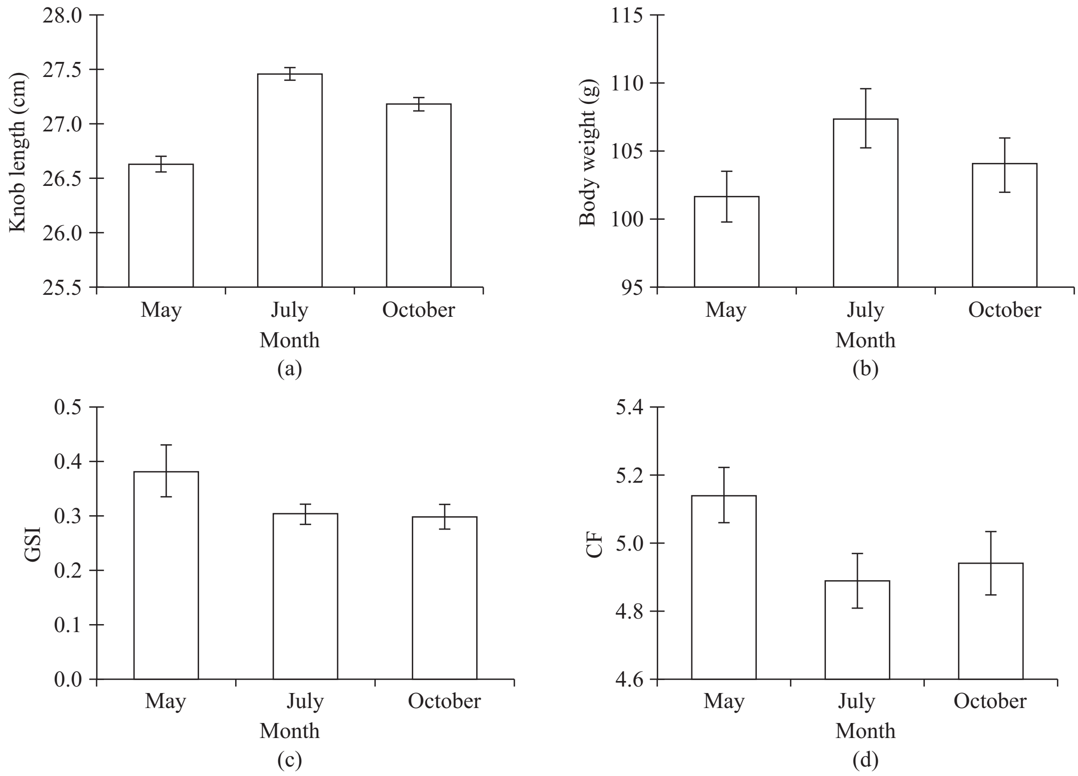

Fig. 3. (a) Knob lengths, (b) body weights, (c) gonadosomatic indexes (GSI), and (d) condition factors (CF) for the Pacific saury in May, July, and October, 2009 in the Northwest Pacific. Vertical lines are 95% bootstrap confidence intervals.

October, respectively (Table 1). Bootstrap methods with 1000 replications of the simulation were used to generate estimates of confidence intervals around parameter estimates (Davison and Hinkley, 1997). The 25th and 975th ordinal values were used to determine the 95% bootstrap confidence interval (95% CI) (Haddon, 2011). The software used for the statistical analyses was Microsoft Excel 2010 and all statistical tests were considered significant at a level of $p < 0.05$.

III. RESULTS

The KnLs and BWs of saury significantly varied among May, July, and October ($p < 0.05$) (Figs. 3(a) and (b)). The KnLs and BWs in May, the beginning month of the summer fishing season, were the smallest (mean ± 95% CI: 26.63 ± 0.07 cm and 101.7 ± 1.9 g), increased to the largest (27.45 ± 0.06 cm and 107.4 ± 2.2 g) in July, the end month of the summer fishing season, and decreased to medium (27.18 ± 0.06 cm and 104.1 ± 2.0 g) in October, the most abundant month of the autumn fishing season (Figs. 3(a) and (b)).

