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REPRODUCTIVE BIOLOGY OF BIGEYE TUNA IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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The Reproductive Biology of Female Bigeye Tuna (*Thunnus obesus*) in the Western Pacific[1]
(DRAFT)

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Abstract

A total of 890 fish were examined for the bigeye tuna (*Thunnus obesus*) caught by the Taiwanese offshore longline fishing vessels from the tropical western Pacific Ocean and landed at the Tungkang fish market, November 1997 to November 1998 and in November-December 1999.   The sex ratio was about 1:1 but males became predominant at sizes larger than 146 cm (fork length).   Based on histological characters of ovaries, spawning occurred throughout the year with a peak season in February to September. The smallest mature female was 99.7 cm. The spawning frequency estimated with the postovulatory follicle method was at intervals of 1.10 days for females in spawning condition. This implies that bigeye tuna spawns almost every day. The average relative batch fecundity was 59.5 oocytes per gram of body weight.

Introduction

Bigeye tuna (*Thunnus obesus* Lowe, 1839) is a commercially important species of tuna inhabiting the warm waters of the Atlantic, Indian, and Pacific Oceans.   They are found across the entire Pacific between northern Japan and the North Island of New Zewland in the west and from 40°N to 30°S in the east (Calkins, 1980; Matsumoto, 1998). Adult bigeye tuna are caught mainly by longlines, but substantial numbers of juveniles are taken by purse seines (Sun *et al.*, 2001).

Taiwanese distant water tuna longline fleets have operated throughout the three oceans since the late 1960's with albacore as the target species.   In the early 1980's, the Taiwanese began equipping their longliners in the Indian and Atlantic Oceans with very cold (-55 ^{o}C) freezers and deep longlines. These two developments allowed the Taiwanese to target bigeye tuna for the lucrative sashimi market in Japan.   In the

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western Pacific the Taiwanese offshore longline fleets, whether based in domestic (Tungkang mainly) or foreign fishing ports, have landed more bigeye tuna than in the past (Sun *et al,* 2001).

Understanding and quantifying the reproductive potential of any species is of great importance in population dynamics and management models for this species (Schaefer, 1998). Limited papers have been presented on the aspects of reproductive biology for bigeye tuna in the Pacific Ocean. Yuen (1955) studied the maturity and fecundity of bigeye tuna for the central equatorial, western equatorial and Hawaiian area of the Pacific. Kikawa (1953, 1957, 1961 and 1966) studied the length of maturity, spawning period and spawning area for the Pacific bigeye tuna. Kume (1969a, 1969 b) also conducted spawning season, sex ratio, and spawning area research for Pacific bigeye tuna. Kume and Joseph (1966) studied the sex ratio and maturity at length for eastern Pacific bigeye tuna. Nikaido *et al*. (1991) studied the spawning time and frequency of bigeye tuna captured in the waters off Java (12°-14° S, 109° -115° E) and of offshore of southwestern Hawaii (11° -13° N, 163° -176° W) respectively. Obviously, the reproductive biology for western Pacific bigeye tuna has not been studied since 1970. In Taiwan, only age and growth research has been conducted for the bigeye tuna (Sun *et al.*, 2001).

The objectives of this study were to classify female bigeye tuna throughout the size range caught by the Taiwan offshore longline fishery in the western Pacific by reproductive status and to define with precision: (1) sex ratios; (2) spawning season; (3) spawning frequency; (4) batch fecundity; and (5) maturity length.

Material and Methods

Field Sampling and Processing

Specimens were collected monthly between November 1997 and November 1998 in the Tungkang fish market from the landings of the offshore longline fleets which operated in the western Pacific (Figure 1). Two additional samples were collected in November and December of 1999 due to too small sample sizes in November and December of 1997-1998. Random samples were drawn from one to two boats with respect to different fish size.

Fork length was measured with calipers to the nearest millimeter and body weight was measured with electronic balance to the nearest 0.1 kg. The gonads of female were removed and weighed to the nearest gram by using an electronic balance.

Small sections from the posterior portion of the gonad were removed and placed in a 250-ml jar with 10% neutral buffered formalin (Cellar *et al.*, 1996) for histological purposes.

In order to obtain an unbiased sample of oocytes from ovaries, three sections (anterior, middle and posterior) with each about 3 cm in thick were taken from each ovary lobe of four reproductively active fish. Oocytes were teased from thawed wedges of each ovary section and the diameters of 300 oocytes (per section) were measured randomly using the Image-Pro Plus image analysis software package in combination with a dissecting microscope (model: Leica MZ6) equipped with a CCD camera (model: JVC TK-C1380) and a high-resolution computer monitor.

An ANOVA test found no significant difference in oocyte size either between ovary lobes (P>0.05) or among sections within ovary (P>0.05) (Table 1). Therefore, a sub sample consisting of a gonad weighing approximately 0.1 g was cut from the posterior portion of the right or left ovary lobe, placed on a glass slide, immersed in a 33% glycerol solution for about 10 minutes, and then teased apart with a blunt probe. The mean diameter (random axis) was determined from all oocytes per fish (with oocytes >150 μ m). The histological processing (with minor modification), including the dehydration, clearing, infiltration, embedding, sectioning, staining and mounting, followed the methods used by Sheehan and Hrapchak (1973) and Stevens and Wilson (1996).

Data Analysis

<u>Sex Ratio</u>

Sex ratio was expressed by the proportion of males by month and by size class (2cm). Chi-square tests were used to test for any significant difference in sex ratio among months or sizes.

<u>Spawning Season</u>

The following criteria determined the spawning season:
1. Gonad somatic index (GSI):

    The GSI was calculated as follows (Kikawa, 1957):

$$GSI = \frac{W}{FL^3 \times 10^4}$$

    where W = gonad weight (g); FL = fork length (cm).

2. Average mean oocyte diameter (D) per month:

The average mean oocyte diameter per month was determined by summing the individual specimen's mean oocyte diameter (most advanced) by month and dividing the sum by the number of specimens collected in that month as follows (McDermott and Lowe, 1997):

$$\overline{D_j} = \frac{\sum \overline{d_{ij}}}{n_j}$$

where $\overline{D_j}$ = average mean oocyte diameter in month j; d_{ij} = the mean diameter of the most advanced oocytes of specimen i in month j; and n_j = number of specimens in month j.

