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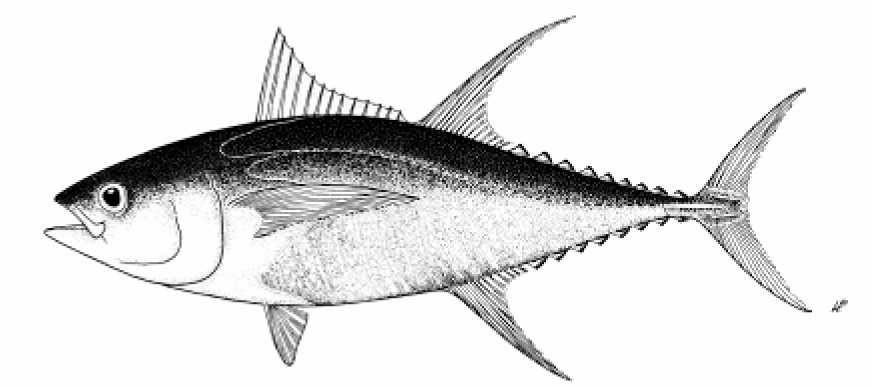
Reproductive biology of yellowfin tuna in the central and western Pacific Ocean



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Reproductive biology of the female yellowfin tuna *Thunnus albacares* in the western Pacific Ocean[1]

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Introduction

An understanding of the reproductive biology of any species is important for the purpose of stock assessment (Schaefer, 1987, 1996, 1998). In this study we use both anatomical and histological methods (1) to determine sex ratio and spawning season; (2) to classify female maturation stages, and (3) to estimate the length at 50% maturity, and (4) to estimate spawning frequency and batch fecundity. The results obtained would provide reproductive parameters important for population dynamics and management modeling of the yellowfin tuna in the western Pacific Ocean.

Materials and Methods

Sample collection and preparation

Samples were collected on a monthly basis between September 2001 and September 2002 in the Tungkang fish market from the offshore longline fleets which operated in the western Pacific (Fig. 1). Fresh ovarian tissue was preserved and later prepared for histological examination and analysis using the Image-Pro Plus image analysis software package in combination with a dissecting microscope equipped with a CCD camera and a high resolution computer monitor. Only female samples were used in this study. Males were only identified to sex and measured to fork length to determine sex ratios for different size classes of fish.

Sex ratio and gonadosomatic index

The sex ratio was expressed as the proportion of males to the total number of the

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fish sampled. The gonadosomatic index (GSI) was calculated using the formula $GSI = W \times 10^4 / FL^3$, where W is gonad weight in grams and FL is fork length in centimeters (Uosaki and Bayliff, 1999).

Spawning season

The spawning season was determined by the monthly variations in the mean gonadosomatic index, the mean diameter of the most advanced stage of oocytes, and the proportion of the developmental stages of ovaries.

Length at 50% maturity

The length at which 50% of all individuals were sexually mature (L_{50}) was estimated from the percentage of mature individual fish in each length class of 5 cm interval, and the fitted logistic equation (King, 1995):

$$P = \frac{1}{1 + \exp\left[r \times \left(L - L_{50} \right) \right]}$$

where P is the percentage of mature individuals within a length class, r is the slope of curve, and L_{50} is the length at 50% sexual maturity. L_{50} and r were obtained, using the nonlinear least square procedure (Gauss-Newton method, NLIN of SAS Institute, 1990).

Spawning frequency

Spawning frequency was estimated as inverse of the spawning fraction determined by both the hydrated oocyte method and the postovulatory follicle method (Hunter and Macewicz, 1985a, 1985b). Spawning fraction was calculated as the total number of ovaries with postovulatory follicles (and hydrated or migratory-nucleus oocytes) divided by the total number of all females, matures and reproductively active females.

Batch fecundity

Batch fecundity was determined using the hydrated oocyte method (Hunter *et al.*, 1985). Batch fecundity estimates were made on ovarian samples that contained migratory-nucleus or hydrated oocytes without new postovulatory follicles (Schaefer, 1996). Relative fecundity was calculated as the number of oocytes per gram of body weight.