The GSIs and CFs values of saury were also found to vary significantly among May, July, and October ($p < 0.05$) (Figs. 3(c) and (d)). The GSIs (0.38 ± 0.05) in May were larger than those in July (0.30 ± 0.02) and October (0.30 ± 0.02) (Fig. 3(c)). The individual of largest GSIs with its KnL were 2.57 with 31.6 cm, 1.01 with 33.9 cm, and 1.18 with 32.1 cm in May, July, and October, respectively. There were only 3, 1,

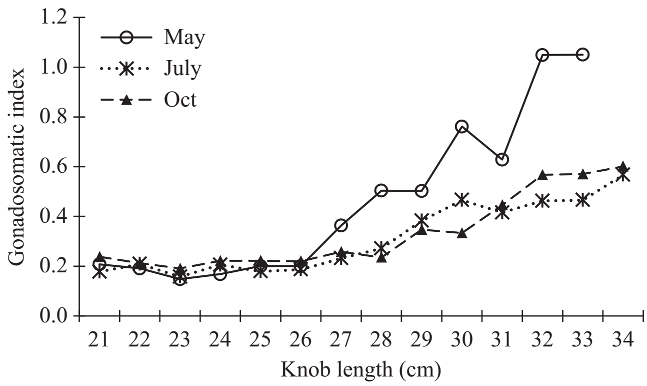

Fig. 4. Variations of the gonadosomatic index (GSI) from 21 to 34 cm knob length for the Pacific saury in May, July, and October, 2009 in the Northwest Pacific.

and 1 individuals of GSIs larger than 1.0 in May, July, and October, respectively. Following the KnL increase, an increase of GSI was found in the 3 sample months (Fig. 4). When the KnL of saury was larger than 27 cm, the GSIs in May were larger than those in July and October. The largest mean GSI among the 1-cm interval groups was 1.05 in both the 32 and 33 cm groups in May, 0.57 in the 34 cm group in July, and 0.60 in the 34 cm group in October.

The CFs in May (5.14 ± 0.08) were larger than those in July (4.89 ± 0.08) and October (4.94 ± 0.09) ($p < 0.05$) (Fig. 3(d)).

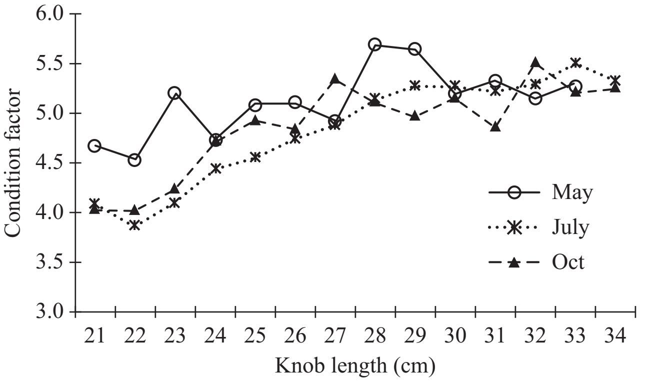

Fig. 5. Variations of the condition factor (CF) from 21 to 34 cm knob length for the Pacific saury in May, July, and October, 2009 in the Northwest Pacific.

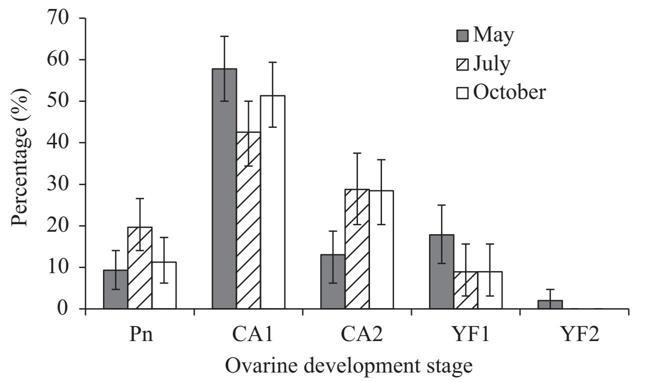

Fig. 6. Variations in percentage compositions of the 5 ovarian developmental stages, peri-nucleolus stage (Pn), early cortical alveoli stage (CA1), late cortical alveoli stage (CA2), primary yolk stage (YF1), and secondary yolk stage (YF2), for the Pacific saury in May, July, and October, 2009 in the Northwest Pacific. Vertical lines are 95% bootstrap confidence intervals.