3. The female mature stage by the histological classification of ovaries:
The ovary of bigeye tuna is considered asynchronous because oocytes in various developmental stages are present in the ovary simultaneously (Wallace and Selman, 1981). For each ovary, the oocytes in the most-developed mode were classified as: (1) Undeveloped stage; (2) Early developing stage; (3) Later developing stage; (4) Mature stage; (5) Spawned stage; and (6) Spent stage by following the Hunter and Macewicz (1985) system, modified by Schaefer (1996) (Wallace and Selman, 1981; Nagahama,1983; Hunter and Macewicz, 1985a; Schaefer, 1987, 1996 and 1998; McPherson, 1991; Nikaido et al., 1991).

Spawning frequency

Spawning frequency was determined by postovulatory follicle method suggested by Hunter and Macewicz (1985a) and applied to southern bluefin tuna by Farley and Davis (1998). This method uses the incidence of females with postovulatory follicles less than 24 hours old to define the fraction of the spawning population. The total number of spawning females divided by the total number of mature females yields the mean spawning fraction. Spawning frequency equals the inverse of the spawning fraction (McPherson, 1991).

Batch fecundity

The number of hydrated oocytes released per spawning was considered batch fecundity. The oocyte size-frequency method (Hunter et al., 1985) yielded the estimate for the number of oocytes in the most advanced spawning batch in the sub sample (this study used 0.1 g). We applied the gravimetric method to estimate total numbers of oocytes as follows:

$$BF = GW \times \frac{\beta}{w}$$

where BF = batch fecundity; GW = gonad weight (g); β = the numbers of oocytes in the sub sample, and w = the weight of sub sample of gonad (= 0.1 g).

The relative fecundity is defined as fecundity divided by female weight (Hunter *et al.*, 1992) as follows:

$$RF = \frac{BF}{W_f}$$

where RF = relative fecundity, and W_f = the weight of female (g).

Minimum Maturity Length

To determine the minimum maturity length, the exterior of the gonad was observed for spawning activity or spent, and further confirmed by checking the relevant histological examination.

Results

Sex Ratio

Fork lengths ranged from 84.9 to 174.4 cm for 380 female specimens and 87.6 to 173.7 cm for 508 male specimens. The proportion of males (Figure 2) had greater variation at sizes less than 146 cm. The proportion became significantly greater than 50% at sizes larger than 146 cm. Chi-square analysis of the sex ratio by month showed no significant deviation ($P > 0.05$) from the expected 1:1 ratio, but when the data are pooled, the overall ratio differs significantly from the expected 1:1 ratio. Grouping sizes into a 2 cm length class and then using Chi-square analysis of the sex ratio indicated a significant deviation ($P < 0.05$) in classes greater than 146 cm, with males being more prevalent than females. The overall sex ratio for the sampling period deviated from the expected 1:1 ratio ($P < 0.01$).

Spawning season

As mentioned before, the bigeye tuna spawning season was determined by the monthly variations in the mean GSI, the average mean diameter of the oocytes at the most advanced stage, and the proportion of specimens in various ovarian maturing stages.

1. Monthly mean GSI:

Figure 3 shows the monthly variations of mean GSI. A GSI value lower than 2.2 was obtained during the period from November 1997 to January 1998. In

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February 1998, the GSI increased abruptly to 4.8. Since then, the GSI has increased slowly, reaching a maximum level of 5.7 in April 1998. After April 1998, the GSI decreased gradually until September. The GSI was 3.3 in September 1998. Then the GSI decreased sharply to 1.3 in October. The GSI were high in November and December 1999 compared to the same months of previous years.

2. Monthly mean oocyte diameter:

The monthly variation in mean diameters of the most advanced stage of oocytes is shown in Figure 4. The monthly mean diameter was less than 400 um during the period of November 1997 to January 1998. In February 1998, the mean diameter increased to 650 μm and then peaked at 730 μm in March. During April to September, the monthly mean diameter remained at a high and stable condition of above 600 μm. The mean diameter decreased sharply to around 230 μm in October. The mean diameter were high in November and December 1999 compared to the same months of previous years.

3. Monthly proportion of specimens in various ovarian maturity stages:

Six maturity stages were identified for bigeye tuna. The GSI values and the mean oocyte diameters of each stage are shown in Figures 5 and 6, respectively. The characteristics based on histological examination and the ranges of GSI and mean oocyte diameters of each stage are described as follows:

1) Undeveloped Stage: The oocytes are in the oogonia stage, the chromatin nucleus stage, and the peri-nucleolus stage of oogenesis. The mean diameter was less than 105 μm. The GSI value was between 0.4-1.4.

2) Early developing stage: The oocytes are in the yolk vesicle stage, the primary yoked globule stage, and the secondary yoked globule stage. The mean diameter ranged from 290 to 340 um. The GSI varied from 1.0 to 2.0.

3) Later developing stage: The oocytes are in the tertiary developing stage. The mean diameter ranged from 445 to 570 μm. The GSI was from 1.9 to 2.6.

4) Mature stage: The oocytes are in the germinal vesicle migratory stage, the germinal vesicle breakdown stage, and the ovulation stage. The mean diameter was from 595 to 830 μm. The GSI ranged from 4.8 to 10.

5) Spawned stage: Postovulatory follicles appear as an involuted structure. The mean diameter was from 490 to 975 μm. The GSI ranged from 1.6 to 9.6.

6) Spent stage: The atretic oocyte appears, and the stage above the yolk globule

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stage has not existed. Ovaries become shrunken and lumen of the ovary empty; occasionally eggs remain in the lumen. The mean diameter was 80 to 340 μm. The GSI was from 0.7 to 2.4.

The proportion of specimens in various ovarian maturity stages (Figure 7) shows that the western Pacific bigeye tuna spawned year round, and the main spawning period happened between February and September. This figure also shows that the spent stage occurred mainly from October to January.

Spawning frequency

Spawning frequency was estimated based on the presence of postovulatory follicles in histological examinations of ripe fish. Three stages for postovulatory follicles were decided by the degree of degenerating.

In early stage, the new postovulatory follicles have formed (near the time of spawning) and show no signs of degeneration. The thecal layer appears as an irregularly looped cord. The granulosa layer cells are arranged orderly along the edge of the lumen with cell walls usually evident and possessing prominent nuclei.

In middle stage, the postovulatory follicles show significant degeneration and have greatly shrunken. The thinly stretched thecal layer becomes thick. The linear arrangement of the granulosa layer cell nuclei becomes less distinct.