Results

Sex ratio

Of 1,613 fish whose sexes were identified, 902 fish were males and 711 fish were females, with a sex ratio of 0.559 (or 1.27:1 for males to females) significantly different from the hypothetical ratio of 0.5 (or 1:1) (x^2 value = 22.35, $P < 0.01$).

When the fish were divided in groups at 2-cm length intervals, females were significantly predominant at the lengths at and smaller than 104 cm ($P < 0.05$), the sex ratio was about 1:1 between 104 cm and 138 cm, and males became predominant at 138 cm and larger. There was an obvious shift in predominance of sex from female to male with the increase in sizes of the fish.

Spawning season

1. Gonadosomatic index

Monthly variation in mean gonadosomatic indices (GSI) of females is shown in Fig 2. Mean monthly GSI decreased from 2.92 in September to 1.46 in December, and then increased to 3.15 in January and to 4.13 in February. It remained around 3.37 between March and June, and decreased to 2.57 in July and August. During the study period, the mean monthly indices were always above 2, except for December. According to the histological characters of ovaries, a GSI of 2.4 was considered as the indicator of reproductive maturity for female yellowfin tuna in this study, instead of 2.0 and 2.1 used by other investigators (Kikawa, 1962; Koido and Suzuki, 1989; Uosaki and Bayliff, 1999).

2. Oocyte diameters

Monthly variation in mean diameters of the most advanced oocytes is shown in Fig. 3. Monthly profile of the mean diameters showed the same trend to that of the mean monthly GSIs.

3. Histological characters of ovaries

Based on histological analyses of ovaries (Fig. 4), spawning females were found in all months of the year in this study. The percentage of spawning females was above 50% in the months between February and September, and above 60% (maximum) between February and June. At the same time, the number of post-spawning females decreased with the increase in spawning females. The post-spawning females were more abundant in the months from October to January than from February to September.

According to the monthly variations in gonadosomatic indices (Fig. 2), oocytes diameters (Fig. 3), and histological characters of ovaries (Fig. 4), spawning of the yellowfin tuna in the western Pacific Ocean (Fig. 1) occurred all the year around with a peak season in February to June.

Length at 50% maturity

The proportion of mature females in each 5 cm length class was fitted to the logistic curve to estimate the L_{50}:

$$P = \frac{1}{1 + \exp\left[-0.2572 \times \left(FL - 107.77\right)\right]} \qquad (r^2 = 0.984\text{；} n = 16)$$

The length at 50% maturity was estimated to be 107.77 ± 1.34 （±95% CI）cm, and the length at 90% maturity was 116.31 ± 1.23（±95% CI）cm（Fig. 5）。

Spawning frequency

Spawning frequency was estimated by postovulatory follicle method for all females, mature females, and females in spawning condition. The mean fraction of all females with postovulatory follicles was 0.55, equivalent to a mean spawning interval of 1.82 days. The mean fraction of mature females with postovulatory follicles was 0.59, equivalent to a mean spawning interval of 1.69 days. The mean fraction of reproductively active females with postovulatory follicles was 0.75, equivalent to a mean spawning interval of 1.33 days. The above results implied that reproductively active yellowfin tuna spawned almost daily.

Also, the spawning frequency was calculated with the hydrated oocyte method for all females, mature females, and females in spawning condition. The mean fraction of all females with migratory-nucleus or hydrated oocytes was 0.37, equivalent to a mean spawning interval of 2.69 days. The mean fraction of mature females with migratory-nucleus or hydrated oocytes was 0.40, equivalent to a mean spawning interval of 2.51 days. The mean fraction of reproductively active females with migratory-nucleus or hydrated oocytes was 0.51, equivalent to a mean spawning interval of 1.97 days. The spawning intervals estimated from the hydrated oocyte method were greater than those by the postovulatory follicle method.

Batch fecundity

Batch fecundity estimated for 149 females ranged between 0.97 and 4.69 million oocytes, with an average of 2.71 million oocytes. There were significant, positive relationships of the batch fecundities (*Y*) to fork lengths (*FL*) （Fig. 6）and to weights (*W*) (Fig. 7) expressed by the following equations :

$$Y = 4.46 \times 10^{-9} FL^{4.16} \qquad (r^2 = 0.52)$$

$$Y = 1.18 \times 10^{-2} W^{1.43} \qquad (r^2 = 0.53)$$

The relative batch fecundities ranged between 31 and 98 oocytes per gram of body weight with an average value of 62.1 oocytes per gram of body weight.

