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# Estimate of the Age and Growth Parameters for North Pacific Bluefin Tuna (*Thunnus thynnus*)

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## ABSTRACT

The spawning stock of North Pacific bluefin tuna (*Thunnus thynnus*) is caught by Taiwanese offshore longliners in the waters off eastern Taiwan every year between April and July. The catch of North Pacific bluefin tuna by Taiwanese longliners reached a historic high of 3089 metric tons in 1999, which exceeded that of the US, but was less than that of Japan. The fork lengths of our specimens ranged from 160 to 270 cm, and eviscerated weights were between 80 and 300 kg. The annual frequency distribution of eviscerated weight fluctuates somewhat. Scales from 228 fish were sampled for age determination, but only 133 which ranged from 204 to 255 cm fork length were readable. Under the assumption that one ring forms each year, the corresponding ages of the specimens were from 8 to 13 years. No significant linear relationship was found between fork length and scale radius. However, the greater number of rings which appeared in the scales, the bigger the fish was. The von Bertalanffy growth equation for the spawning stock of North Pacific bluefin tuna sexes combined was $L_t = 366.681 \times (1-e^{-0.086\times(t+0.926)})$, as derived from the ageing results.

**Key words:** North Pacific Ocean, bluefin tuna, *Thunnus thynnus*, age, growth

## INTRODUCTION

Bluefin tuna, *Thunnus thynnus*, the largest species in the Scombridae, can grow to over 300 cm in fork length, and over 550 kg in weight (Collette and Nauen, 1983). Usually two subspecies are observed, *T. thynnus thynnus* in the Atlantic Ocean and Mediterranean Sea and *T. thynnus orientalis* in the North Pacific Ocean.

The North Pacific bluefin tuna is a highly migratory species. Between April and July, it migrates to the western central Pacific Ocean near the waters off northeastern Philippines, eastern Taiwan, the Ryukyu Islands, southern Kyushu, and the Sea of Japan for spawning (Kishinouye, 1923). It has become the essential seasonal target for the Taiwanese small-scale longline fleet in the southwestern North Pacific; the fishing ground is in the waters off eastern Taiwan (Fig. 1) (Anon, 2002). In addition, the bluefin is mainly caught by Japan, the US, and Korea using longlines, purse seines, pole and lines, gillnets, and trolling. The annual catch for all countries together ranged from 6,000 to 27,000 metric tons (mt) during the period of 1970~2000 (Fig. 2) (FAO, 2002).

Ageing studies have been pursued for North Pacific bluefin tuna by annulus reading of the scales (Yukinawa and Yabuta, 1967), by length frequency progression (Yokota *et al.*, 1961), and by tag-recapture methods (Anon, 1985). Yukinawa and Yabuta (1967) used scale annulus readings to

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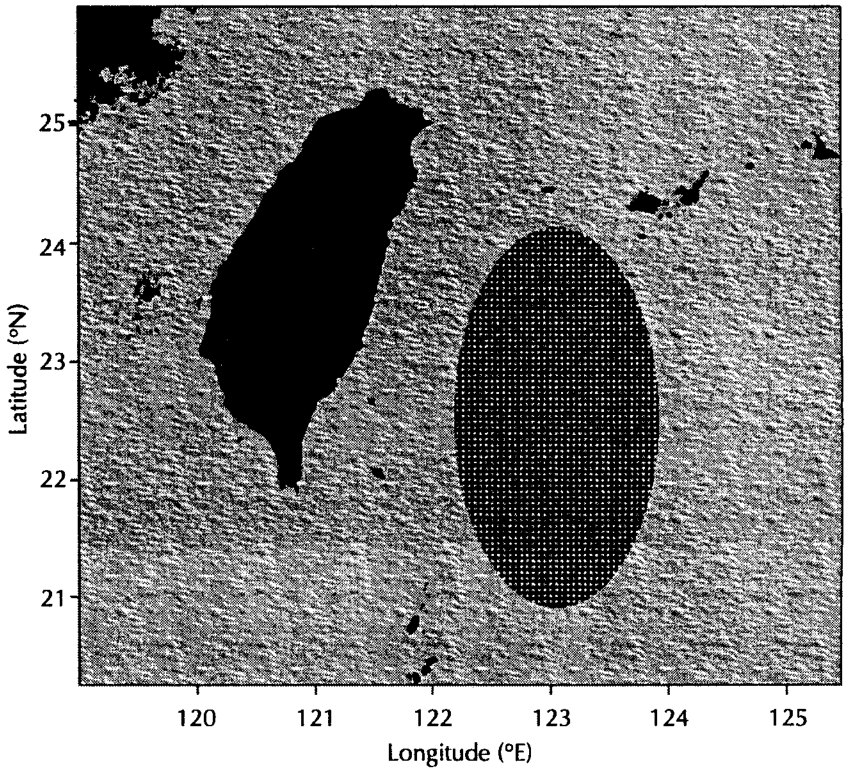