In late stage, the postovulatory follicles are absorbed completely and are not readily distinguished from atretic oocytes. In addition, only a few non-distinct granulosa cells remain.

Table 2 details the spawning frequency estimates based on histological examination of the three stages of postovulatory follicles for the western Pacific bigeye tuna. If total females (sample size is 237) are included in the spawning frequency estimate, the spawning fraction is 0.75 and the mean spawning interval is 1.34 days.   If only ripe females (sample size equals 186) are included in spawning frequency estimate, then the spawning fraction is 0.95, giving a weighted mean spawning interval of 1.05 days. This value suggests that once a female starts spawning, she spawns daily.

Batch fecundity

The relationship between batch fecundity and length (Figure 8), and weight (Figure 9) for 129 female fish (one fish was not included due to too low fecundity) can be described by the following two equations, respectively:

$$BF = 8.815 \times 10^{-4} FL^{4.419} \qquad r^2 = 0.459; \, n = 129$$
$$BF = 6.153 \times 10^3 W^{1.543} \qquad r^2 = 0.459; \, n = 129$$

where BF = batch fecundity in number of oocytes; FL = fork length in centimeters; and W= body weight in kilograms.

The batch fecundities predicted from the first equation for bigeye tuna of 100 cm and 180 cm fork length are 845,000 and 11,848,000, respectively (Table 3). The estimated mean relative fecundity for 129 female fish was 59.5 oocytes per gram of body weight. The smallest and largest values were 16 and 150 oocytes per gram of body weight. This represents a large variance.

Minimum maturity length

In our study, we found that female bigeye tuna larger than 99.7 cm fork length have spawning activity or spent. These can be confirmed by checking the histological examination and observing on outside view of gonads. In our sample, the fork length ranged from 90.5 to 95.5 cm belonged to immature fish, because all the GSI values were less than 1.4, the maximum value for immature fish. Most of our sample's fork lengths are larger than 100 cm; therefore, it is impossible to estimate a length at 50% maturity. This study only estimated the minimum maturity length (99.7 cm).

Discussions

Sex ratio

In this study, overall sex ratios deviate significantly from the expected 1:1 ratio. Sex ratio analysis by month does not indicate the observed deviations from the expected 1:1 ratio. Sex ratio analysis by length indicates a preponderance of male bigeye tuna greater than 146 cm in length. In almost all relevant studies, there were proportionally more males than females (Kataoka, 1957; Kume, 1969a, 1969b; Kume and Joseph, 1966; Stequert and Marsac, 1989; Nikaido *et al*, 1991). Schaefer (1987) mentioned a similar phenomenon for several other tuna species investigated; albacore (Otsu and Sumida, 1968), kawakawa (Williamson, 1970), skipjack (Marr, 1948; Brock, 1954; Raju, 1964), and yellowfin (Orange, 1961; Murphy and Shomua, 1972; Lenarz and Zweifel, 1979). Schaefer (1987) also mentioned that differentials in sex ratio with size classes have been suggested to be differences between males and females with respect to growth, mortality, or availability. Moreover, the almost complete absence of females within large size classes of tuna seems to be caused by

differential natural mortality, rather than differential growth or availability to capture. In discussing the natural mortality, Schaefer (1987) indicated that numerous possible causes of natural mortalities in larger fish, such as disease and spawning stress, which have not been investigated in this study.

Spawning season

All above observations suggest that bigeye tuna spawn year round with peaks in February to September. Kikawa (1961) studied the seasonality of maturation in bigeye tuna from 1951 through 1960 at 130 ^{o}E to 110 ^{o}W and 12 ^{o}N to 10 ^{o}S and found the main spawning season was from April to September throughout the entire equatorial Pacific, except for the eastern area south of equator, where spawning took place most intensively from January to March. Kikawa (1966) reported that western Pacific bigeye tuna spawn throughout the year, with peaks in June and September. These results are similar to our study.

Spawning frequency

Nikaido et al. (1991), using the postovulatory follicle method, estimated the spawning frequency for bigeye tuna in Java and Hawaii waters. Their results (1 to 1.1 days) are very similar to our results. Batalyants (1992) also estimated the spawning frequency for the Atlantic bigeye tuna during 1969-70, 1975, 1979, and 1990 by using the hydrated oocyte method. The mean spawning interval for each year showed little difference, 2.3 days in 1969-70, 3.1 days in 1975, 1.7 days in 1979, and 1.6 days in 1990.

Other tuna spawning frequency used similar methods as follows: Hunter et al. (1986) estimated 1.18 days for south Pacific skipjack tuna. McPherson (1991) estimated 1.54 days for Coral Sea yellowfin tuna. Schaefer (1996, 1998) estimated 1.14 and 1.52 days for eastern Pacific yellowfin tuna. Farley and Davis (1998) estimated 1.1 days for southern bluefin tuna. All of these studies' results were similar to this study. Schaefer (1987) estimated 2.1 to 5.7 days for black skipjack tuna using the hydrated oocyte method. Obviously, this result differs from the other studies probably due to the use of different methods or the study of different species.

Batch fecundity

Table 3 lists the batch fecundity of bigeye and other tuna species within different size ranges. The number of eggs spawned per day varied from 0.85 (100 cm fork length) to 11.85 millions (180 cm fork length) in our study. Yuen (1955) observed

that the batch fecundity ranged from 2.9 to 6.3 million eggs for fish weighing between 39 and 102 kg. The batch fecundity estimated by Nikaido *et al*. (1991) in Hawaii waters ranged from 0.4 (100 cm fork length) to 4.7 (180 cm fork length) million eggs and 0.56 to 5.9 million eggs in Java waters. Our results are closer to Yuen's (1955), but larger than Nikaido's *et al*. (1991) (see Table 3).   The Nikaido *et al*. (1991) differences may result from different study methods (oocyte size-frequency method vs. the hydrated oocyte method). Table 3 also shows the estimate of batch fecundity for yellowfin (Schaefer, 1996, 1998), southern bluefin tuna (Farley and Davis, 1998), and skipjack tuna (Goldberg and Au, 1986). The large variance of batch fecundity among these studies may be due to different species and the shape of the fish body.

In our study, the estimated mean relative fecundity was 59.5 oocytes per gram of body weight. This result was close to Yuen's estimate (49.9 oocytes per gram of body weight), but larger than Nikaido's *et al*. (1991) (31 oocytes per gram of body weight).