Discussion

Sex ratio

Predominance of males in the size classes of yellowfin tuna larger than 138 cm found in the western Pacific Ocean in this study was fairly similar to that males became predominant at the sizes larger than 130 cm reported from various waters of the Pacific Ocean by other studies (Orange, 1961; Kikawa, 1966; Murphy and Shomura, 1972; Hu, 1972; Lenarz and Zweifel, 1979; Shung, 1980; Sun and Yang, 1983; Yesaki, 1983; Wild, 1986, 1994; Yamanaka, 1990; Suzuki, 1994; Schaefer, 1998). The same phenomenon of male preponderance in larger size classes has been also reported for other tuna species, such as the albacore tuna *Thunnus alalunga* (Wu and Kuo, 1993; Ramon and Bailey, 1996), the bigeye tuna *Thunnus obesus* (Nikaido *et al*., 1991; Chu, 1999), the Atlantic bluefin tuna *Thunnus thynnus* (Clay, 1991).

Spawning season

According to the gonadosomatic indices, mean oocyte diameters and histological analyses obtained in this study, the spawning of yellowfin tuna in the western Pacific Ocean occurred all the year around with a peak season from February to June. Several authors reported that the yellowfin tuna spawns throughout the year in tropical waters, but seasonally in subtropical waters in the western and central Pacific Ocean (Kikawa, 1962; Hu, 1972, Sun and Yang, 1983; Itano, 2000).

Length at sexual maturity

In this study length at 50% maturity was estimated to be 107.77 cm for the yellowfin tuna in the western Pacific Ocean. According to the age-length relationship equation of Su (2003), the average age at the 50% maturity was estimated to be 2.4 years old.

The length at 50% maturity obtained in this study is compared to those estimated from other oceanic regions. Our estimated length of 107.77 cm was larger than 98.1

cm from the Philippines and Indonesia (Itano, 2000). The difference is likely due to different latitudes and oceanic environments; the latter regions have many landmasses and are near to the equator, so that the yellowfin tuna attains sexual maturity sooner. It is suggested that there may be a delay in maturity for the yellowfin tuna in higher latitudes (lower sea surface temperatures) (Itano, 2000).

In the eastern Pacific Ocean, Schaefer (1998) estimated the length at 50% maturity of the yellowfin tuna to be at 92.1 cm which was significantly shorter than 107 cm of this study and 107 to 120 cm from the central and western Pacific Oceans (McPherson, 1991; Itano, 2000). The female yellowfin tuna in the eastern Pacific attain sexual maturity sooner than those in the central and western Pacific Ocean.

Spawning frequency

In this study the spawning frequency was estimated at an interval of 1.33 days by the postovulatory follicles method and at 1.97 days by the hydrated oocyte method for reproductively active yellowfin tuna in the western Pacific Ocean. This is a mean spawning frequency for the reproductively active females in the population during the spawning period, and does not imply that an individual fish spawns at this rate throughout the year. During the peak spawning season in the months of February to June, 71.1% of the mature fish sampled was found to be actively spawning, equivalent to a spawning interval of 1.4 days estimated in this study. On the other hand, only 48.7% of the mature fish were actively spawning in the remaining months of July to January. Apparently, female yellowfin tunas progress rapidly to a spawning condition with fully yolked oocytes, so that majority of the reproductively active fish are in a daily or near-daily spawning mode.

Spawning intervals of the yellowfin tuna have been estimated with the hydrated oocyte method to be 1.7 days in the western pacific (Nikaido, 1988), 1.54 days in the Australian Coral Sea (McPherson, 1991), 1.27 days in the eastern tropical Pacific near Clipperton Atoll (Schaefer, 1996), 1.52 days in the eastern Pacific (Schaefer, 1998), and 1.99 days in the western tropical Pacific (Itano, 2000). For other tuna species, the fairly similar spawning intervals have been reported: 1.18 days for skipjack tuna (Hunter *et al*., 1986); 1.11 days and 1.05 days for bigeye tuna (Nikaido et al., 1991； Chu, 1999); 1.61 days for southern bluefin tuna (Farley and Davis, 1998) and 1.02 days for northern bluefin tuna (Medina *et al*., 2002).