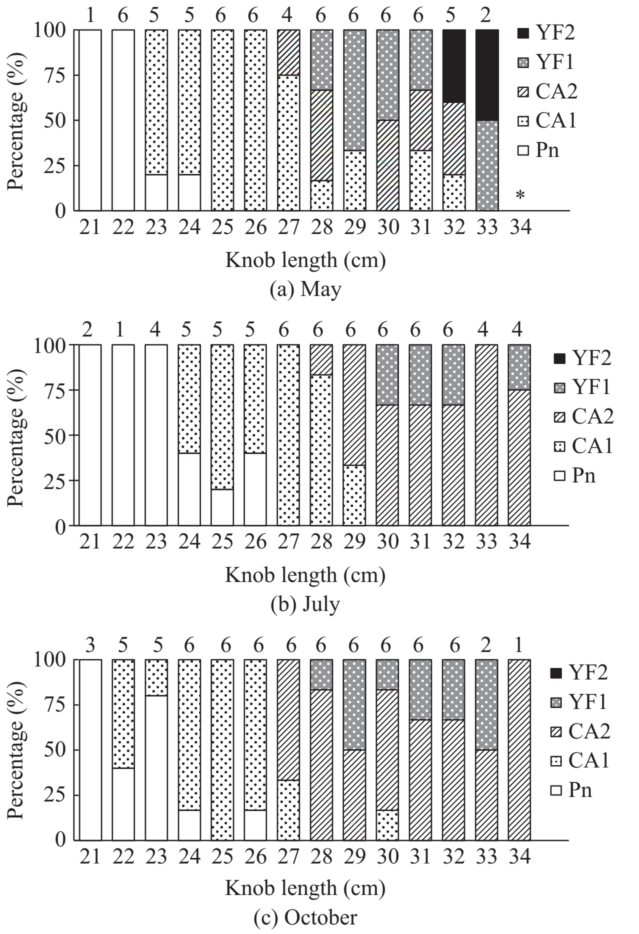

Fig. 7. Variations in percentage compositions of the ovarian developmental stages from 21 to 34 cm knob length for the Pacific saury in (a) May, (b) July, and (c) October, 2009 in the Northwest Pacific. Pn, peri-nucleolus stage; CA1, early cortical alveoli stage; CA2, late cortical alveoli stage; YF1, primary yolk stage; YF2, secondary yolk stage. Numbers on the bar tops are sample sizes.

The individual of largest CFs with its KnL were 6.46 with 28.9 cm, 5.97 with 33.4 cm, and 6.08 with 31.6 cm in May, July, and October, respectively. Following the KnL increase, an apparent increase of CF was found in both July and October, but only a slight increase in May (Fig. 5). When the KnL of saury was smaller than 29 cm, the CFs in May were generally larger than those in July and October. The largest mean CF among the 1-cm interval groups was 5.68 in the 28 cm group in May, 5.49 in the 33 cm group in July, and 5.49 in the 32 cm group in October.

There were 5 saury ODSs observed in this study, including the Pn, CA1, CA2, YF1 and YF2. The most advanced ODS, YF2, was found only in May and its individuals comprised 2.0% of the May samples (Fig. 6). Also, postovulatory follicles and atretic oocytes were found only in a few of the May specimens. Most of the saury was at the CA1 stage with 57.8, 42.5, and 51.3% of the samples in May, July, and October, respectively (Fig. 6). The CA1 and CA2 stages occurred initially at the KnL of about 22-24 cm and 27-28 cm, respectively, in the 3 months (Fig. 7). The percentage of CA1 stage in the samples for size classes of larger than 28 cm was higher in May than those in July and October. Higher percentages of the CA1 stage for the size classes of 27 cm and 28 cm were found in July than those in May and October. In addition, the YF2 stage was only found in May when the saury KnL was larger than 32 cm (Fig. 7).