The estimated relative fecundity for yellowfin was 67.3 and 68 oocytes per gram of body weight (Schaefer 1996, 1998). For southern bluefin tuna, relative fecundity was 57 oocytes per gram of body weight (Farley and Davis, 1998), which is close to our estimate. However, for black skipjack, the mean relative fecundity was 13,699 and 106 oocytes per gram of body weight (Schaefer, 1987)

Minimum maturity length

Kikawa (1957, 1961) studied the percentage of mature fish in the bigeye tuna population. Based on his results, 100 cm yielded the length with potential for sexually maturity. Yuen (1955) recorded a weight of 14 to 20 kg as the range necessary to attain sexual maturity. Kume (1962) recorded the minimum size for spawning as 92 cm in fork length, while Kume and Joseph (1966) estimated that bigeye tuna in the eastern Pacific reached maturity at 100 to 130 cm. McPherson (1988) and Nikaido *et al*., (1991)   noted that some fish as small as 100 cm long could be mature.   Most of above studies yielded similar results to ours. Our samples of offshore longliners showed that this fishery mainly catch mature bigeye tuna.

References cited

Batalyants, K. Ya. 1992. On the study of spawning frequency for bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*), based on the Atlantic longline fishery data. *ICCAT Vol. Sci. Pap., 39(1):31-38.*

Brock, V. E. 1954.   Some aspects of the biology of the aku, *Katsuwonus pelamis*, in the Hawaiian Islands.   Pac. Sci. 8(1): 93-104.

Calkins, T. P. 1980. Synopsis of biological data on the bigeye tuna, *Thunnus obesus* (Lowe, 1839), in the Pacifi c Ocean. In Synopses of biological data on eight species of scombrids (W. H. Bayliff, ed.), p. 219-59. Inter-Am. Trop. Tuna Comm. Spec. Rep. 2.

Cellar, N., G. R. Sedberry, and D. M. Wyanski. 1996. Reproductive seasonality, maturation, fecundity, and spawn-ing frequency of the vermilion snapper, *Rhomboplites aurorubens*, off the southeastern United States. *U. S. Nat. Mar. Fish. Serv., Fish. Bull., 94(4):635-653.*

Farley, J. H. and T. L. O. Davis. 1998. Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii. U. S. Nat. Mar. Fish. Serv., Fish. Bull.,* 96(2):223-236.

Goldberg, S. R., and D. W. K. Au. 1986. The spawning of skipjack tuna from southeastern Brazil as determined from histological examination of ovaries. *In* P. E. K. Symons, P. M. Miyake, and G. B. Sakagawa (eds.), Proceedings of the ICCAT Conference on the International Skipjack Year Program. Int. Comm. Conserv. Atl. Tuna, Madrid, Spain. pp.277-284.

Hirschfield, M. F. 1980.   An experimental analysis of reproductive effort and coast in the Japanese medaka, *Oryzias latipes*.   Ecology 61(2): 282-292.

Hunter, J. R., and B. J. Macewicz. 1985. Measurement of spawning frequency in multiple spawning fishes. *In* Lakser, *R.*(ed.), An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy, *Engraulis mordax*, pp.79-94. *NOAA Tech. Rep. NMFS 36.*

Hunter, J. R., B. J. Macewicz, and J. R. Sibert. 1986. The spawning frequency of skipjack tuna, *Katsuwonus pelamis,* from the South Pacific. *U. S. Nat. Mar. Fish. Serv., Fish. Bull.,* 84(4):895-903.

Hunter, J. R., B. J. Macewicz, N. C. H. Lo, and C. A. Kimbrell. 1992. Fecundity, spawning, and maturity of female Dover sole *Microstomus pacificus,* with an evaluation of assum-ptions and precision. *U. S. Nat. Mar. Fish. Serv., Fish. Bull.,*

90(1):101-128.

Hunter, J. R., N. C. H. Lo, and R. J. Leong. 1985. Batch fecundity in multiple spawning fishes. *In* Lakser, *R.*(ed.), An egg production method for estimating spawning biomass of pelagic fish: Application to the northern anchovy, *Engraulis mordax*, p.67-78. *NOAA Tech. Rep. NMFS 36.*

Kikawa, S. 1953. Observations on the spawning of the big-eyed tuna (*Parathunnus mebachi* Kishinouye) near the sourthern Marshall Islands. Contr. *Nankai Reg. Fish. Res. Lab., 1(42): 10pp.*

Kikawa, S. 1957. The concentrated spawning area of bigeye tuna in the western Pacific. *Nankai Reg. Fish. Res. Lab., 5:145-157.*

Kikawa, S. 1961. The group maturity of bigeye tuna *Parathunnus mebachi* (Kishinouye) in the spawning areas of the Pacific. *Rept. Nankai Reg. Fish. Res. Lab., 13:35-46.*

Kikawa, S. 1966. The distribution of maturing bigeye and yellow-fin and an evaluation of their spawning potential in different areas in the tuna longline grounds in the Pacific. *Rept. Nankai Reg. Fish. Res. Lab., 23:131-208.*

Kume, S. 1969a. Ecological studies on bigeye tuna - V. A critical review on distribution, size composition and stock structure of bigeye tuna in the North Pacific Ocean (north of 16ºN). *Bull. Far Seas Fish. Res. Lab., 1:57-75.*

Kume, S. 1969b. Ecological studies on bigeye tuna - VI. A review on distribution and size composition of bigeye tuna in the equatorial and south Pacific Ocean. *Bull. Far Seas Fish. Res. Lab., 1:77-98.*

Kume, S., and J. Joseph. 1966. Size composition, growth and sexual maturity of bigeye tuna, *Thunnus obesus* (Lowe), from the Japanese longline fishery in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm., Bull., 11(2):45-99.*

Lenarz, W. H. and J. R. Zweifel. 1979. A theoretical examination of some aspects of the interaction between lingline and surface fisheries foe yellowfin tuna, *Thunnus albacares. U.S. Nat. Mar. Fish. Serv., Fish. Bull., 76(4): 807-825.*

Marr, J. C. 1948. Observations on the spawning of oceanic skipjack, *katsuwonus pelamis*, and yellowfin tuna, *Neothunnus macropterus*, in the northern Marshall Islands. *U.S. Fish Wildl. Serv., Fish. Bull., 51(4): 201-206.*

Matsumoto, T. 1998. Preliminary analyses of age and growth of bigeye tuna 509 (*Thunnus obesus*) in the western Pacifi c Ocean based on otolith increments. In Proceedings of the fi rst world meeting on bigeye tuna (R. S. Deriso, W. H.