Batch fecundity

Hunter *et al*. (1985) reported that the minimum number of females needed for a reliable batch fecundity estimate was 50. In our study, we provided 149 yellowfin tuna ovaries with unovulated hydrated oocytes from the region to estimate batch fecundity with a range between 0.97 million and 4.69 million oocytes with a mean value of 2.71 million oocytes.

The batch fecundity of 2.71 million oocytes obtained from this study was significantly higher than that 1.57 million oocytes obtained by Schaefer (1996), perhaps due to the difference in the length frequency distribution of samples between the two studies; However, the batch fecundity obtained in this study was lower than that 3.45 million oocytes of Itano (2000), perhaps due to small set of data with high variability for the latter, particularly to two fish with very low fecundity and one with very high fecundity. When these three fish were excluded in the estimation, Itano's (2000) mean batch fecundity was similar to that of our study.

The differences in the estimates of batch fecundity by different authors might be resulted from factors other than the methodological differences alone.

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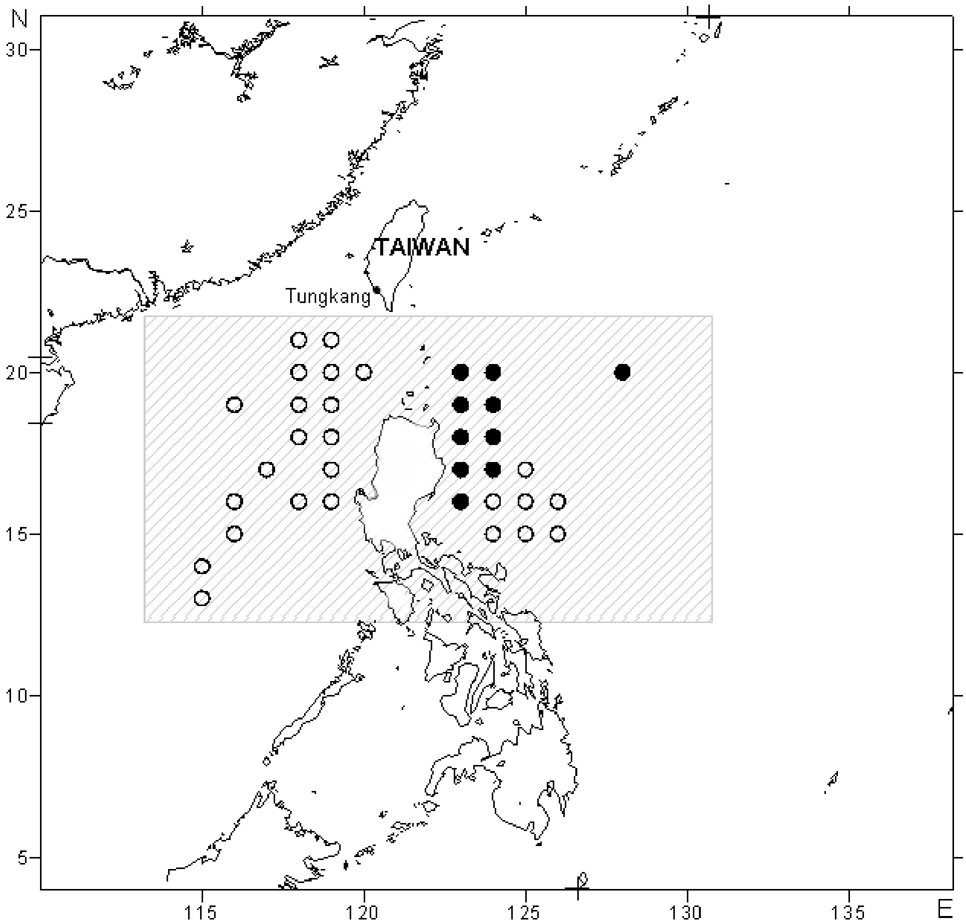

Fig. 1. The fishing ground (shaded area) of Taiwanese offshore tuna longline fishery and the fishing sites (solid circles, during April to July; open circles, August to March) of the yellowfin tuna *Thunnus albacares* sampled in this study.