**Fig. 1** Map showing the fishing grounds of Taiwanese offshore longliners for North Pacific bluefin tuna.

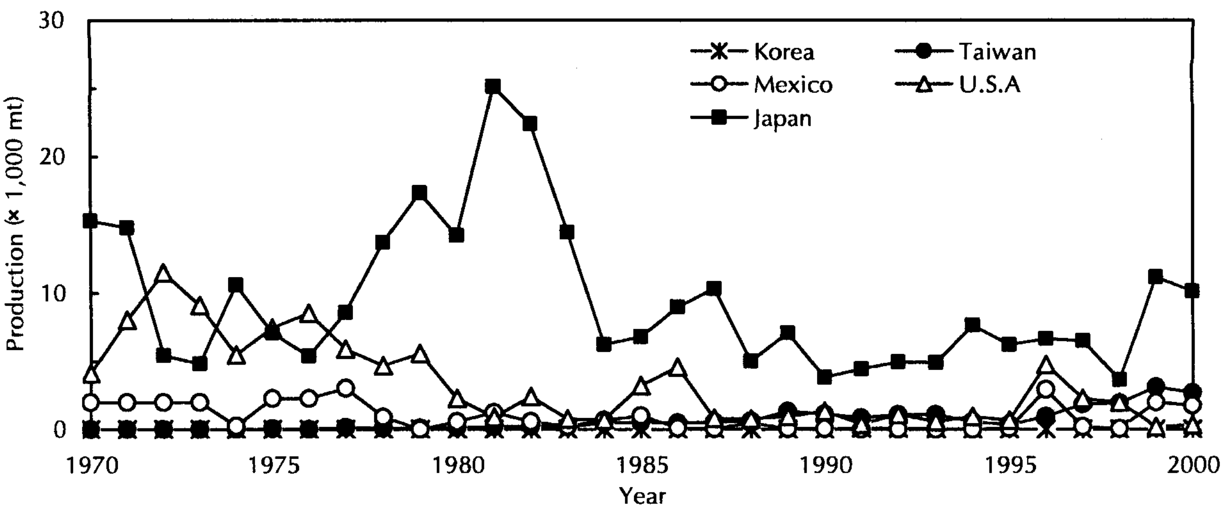


**Fig. 2** Annual production of North Pacific bluefin tuna by country, 1970~2000.

estimate the von Bertalanffy growth equation, and small fish with a length modal of between 50 and 70 cm obtained from trolls and pole and lines were predominant. On the other hand, released tagged fish were 49 ~ 54 cm in fork length and grew to 140 cm in fork length after 3 ~ 4 year (Anon, 1985). Thus, both studies (Yukinawa and Yabuta, 1967; Anon, 1985) seemed to age juvenile fish, and the study by Bayliff *et al.* (1991) using length frequency progression was necessarily validated by the hard parts of the fish. Previous studies on the age and growth of the North Pacific bluefin tuna lacked mature samples, and thus, it has been difficult to understand growth patterns especially for mature sizes of North Pacific bluefin tuna.