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Bayliff, and N. J. Webb, eds.), p. 238-42. *Inter-Am. Trop. Tuna Comm. Spec. Rep. 9.*

McPherson, G. R. 1988. Verification of the postovulatory follicle method for establishing the spawning frequency of yellowfin, bigeye and skipjack tuna in the Coral Sea. Queensland Dep. Primary Industries, Northern Fisheries Res. Center, Cairns, Australia, Tech. Rep. FRB 88/9, 42 p.

McPherson, G. R. 1991. Reproductive biology of yellowfin tuna in the eastern Australain fishing zone, with special reference to the North-western Coral Sea. *Aust. J. Mar. Freshw. Res., 42:465-477.*

Murphy, G. I. and R. S. Shomura. 1972. Pre-exploitation abundance of tunas in the equatorial central Pacific. *U.S. Nat. Mar. Fish. Serv., Fish. Bull. 70(3): 875-913.*

Nagahama, Y. 1983. The functional morphology of teleost gonads. *In* 'Fish Physiology. Vol.IX: Reproduction'. (Eds. W. S. Hoar, D. J. Randall and E. M. Donaldson.), pp.223-275. Academic Press, New York.

Nikaido, H., N. Miyabe, and S. Ueyanagi. 1991. Spawning time and frequency of bigeye tuna, *Thunnus obesus. Bull. Nat. Res. Inst. Far Seas Fish., 28:47-73.*

Orange, C. J. 1961. Spawning of yellowfin tuna and skipjack in the eastern trpical Pacific as inferred from studies of gonad development. *Inter-Am. Trop. Tuna Comm. Bull. 5(6): 457-526.*

Otsu T. and R. F. Sumida. 1968. Distribution, apparent abundance, and size composition of albacore, *Thunnus alalunga*, taken in the longline fishery based in American Samoa, 1054-65. *U.S. Fish Wildl. Serv., Fish. Bull. 67(1): 47-69.*

Raju, G. 1964. Fecundity of the oceanic skipjack, *Katsuwonus pelamis* (Linnaeus) of Minicoy. Mar. Biol. Assoc. India. Proceedings of the symposium on scombroid fishes Symp. Ser. 1: 725-732.

Schaefer, K. M. 1987. Reproductive biology of black skipjack, *Euthynnus lineatus*, an eastern Pacific tuna. *Inter-Amer. Trop. Tuna Comm., Bull., 19(2):169-260.*

Schaefer, K. M. 1996. Spawning time, frequency, and batch fecun- dity of yellowfin tuna, *Thunnus albacares*, near clipperton Atoll in the eastern Pacfic Ocean. *U. S. Nat. Mar. Fish. Serv., Fish. Bull., 94(1):98-112.*

Schaefer, K. M. 1998. Reproductive biology of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific tuna. *Inter-Amer. Trop. Tuna Comm., Bull., 21(5):205-272.*

Sheehan, D. C., and B. B. Hrapchak. 1973. Theory and practice of histotecnology. The C. V. Mosby Comp. Toronto, London. 218pp.

Stevens, A., and I. G. Wilson. 1996. The haematoxylins and eosin. *In* 'Theory and Practice of histological techniques'.(*Eds*. Bancroft J. D., A. Stevens, and D. R. Turner) 4th ed., Churchill Livingstone, New York. pp.99-112.

Sun, C.L., C.L. Huang, and S.Z. Yeh, 2001. Age and growth of the bigeye tuna *Thunnus obesus* in the western Pacific Ocean. *U. S. Nat. Mar. Fish. Serv., Fish. Bull.,* 99: 502-509.

Wallace, R. A., an Selman, K. 1981.Cellular and dynamic aspects of oocyte growth in teleosts. *Amer. Zool., 21:325-345.*

Williamson, G. R. 1970. Little tuna *Euthynnus affinis* in the Hong Kong area. Bull. Jpn. Soc. Sci. Fish., 36(1): 9-18.

Yuen, H. S. H. 1955. Maturity and fecundity of bigeye tuna in the Pacific. *U. S. Fish Wildl. Serv., Spec. Sci. Rept. Fish., 150: 30 pp.*
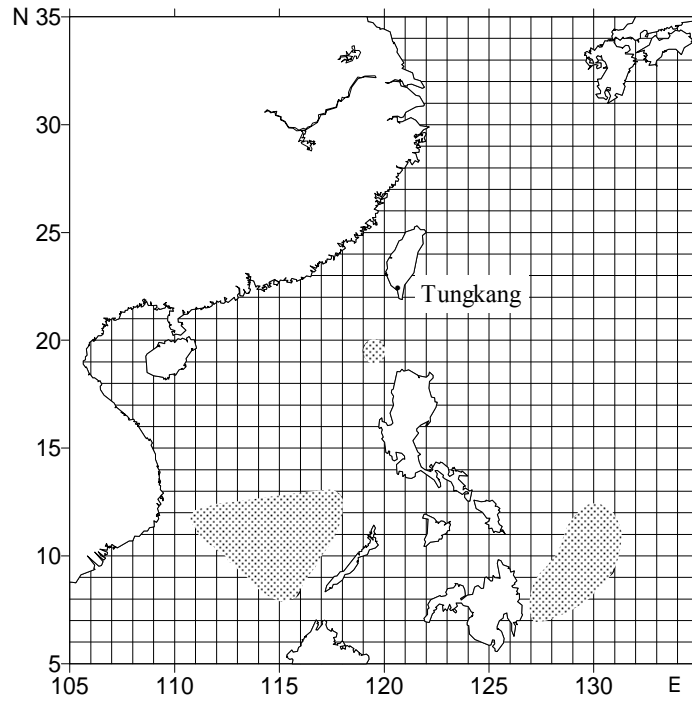
Figure 1. Fishing grounds (dotted areas) of the bigeye tuna *Thunnus obesus* sampled in this study.
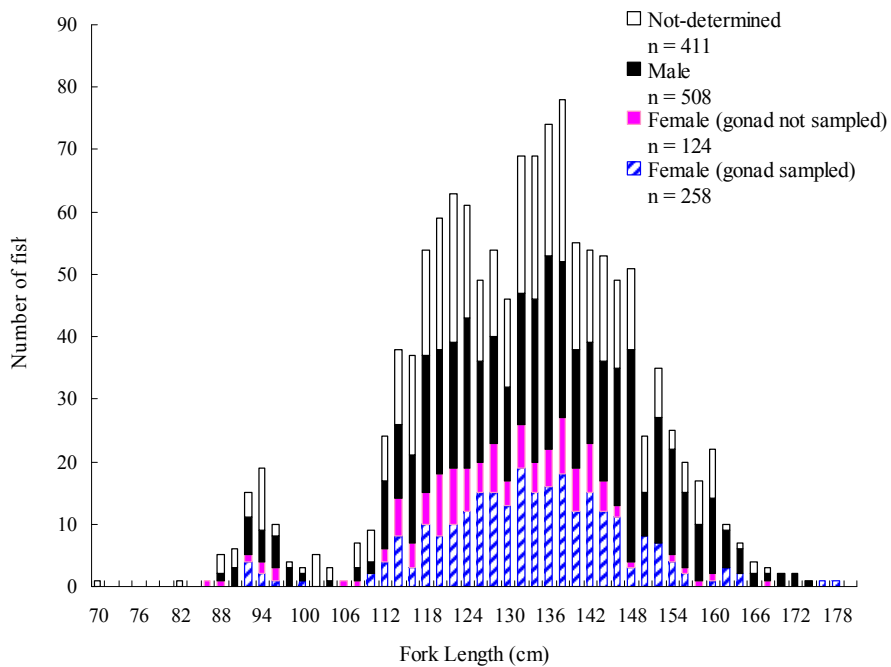