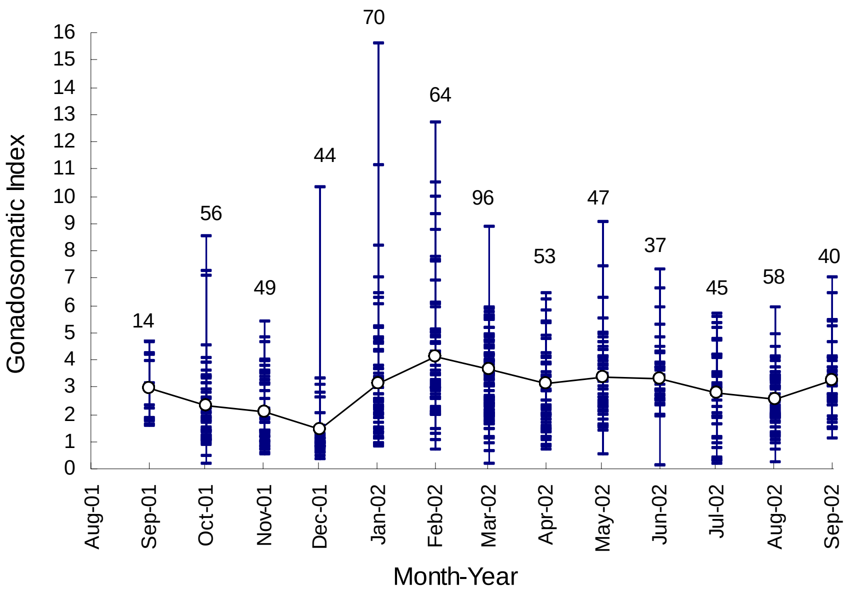

Fig. 2. Monthly variation in mean gonadosomatic indices of the female yellowfin tuna *Thunnus albacares* in the western Pacific Ocean, September 2001 to September 2002 (open circles with connecting line, averages; vertical bars, ranges; short horizontal bars on the vertical lines, individual measurements; numbers above vertical bars, sample sizes).

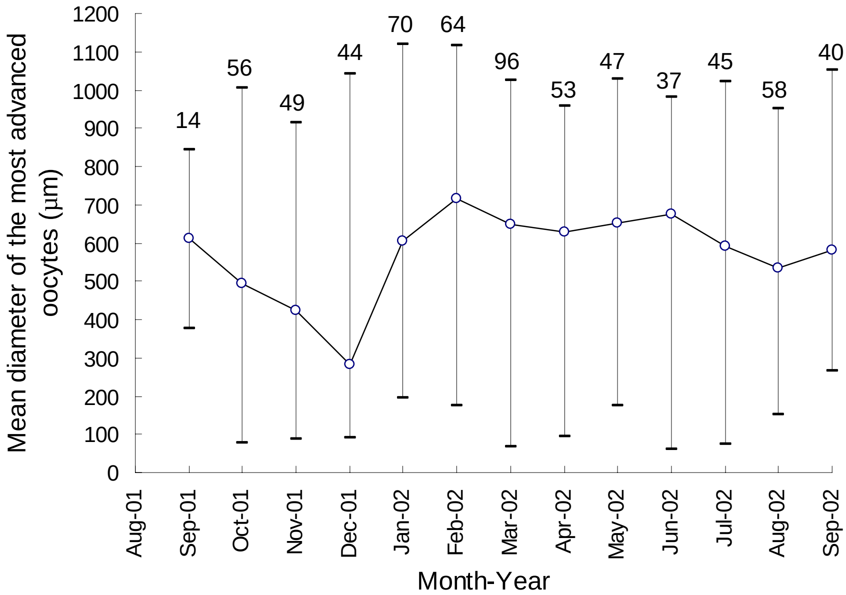

Fig. 3. Monthly variation in mean diameters of the most advanced oocytes of the female yellowfin tuna *Thunnus albacares* in the western Pacific Ocean, September 2001 to September 2002 (open circles with connecting line, averages; vertical bars, ranges; numbers above vertical bars, sample sizes).