IV. DISCUSSION

1. Variations of the Saury Maturity Characteristics in the Summer and Autumn Fishing Seasons

Large GSI and CF values with advanced ovarian developmental stages but small body lengths and weights were found in May, the beginning month of the summer fishing season (Fig. 3). Also in this month, the large-sized saury (> 29 cm) had large GSI values and the medium- and small-sized saury (≤ 29 cm) had large CF values (Fig. 4). It is apparent that the large GSI and CF values in May resulted from the large-sized saury having large GSI values and the medium- and small-sized saury having large CF values, respectively (Fig. 5). This indicates that, in May, the saury stock composes of some older saury and a larger number of young recruitment saury. The older saury with high GSI values suggests that they are still fertile, though probably at the end of the reproductive process. The younger recruitment saury with large CF values suggests that they are at the beginning of their reproductive cycle and prepare to go forward with their ovarian maturation.

Most ovaries of the medium-sized saury (27-29 cm) developed to the CA1 and CA2 stage in July and October, respectively (Fig. 7), although the GSI and CF values were similar in these two sample months (Figs. 3 and 4). This indicates that young saury were continuously recruiting into the fish stock in the summer and autumn fishing seasons, and had been going forward with their ovarian maturation mainly from the CA1 stage in July to the CA2 stage in October. However, October is one of the spawning months for the autumn spawning group. The most advanced development stage of the ovary in October only being YF1 implies that the saury with ovarian development stage higher than YF1 were not present in the catch, likely due to fishing methods.

The high CF value of saury in May was a result of high fat storage in the body of the young saury due to the abundant prey intake. In spring and summer saury were distributed in the Kuroshio-Oyashio transitional region and the Oyashio (cold current) area where they mainly fed on *Euphausia pacifica* and had a higher gut fullness than the other seasons (Sugisaki and Kurita, 2004). In addition, the low CF value in July and October was due to proceeding maturation during the southward migration of saury for spawning. Values of the saury CF have been reported to vary markedly over fishing periods, longitudes and latitudes, and waters of sampling in a year, reflecting the spatiotemporal migration experiences in their life history (Hara, 1986; Imai, 1993). The saury CF value was generally high in the subarctic waters, decreased gradually during the southward migration period, and became low in the subtropical waters (Meguro et al., 1987; Imai, 1993). The CF value became the lowest in winter, the main spawning season of saury (Kurita et al., 2002).

In general, it is suggested that the female saury with a GSI larger than 1.0 is mature and would spawn in the reproductive season (Hatanaka et al., 1953). The GSI of saury with ovary developed to the YF1 stage would exceed 1.0 (Suyama et al., 1996). In this study, few individuals, only 5, had a GSI larger than 1.0 in the 3 months of May, July, and October, and the highest mean GSI of saury in these 3 months was 0.38 (Figs. 3 and 4). This indicates that the female maturity is low and most females do not reach the mature stage to spawn in the saury stock exploited mainly by the Taiwanese saury fishing vessels in the offshore waters of the Northwest Pacific.

It is considered that the spawning season of the saury extends to June (Watanabe and Lo, 1989). There was evidence that postovulatory follicles were observed in the gonad tissues collected from March (Kosaka, 2000). In this study, few ovaries were found to contain the YF2 stage oocytes and postovulatory follicles in the May samples, indicating that the large-sized saury females might spawn around May.

2. Maturity Characteristics of Saury in the Taiwanese Catch

Most saury were found at the CA1 stage, comprising 42.5-57.8% of the monthly samples (Fig. 6). The most advanced ovarian development stage (YF2 stage) found only in May and made up only 2.0% of the May samples in this study (Fig. 6). In contrast, the YF3 stage, maturation stage, and ripe stage was found in the studies of Kosaka (2000) and Suyama (2002) and individuals of these 3 stages comprised 29.8% of the samples in Suyama's (2002) study. The mean GSI value recalculated from the data in Suyama (2002) was 0.41, which was close to the mean GSI value of 0.38 in May, but was significantly larger than the mean GSI values of 0.30 and 0.30 in July and October in this study, respectively (Fig. 3). In addition, the monthly mean CF values of 5.14, 4.89, and 4.94 in May, July, and October, respectively, in this study (Fig. 3) were larger than the mean CF value of 4.79 recalculated from the data in Suyama (2002). Huang (2007) also indicated that all mean CF values of saury in the 6 commercial size-classes of the Taiwan catch were significantly larger than those in all size classes from 1953 to 1989 in Japan. The above comparisons of the maturity characteristics indicate that, saury caught by the Taiwanese fishing vessels from the last month of the summer fishing season to the autumn fishing season, the females were almost immature and hardly developed to the condition of instantaneous spawning.