Figure 2. The length-frequency distribution of bigeye tuna *Thunnus obesus* sampled at the Tungkang fish market, November 1997 - December 1999.
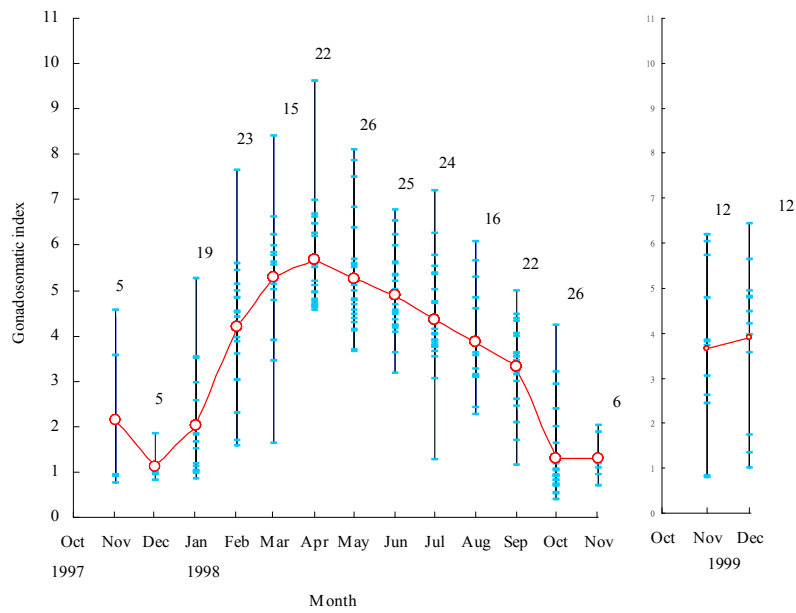
Figure 3. Monthly variation in mean gonadosomatic index of female bigeye tuna *Thunnus obesus* in the western Pacific Ocean, November 1997 - December 1999 (vertical bars, ranges; numbers above vertical bars, sample size).
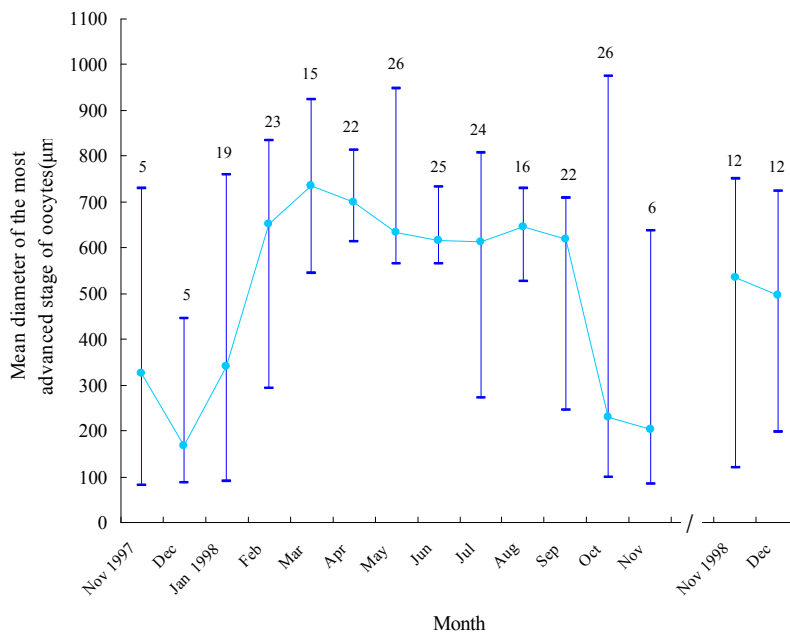