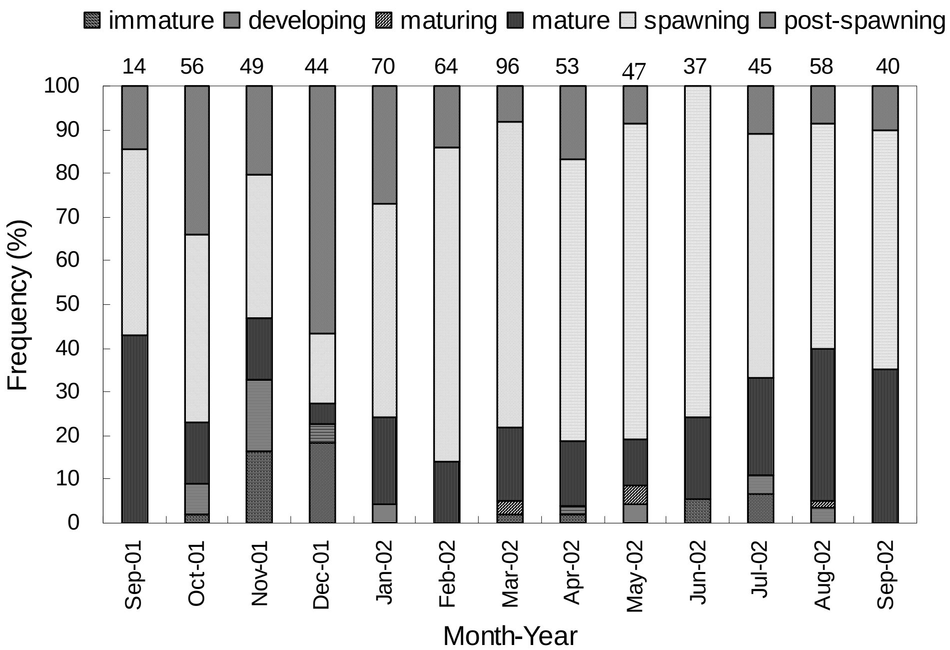

Fig. 4. Monthly percentage frequency of the ovarian stages of the female yellowfin tuna *Thunnus albacares* in the western Pacific Ocean, September 2001 to September 2002 (numbers above vertical bars, sample sizes).

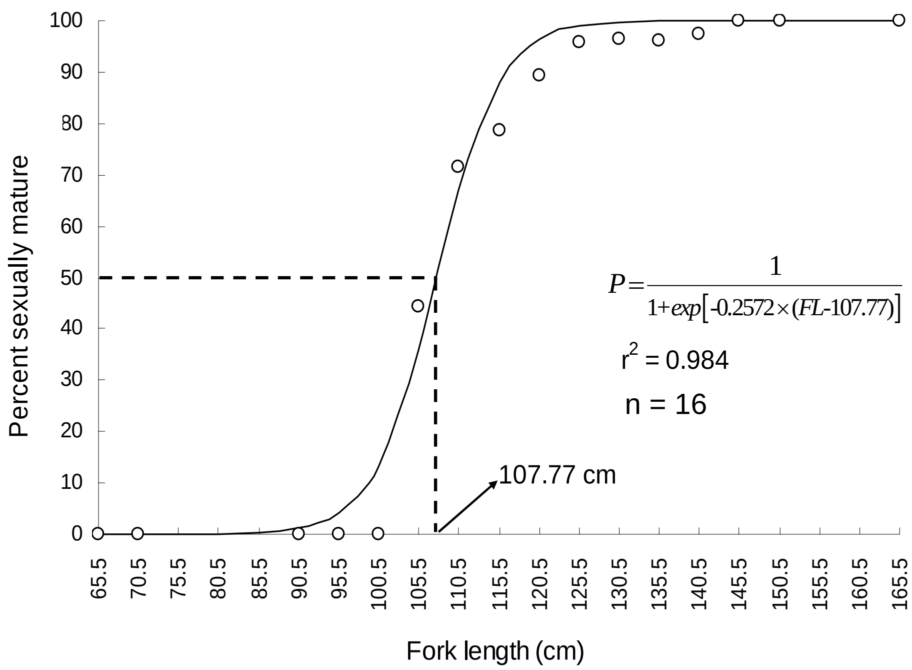

Fig. 5. Relationship between percentages of mature individuals and the length classes at 5-cm intervals of the female yellowfin tuna *Thunnus albacares* in the western Pacific Ocean.