The maturity characteristics of low mature stage, low GSI, and large CF values for saury in the Taiwanese catch resulted from effects of the fishing areas and the fishing gear. In addition to the saury fishing areas being different between the Taiwanese and Japanese fishing fleets, the main types of fishing gears used by the Japanese saury fishing vessels and the previous studies were gillnet and dip net (Kosaka, 2000; Suyama, 2002). In contrast, only one type of the fishing gear is performed by the Taiwanese saury fishing vessels, i.e. the stick-held net, a torch-light fishing method. The phototaxis behavior of saury is not displayed when the fish is mature but returns after spawning (Yin, 1998). Hatanaka et al. (1953) indicated that the GSI of the saury caught by the torch-light method was lower than that caught by gillnet in the same time and area. It is possible that the mature fish, even if present in the fishing area, would not be abundantly caught by the Taiwanese saury fishing fleets with the stick-held net. In short, the maturity of the female saury estimated in this study might be lower than it would be in the ocean due to the selectivity of fishing gears. However, for the benefit of sustainable spawning stock biomass, such fishing gear (stick-held net) shows lesser impact than others.

3. Suggestions to the Management of the Saury Fishery

Utilization of the Pacific saury stock should be managed sustainably. The main saury spawning group is the fish larger than 28 cm (Suyama, 2002; Kurita et al., 2002), although the mean body length at the beginning of spawning was about 25 cm in laboratory (Nakaya et al., 2009). In this study, the saury stock in May composed of a small proportion of large-sized fish which could be at the end stage of their reproductive process, and a larger proportion of young fish which recruits to feeding migration in summer and spawning in the following autumn and winter. If fishing operates in May, a larger number of saury in the catch are small, around 24-25 cm. In addition, the prevalence, mean intensity, and the abundance of the ecto-parasitic copepod *Caligus macarovi* infecting the saury were highest in May but lowest in the autumn fishing season (Huang and Huang, 2011). This parasite affects the appearance of saury at market. The market price of saury is correlated to its body size and appearance and the profit of fishing in May seems likely to be not worthwhile. In practice, for the recent 8 years (from 2005 to 2012), the Taiwanese fishing vessels harvested saury in May only in four years; 2005, 2007, 2009, and 2012. The economic impact would be minor if fishing vessels were prohibited from fishing saury in May in the North Pacific.

The female saury in July, the last fishing month in summer, featured low GSI and CF values but large body lengths, about 27.5 cm (Fig. 3). The body size is close to the size of larger than 28 cm in the main spawning group of saury (Suyama, 2002; Kurita et al., 2002). This indicates that a number of fast grown saury recruit into the stock in July, and they would spawn after a couple of months from autumn to winter. Also, a high proportion of the large-sized saury was found in July-August (Huang, 2010). Therefore, the fishing effort in these months should not be large to allow most of the large saury to migrate southward to their main spawning grounds. Limiting the number of saury fishing vessels to a conservative number is suggested to be one proper way to reduce the fishing effort in July-August for sustainability.

In conclusion, from the point of view of maturity characteristics and body size for saury in the summer fishing season, it is suggested that it is better not to harvest saury early in May and that the fishing effort in July should be controlled, perhaps, by limiting the number of fishing vessels, in the Northwest Pacific. This management would allow most of the young recruitment saury in the summer to grow to a large size in the main fishing season, and the recruited fast grown saury to spawn in autumn and even winter. Therefore, a comparatively large spawning stock in the current year and a comparatively large recruitment for the following year could be expected if the ocean-climatic conditions are normal, indicating that the saury resource would be sustainable and fishing saury in the autumn would be profitable.