Figure 4. Monthly variation in mean diameter of the most advanced stage of oocytes for female bigeye tuna *Thunnus obesus* in the western Pacific Ocean, November 1997 – December 1999 (vertical bars, ranges; numbers above vertical bars, sample sizes).
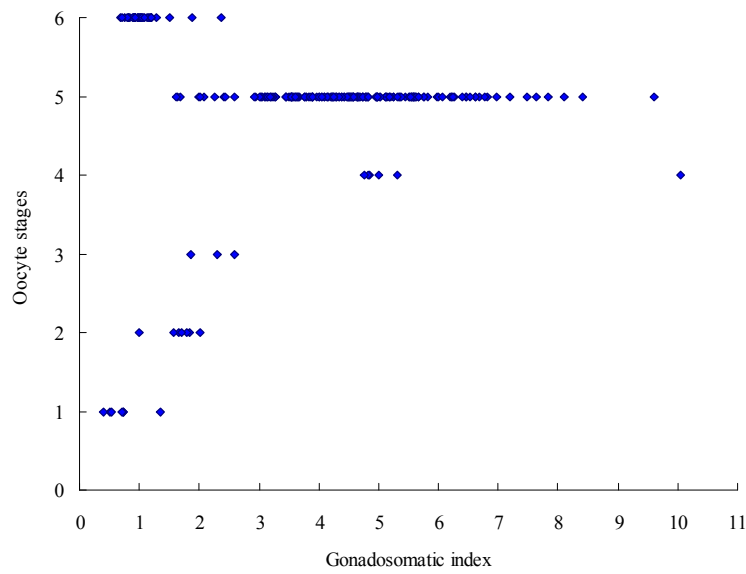
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Figure 5. Relationship between oocyte stages and gonadosomatic index of female bigeye tuna T*hunnus obesus* in the weastern Pacific Ocean, September 1997 - December 1999 (Oocyte stage: 1, undeveloped stage; 2, early developing stage; 3, later developing stage; 4, mature stage; 5, spawned stage; 6, spent stage).
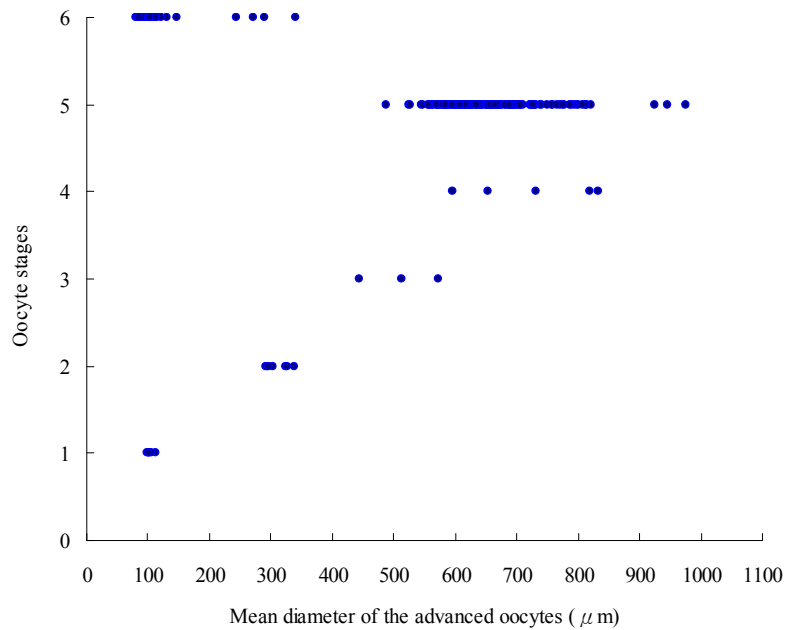

Figure 6. Relationship between oocyte stages and mean diameter of the advanced oocytes of female bigeye tuna *Thunnus obesus* in the western Pacific Ocean, September 1997 - December 1999 (Oocyte stage: 1, undeveloped stage; 2, early developing stage; 3, later developing stage; 4, mature stage; 5, spawned stage; 6, spent stage).
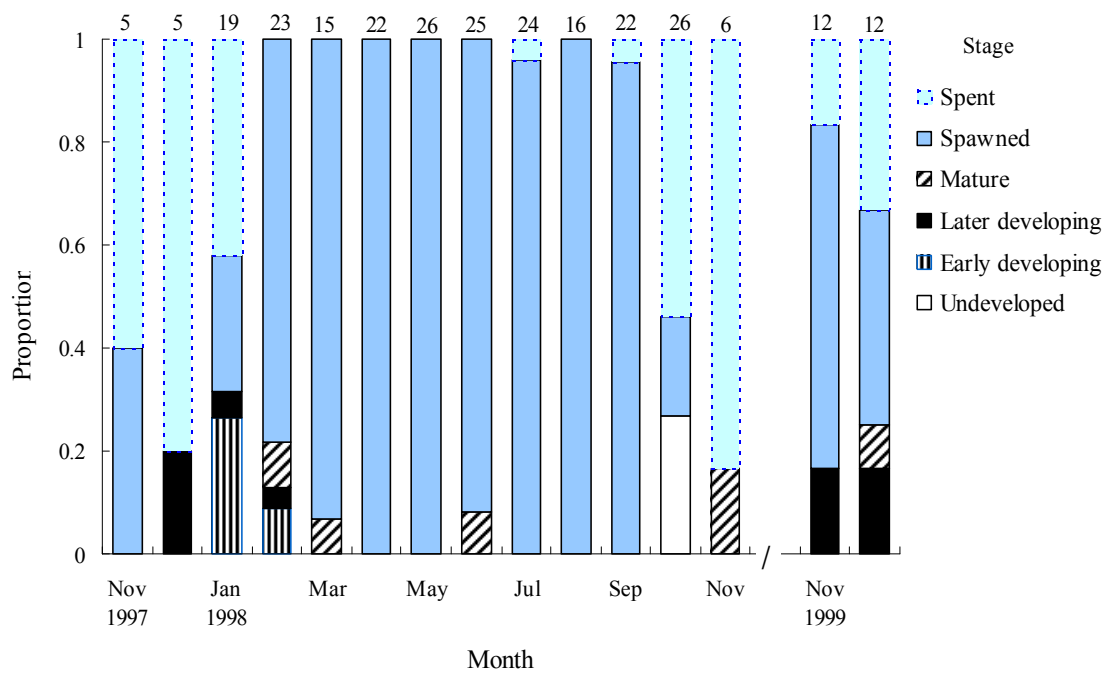
Figure 7. Monthly variation in the proportion of various ovarian maturing stages of female bigeye tuna *Thunnus obesus* in the western Pacific Ocean, November 1997 - December 1999 (numbers, sample size).
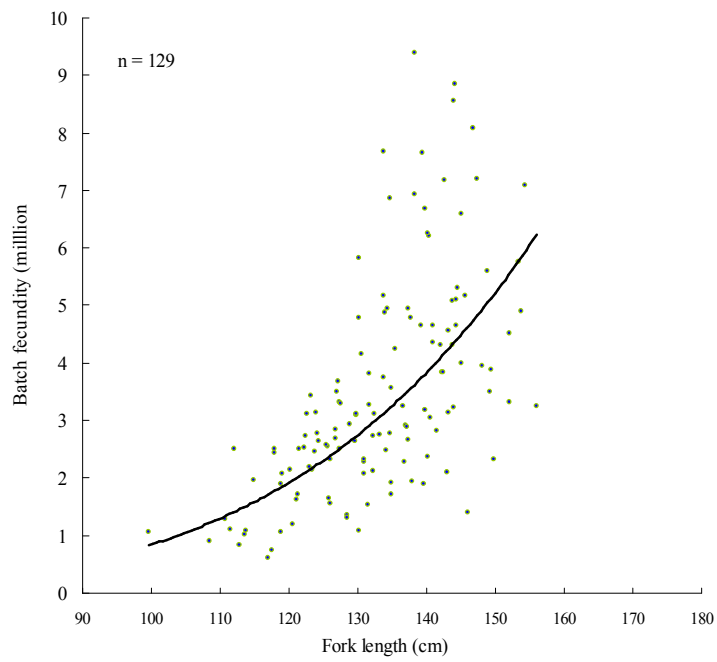
Figure 8. Relationship between batch fecundity and fork length of bigeye tuna
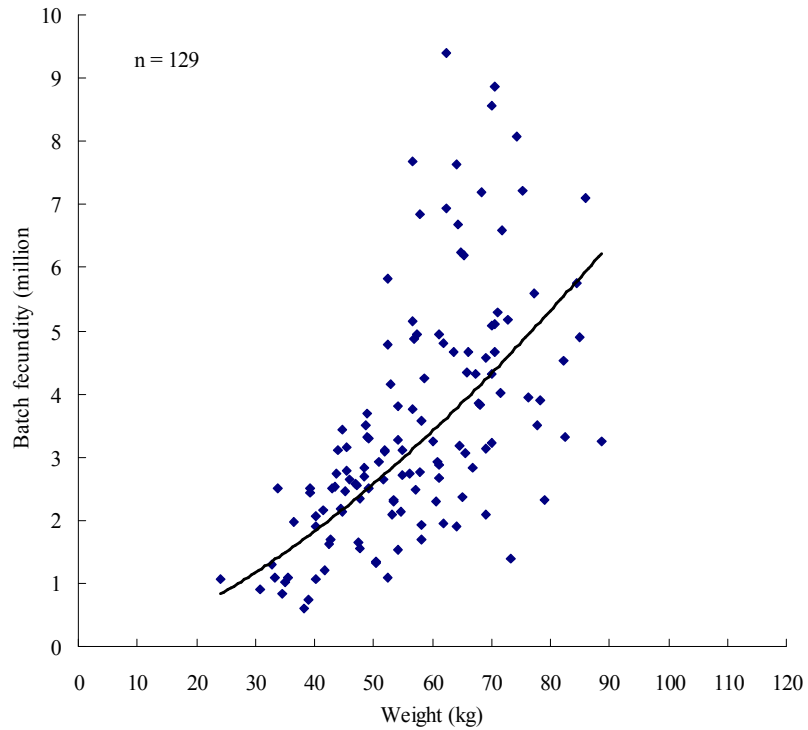*Thunnus obesus* in the western Pacific Ocean.