Therefore, the objective of this study was to estimate the von Bertalanffy growth parameters of North Pacific bluefin tuna with scale annulus readings obtained from breeding stock caught by the Taiwanese small-scale longline fleet operating in the southwestern North Pacific (the waters off the northeastern Philippines and eastern Taiwan).

## MATERIALS AND METHODS

### *1. Sample collection*

In total, 228 North Pacific bluefin tuna were collected from the Tungkang (southern Taiwan) and Suao (northeastern Taiwan) fish markets from May to June 2001. These specimens were caught by the Taiwanese small-scale longline fleet operating in the southwestern North Pacific. For each specimen, 15 scales were taken between the second dorsal fin and lateral line following Yukinawa and Yabuta's (1967) method, and fork length and eviscerated weight were measured.

Scales collected were brought to the laboratory and immersed in a detergent solution for 4 ~ 5 h, then the fingertip was used to clean and completely remove the attached lipids and detritus. Following a rinse in tap water and drying in a dark place, a likely complete and uniformly shaped scale was selected, bound between two slides, and numbered for study.

Scales of finfish can be divided into an overlapping region and a free region (Sire, 1986; Lai *et al.*, 1996). A part of the overlapping region merges into the dermis; its annuli are clear and observable, and are the appropriate scales which can be used for annulus reading and measurement. However, the free region is covered by a thin dermis and epidermis, and the scales are exposed outside the body; those scales show irregular annuli and may be inappropriate for ageing (Sire, 1986). The scales of bluefin tuna are cycloid. Growth lines on the scales exhibit a centric arrangement, and the annuli were determined based on the interruption, density, and convergence of growth lines (Fig. 3, Yang *et al.*, 1969; Suzuki, 1974).

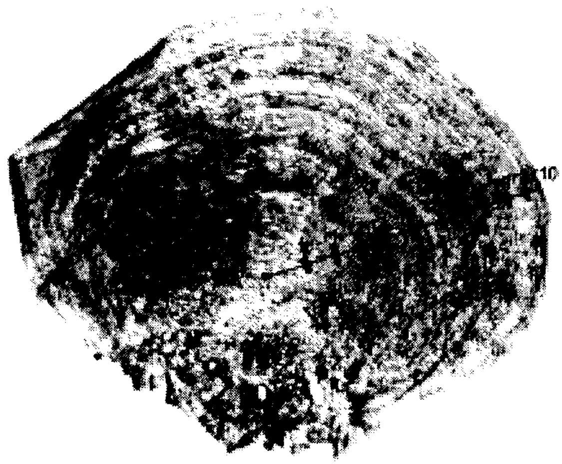


**Fig. 3** Photograph showing the measurement axis and corresponding rings ($r_i$) from the scale of a North Pacific bluefin tuna (with fork length of 229 cm and a eviscerated weight of 206 kg). Its age was 10 years, and first ring was considered to be a fry check (fc).

### *2. Effective ageing character*

According to the results of Yukinawa and Yabuta's study (1968), scale rings of North Pacific bluefin tuna are formed annually, and the linear relationship between the scale radius and fork length is significant; this suggests that the scale is a useful character to represent the growth of North Pacific bluefin tuna.

### *3. Annulus determination and reading*

Before the rings were measured, a photograph of the scale was taken. Eventually, the scale radius from 133 bluefin tuna with fork lengths of 204~255 cm was measured by a transect 45° line through the focus.

### *4. Analysis of growth*

Step 1: The fork length of each annulus formation was estimated by the expression:

$$L_n = \frac{L \times r_n}{R} \qquad (1)$$

where $L_n$ is the estimated fork length of the n$^{th}$ annulus formation; $L$ is the fork length, and $R$ is the scale radius.