ACKNOWLEDGMENTS

The authors are grateful to the Council of Agriculture (102AS-11.1.1-FA-F5) and the National Science Council (NSC 98-2313-B-259-003-MY3), R.O.C. for grant support, to the Taiwan Squid Fishery Association for their assisting in the collection of the saury samples, and to the Overseas Fisheries Development Council in Taiwan for their assisting identification of the sampling locations. The authors also wish to thank Mr. G. R. Elle in the National Dong Hwa University for his comments on the manuscript and help with English writing. We also wish to thank anonymous reviews for their constructive comments on the manuscript.

REFERENCES

Davison, A. C. and D. V. Hinkley (1997). Bootstrap Methods and their Application. Cambridge University Press, New York.

FAO (Food and Agriculture Organization of the United Nations) (2015). Global Production, Fishery Statistical Collections. Available at http://www.fao.org/fishery/statistics/global-production/en

Fukushima, S. (1979). Synoptic analysis of migration and fishing conditions of saury in northwest Pacific Ocean. Bulletin of Tohoku Regional Fisheries Research Laboratory 41, 1-70. (in Japanese, with English Abstract)

Fukusima, S. (1958). Relation between the fishing of the Pacific saury and the oceanographical conditions in the northeastern sea area along the Pacific coast of Japan. Bulletin of the Tohoku National Fisheries Research Institute 12, 1-27. (in Japanese, with English Abstract)

Haddon, M. (2011). Modelling and Quantitative Methods in Fisheries, 2nd Edition. Chapman & Hall/CRC, Boca Raton.

Hara, M. (1986). Change in the fatness coefficient and catch of Pacific saury *Cololabis saira* during south-ward migration. Bulletin of Tohoku Regional Fisheries Research Laboratory 48, 1-12. (in Japanese, with English Abstract)

Hatanaka, M. (1956). Biological studies on the population of the saury, *Cololabis saira* (Brevoort): Part 1 reproduction and growth. Tohoku Journal of Agricultural Research 6, 227-269.

Hatanaka, M., T. Watanabe, K. Sekino, M. Kosaka and K. Kimura (1953). Studies on the reproduction of the saury, *Cololabis saira* (Brevoort), of the Pacific coast of Japan. Tohoku Journal of Agricultural Research 2, 293-302.

Hotta, H. (1960). On the analysis of the population of the Pacific saury (*Cololabis saira*) based on the scales and the otolith characters, and their growth. Bulletin of Tohoku Regional Fisheries Research Laboratory 16, 41-64. (in Japanese, with English Abstract)

Hotta, H. (1962). Fluctuations in the abundance of saury on the north-eastern sea area in Japan (I). Bulletin of the Tohoku National Fisheries Research Institute 21, 1-20. (in Japanese, with English Abstract)

Huang, W. B. (2007). Body length, weight, and condition factor of Pacific saury, *Cololasis saira*, from the landed size-classes of Taiwanese catch in comparison with Japanese statistics. Journal of the Fisheries Society of Taiwan 34, 361-368.

Huang, W. B. (2010). Comparisons of monthly and geographical variations in abundance and size composition of Pacific saury between the high-seas and coastal fishing grounds in the Northwestern Pacific. Fisheries Science 76, 21-31.

Huang, W. B. and Y. C. Huang (2011). Parasitic copepod *Caligus macarovi* infection on Pacific saury in the Northwestern Pacific Ocean. Taiwan Journal of Biodiversity 13(2), 153-165. (in Chinese, with English Abstract)

Huang, W. B., N. C. H. Lo, T. S. Chiu and C. S. Chen (2007). Geographical distribution and abundance of Pacific saury fishing stock in the Northwestern Pacific in relation to sea temperature. Zoological Studies 46, 705-716.

Hubbs, C. L. and R. L. Wisner (1980). Revision of the sauries (Pisces, Scomberesocidae) with descriptions of two new genera and one new species. Fishery Bulletin (U.S.) 77, 521-566.