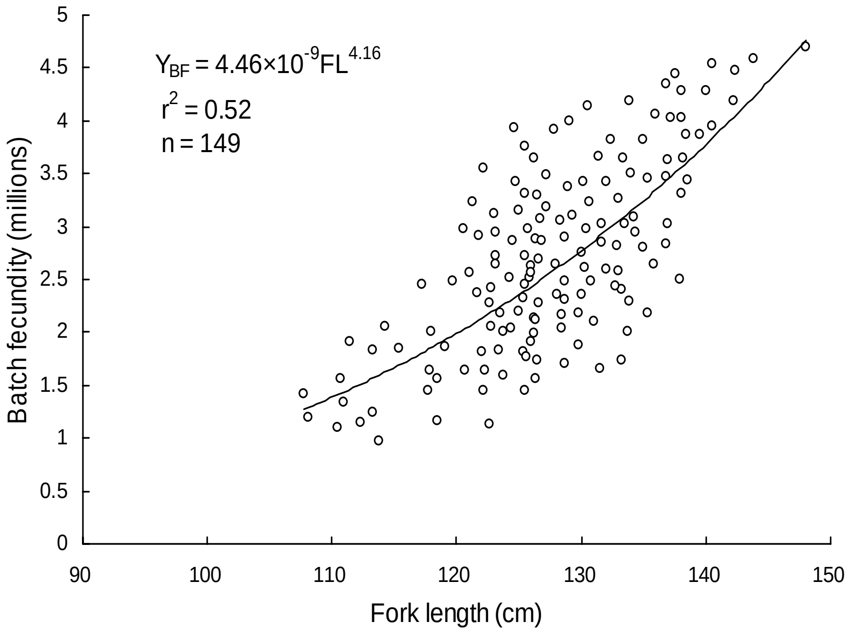

Fig. 6. Relationship between batch fecundity and fork length for the yellowfin tuna *Thunnus albacares* in the western Pacific Ocean.

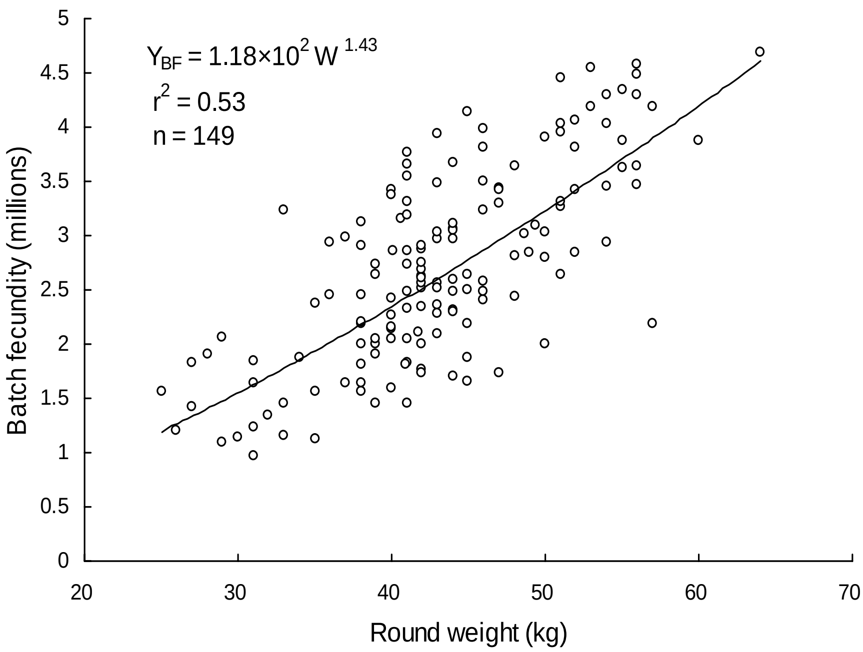

Fig. 7. Relationship between batch fecundity and round weight for the yellowfin tuna *Thunnus albacares* in the western Pacific Ocean.