Figure 9. Relationship between batch fecundity and weight for bigeye tuna *Thunnus obesus* in the western Pacific Ocean.

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Table 1. Analysis of variance for the effect of sample locations of ovaries on the
diameters of the most advanced stage oocytes of bigeye tuna.

	Mean diameter							
	Right ovary			**Left ovary**			**Both ovaries**	
Location	-			-			-	
Anterior	451.13	± 101.39	4	448.26	± 98.24	4	449.70	± 92.44	8
Central	429.53	± 112.43	4	429.17	± 94.51	4	429.35	± 96.15	8
Posterior	430.55	± 104.26	4	421.62	± 81.11	4	426.08	± 86.61	8
All	437.67	± 96.56	12	433.01	± 83.66	12			

Two-way analysis of variance					
Source of variation	df	SS	MS	F	P
Ovary (left or right)	1	98.62	98.62	0.010	0.9213
Position within ovary	2	2618.70	1309.35	0.133	0.8761
Interaction	2	77.72	38.86	0.004	0.9961
Error	18	176861.30	9825.63		
Total	23	179656.33			

Table 2. Spawning fraction and spawning interval of bigeye tuna *Thunnus obesus* by month for all females and females in spawning condition in the western Pacific Ocean between September 1997 and December 1999 (POF, postovulatory follicles; *n*, number of fish in sample).

Year	Month	All females				Females in spawning condition			
		n	n with POF's	Spawning fraction	Spawning interval (days)	n	n with POF's	Spawning fraction	Spawning interval (days)
1997	Nov	5	2	0.40	2.50	2	2	1.00	1.00
	Dec	5	0	0.00	…	0	0	0.00	…
1998	Jan	19	5	0.26	3.85	6	5	0.83	1.20
	Feb	23	18	0.78	1.28	21	18	0.86	1.17
	Mar	15	14	0.93	1.07	15	14	0.93	1.07
	Apr	22	22	1.00	1.00	22	22	1.00	1.00
	May	26	26	1.00	1.00	26	26	1.00	1.00
	Jun	25	23	0.92	1.09	25	23	0.92	1.09
	Jul	24	23	0.96	1.04	23	23	1.00	1.00
	Aug	16	16	1.00	1.00	16	16	1.00	1.00
	Sep	22	21	0.95	1.05	21	21	1.00	1.00
	Oct	26	4	0.15	6.50	5	4	0.80	1.25
	Nov	6	1	0.17	6.00	1	1	1.00	1.00
1999	Nov	12	8	0.67	1.50	12	8	0.67	1.50
	Dec	12	5	0.42	2.38	12	5	0.42	2.38
Total		258	188	0.73	1.37	207	188	0.91	1.10

Table 3. Comparison of the estimated batch fecundity for four species of tunas by different authors.

Species	Size-range	Batch fecundity (thousand)	Author
Bigeye tuna (*T. obesus*)	100 - 180 (cm)	845- 11,848	This study
	100 - 180 (cm)	403 - 4,689	Nikaido et al 1991 (Hawaii)
	100 - 180 (cm)	564 - 5,902	Nikaido et al 1991 (Java)
	40 - 100 (kg)	1,824 - 7,500	This study
	39 - 102 (kg)	2,900 - 6,300	Yuen 1955
Yellowfin tuna (*T. albacares*)	100 - 180 (cm)	1,199 - 18,767	Schaefer 1996
	100 - 180 (cm)	1,306 - 8,471	Schaefer 1998
	40 - 100 (kg)	2,668 - 6,445	Schaefer 1998
Southern bluefin tuna (*T. maccoyii*)	150 - 250 (cm)	1,163 - 54,467	Farley and Davis 1998
Skipjack tuna (*Katsuwonus pelamis*)	51 - 72 (cm)	130 - 978	Goldberg and Au 1986