Imai, Y. (1993). Body length, condition factor and gonado-somatic index characteristics of otolith type of Pacific saury, *Cololabis saira*, in the eastern waters off Hokkaido. Scientific Reports of the Hokkaido Fisheries Experiment Station 43, 11-24. (in Japanese, with English Abstract)

Kosaka, S. (2000). Life history of Pacific saury *Cololabis saira* in the northwest Pacific and consideration of resource fluctuation based on it. Bulletin of the Tohoku National Fisheries Research Institute 63, 1-96. (in Japanese, with English Abstract)

Kurita, Y. (2001). Seasonal changes in spawning grounds and the abundance of egg-laying of Pacific saury. Annual Report of the Research Meeting on Saury Resource No. 49, Aomori, Japan, 203-205. (in Japanese)

Kurita, Y., S. Suyama and Y. Ueno (2002). The reply about the reproduction characteristic of Pacific saury (*Cololabis saira*) in the variation of environment. Agriculture, Forestry and Fisheries Research Council Secretariat 402, 60-63. (in Japanese)

Meguro, T., G. Anma, Y. Kajiwara, H. Yamaguchi, S. Yamamoto and K. Shimazaki (1987). On the distribution of the Pacific saury, *Cololabis saira*, in the northwestern Pacific Ocean. Bulletin of the Faculty of Fisheries Hokkaido University 38, 126-138. (in Japanese, with English Abstract)

Nakaya, M., T. Morioka, K. Fukunaga, N. Murakami, T. Ichikawa, S. Sekiya and S. Suyama (2009). Growth and maturation of Pacific saury *Cololabis saira* under laboratory conditions. Fisheries Science 6, 45-53.

Novikov, Y. (1982). Some notions of mechanism of long-term variations of stock composition and abundance of Pacific saury. Bulletin of Tohoku Regional Fisheries Research Laboratory 44, 101-107.

Odate, K. (1977). On the feeding habits of the Pacific saury, *Cololabis saira* (Brevoort). Bulletin of Tohoku Regional Fisheries Research Laboratory 38, 75-88. (in Japanese, with English Abstract)

Presnell, J. K. and M. P. Schreibman (1997). Humason's Animal Tissue Techniques, 5th Edition. The Johns Hopkins University Press, London.

Sugisaki, H. and Y. Kurita (2004). Daily rhythm and seasonal variation of feeding habit of Pacific saury (*Cololabis saira*) in relation to their migration and oceanographic conditions off Japan. Fisheries Oceanography 13(Supplement 1), 63-73.

Suyama, S. (2002). Study on the age, growth, and maturation process of Pacific saury *Cololabis saira* (Brevoort) in the north Pacific. Bulletin of Fisheries Research Agency 5, 68-113. (in Japanese, with English Abstract)

Suyama, S., Y. Kurita and Y. Ueno (2006). Age structure of Pacific saury *Cololabis saira* based on observations of the hyaline zones in the otolith and length frequency distributions. Fisheries Science 72, 742-749.

Suyama, S., Y. Sakurai and K. Shimazaki (1996). Maturation and age in days of Pacific saury *Cololabis saira* (Brevoort) in the central North Pacific Ocean during the summer. Nippon Suisan Gakkaishi 62, 361-369. (in Japanese, with English Abstract)

Suyama, S., Y. Sakurai, T. Meguro and K. Shimazaki (1992). Estimation of the age and growth of Pacific saury *Cololabis saira* in the central North Pacific Ocean determined by otolith daily growth increments. Nippon Suisan Gakkaishi 58, 1607-1614. (in Japanese, with English Abstract)

Tian, Y., T. Akamine and M. Suda (2003). Variations in the abundance of Pacific saury (*Cololabis saira*) from the northwestern Pacific in relation to oceanic-climate changes. Fisheries Research 60, 439-454.

Tian, Y., T. Akamine and M. Suda (2004). Modeling the influence of oceanic-climatic changes on the dynamics of Pacific saury in the northwestern Pacific using a life-cycle model. Fisheries Oceanography 13, 125-137.

Watanabe, Y. and N. C. H. Lo (1989). Larval production and mortality of Pacific saury, *Cololabis saira*, in the northwestern Pacific Ocean. Fishery Bulletin (U.S.) 87, 601-613.

Yin, M. C. (1998). Growth. In: Fish Ecology, edited by Yin, M. C., The Sheichan Press, Keelung, 60-116. (in Chinese)