Step 2: The back-calculation fork length was estimated as:

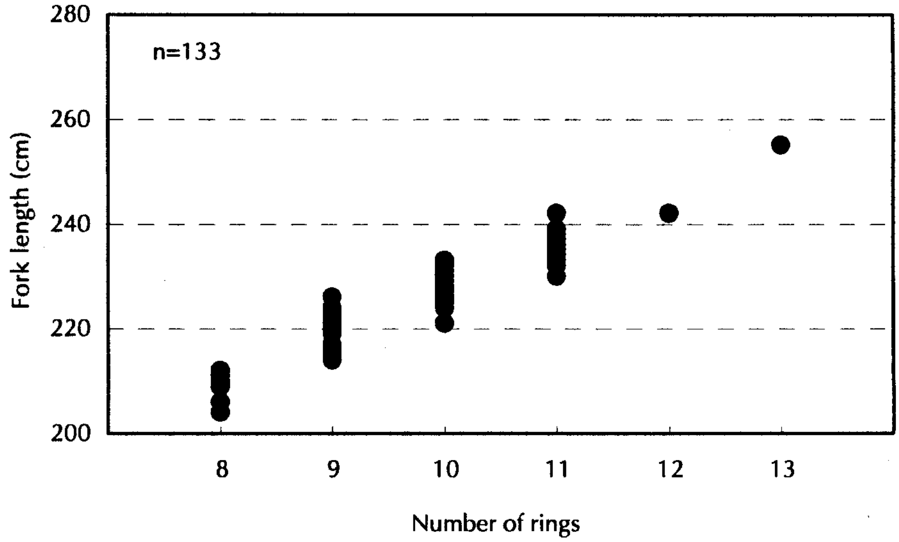


**Fig. 4** Length frequency distribution by scale ring group of North Pacific bluefin tuna. Note that the fry check was excluded from the count.

$$\overline{L}_j = \frac{1}{n}\sum_{i=1}^{n} L_{ji} \qquad (2)$$

where $\overline{L}_j$ is the average back-calculation fork length of the $j^{th}$ ring group, $n$ is the number of observations, and $i$ and $j$ are the index variables.

Step 3: Estimation of the von Bertalanffy growth equation:

The von Bertalanffy growth equation (von Bertalanffy, 1938) is represented by

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right) \qquad (3)$$

where $L_t$ is the fork length at time $t$; $L_\infty$ is the asymptotic length as the age approaches $\infty$; $K$ is the intrinsic growth rate, and $t_0$ is the theoretical age as the fork length approaches 0.

Several methods can be used to estimate $L_\infty$ and $K$, among which, the Ford-Walford plot (Gulland, 1969) is the traditional one used most frequently. The value, $t_0$, can be estimated by solving the von Bertalanffy growth equation for $t_0$ when $L_\infty$ and $K$ are known.

## RESULTS AND DISCUSSION

### *1. Scale selection*

Growth parameters are the most important population parameters for fish stock assessment (Beverton and Holt, 1957). Annulus readings of otoliths, scales, spines, and vertebrae are often used for the age determination of tuna (Casselman, 1983). There are advantages and disadvantages of using each of these ageing characters (Beamish and McFarlane, 1983). Among these, scales are not the best due to a high proportion of regenerate scales (Huang *et al.*, 1990). Although spines are easily obtained, they always lose focus in old age, and pseudo-annuli always occur with spines (González-Garcés and Fariña-perez, 1983). The relationship between fork length and ring groups indicates that fork length increases as the ring group increases (Fig. 4). The annulus diameter distribution within ring groups was similar and showed discrepancies between ring groups (Fig. 5). However, when the number of rings exceeded seven, annuli were less evident. The proportion of scale annuli decreases in accordance with an increase in the fork length (Yukinawa and Yabuta, 1976). Lai (1985) concluded that for most fish, the growth rate is significantly reduced after maturity, and the spacing between adjacent circuli of scales is too narrow to identify the annulus.

### *2. Relationship between scale radius and fork length*

In the present study, no significant linear relationship between the scale radius and fork length was found (Fig. 6). Probably this was due to a narrow range of fork lengths existing in these samples (ranging from 204 to 255 cm), and because immature fish were not included. A similar result was found in a study of Yukinawa and Yabuta (1967). In that study, the fork length of the samples ranged from 50 to 200 cm. However, three fish-length groups, which centered around 50, 110, and 190 cm, respectively were evident. For each fork length group, insignificant relations between scale radii and fork lengths were observed, while a significant linear relation was noted for the entire sample.

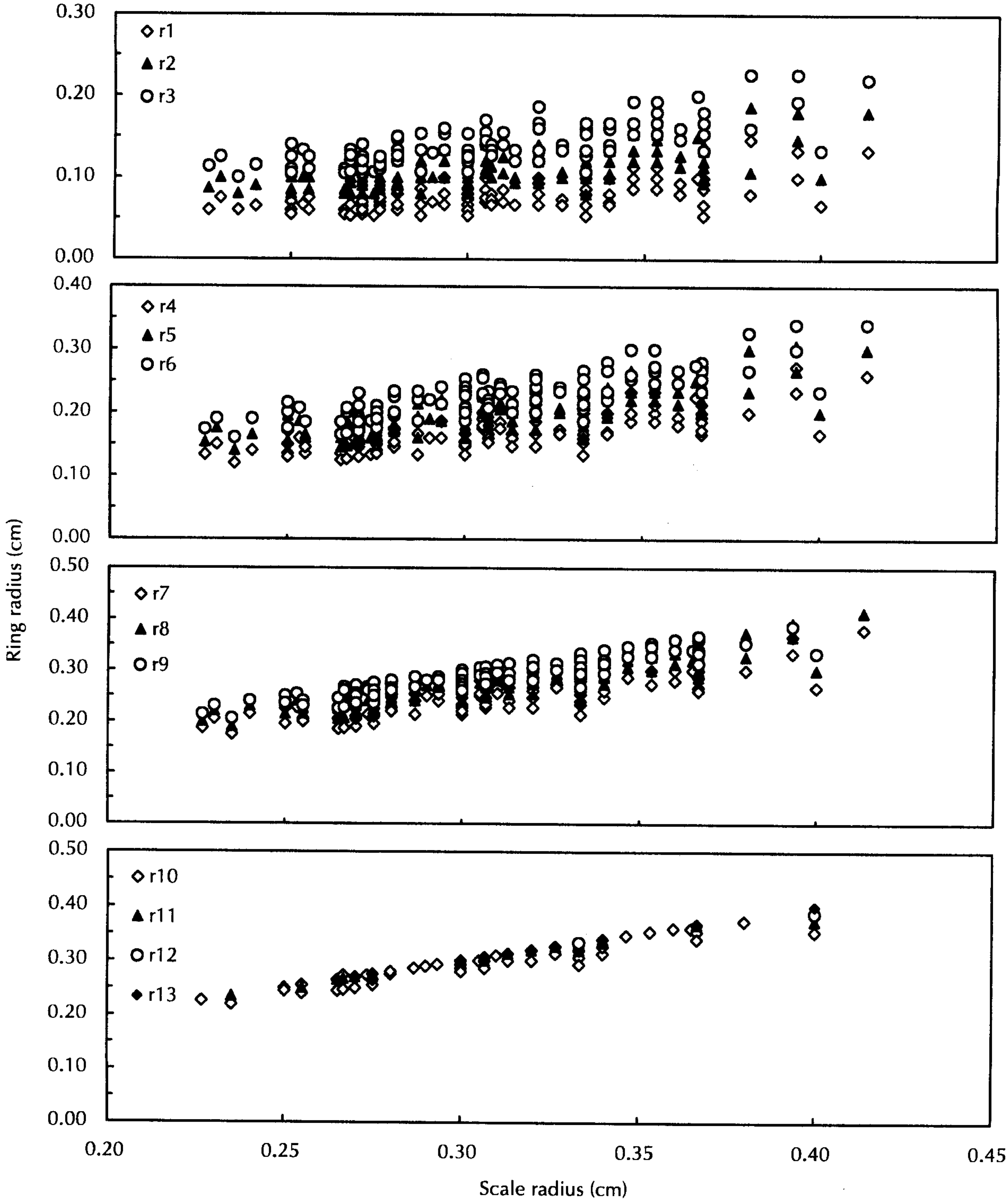


**Fig. 5** Plot of ring radius vs. scale radius from North Pacific bluefin tuna caught by Taiwanese offshore longliners.

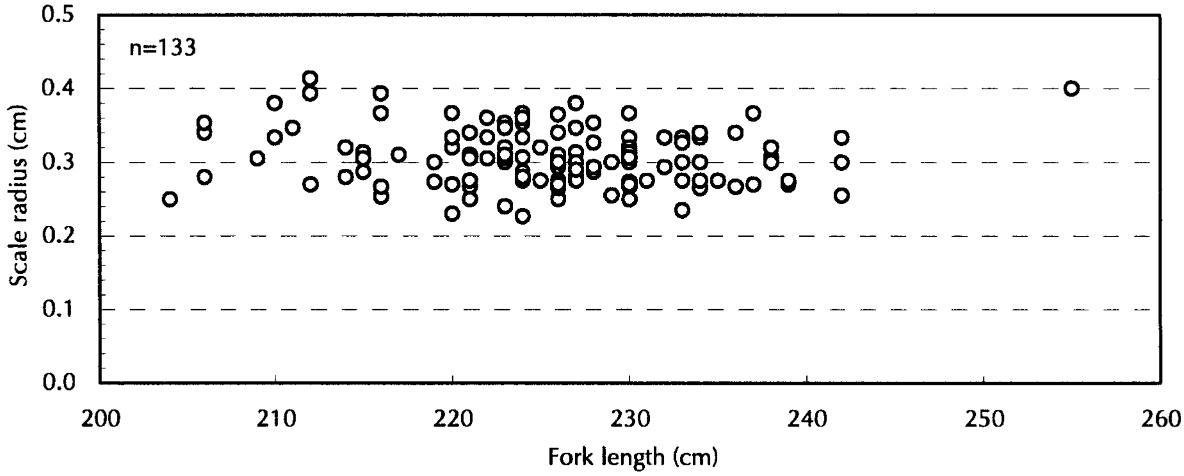


**Fig. 6** Relationship between fork length and scale radius of North Pacific bluefin tuna.

**Table 1** Back-calculation of the length at the time of scale ring formation for North Pacific bluefin tuna caught by Taiwanese offshore longliners

| $r_n$ | No. of observations | Mean radius (mm) | *Ln* (cm) |
|---|---|---|---|
| $r_1$ | 133 | 0.744 | 54.6 |
| $r_2$ | 133 | 1.066 | 78.2 |
| $r_3$ | 133 | 1.379 | 101.2 |
| $r_4$ | 133 | 1.679 | 123.2 |
| $r_5$ | 133 | 1.966 | 144.3 |
| $r_6$ | 133 | 2.240 | 164.3 |
| $r_7$ | 133 | 2.495 | 183.1 |
| $r_8$ | 133 | 2.730 | 200.3 |
| $r_9$ | 121 | 2.885 | 215.1 |
| $r_{10}$ | 74 | 2.949 | 225.1 |
| $r_{11}$ | 27 | 3.051 | 234.7 |
| $r_{12}$ | 2 | 3.600 | 244.3 |
| $r_{13}$ | 1 | 4.000 | 255.0 |

Remarks: $L_n = \frac{L \times r_n}{R}$; *R*, scale radius; $r_n$, ring radius; *L*, fork length.

### *3. Time for ring formation*

Figure 3 is a photo of a bluefin tuna scale which was sampled from the area between the second dorsal fin and lateral line. Because the fish migrate to waters adjacent to Taiwan only in the period of April to July, it is difficult to collect scale samples all year round to determine the timing of ring formation. However, examination of the scale's margin under a microscope showed that the annulus is newly formed. Yukinawa and Yabuta (1967) also demonstrated that a ring is formed each year, and the time of ring formation occurs in April each year based on the monthly variation in the scale's marginal increment.

### *4. Back-calculation of fork length when a ring forms and the von Bertalanffy growth curve*

Results obtained from 133 bluefin tuna with fork lengths ranging 204~255 cm indicated that the

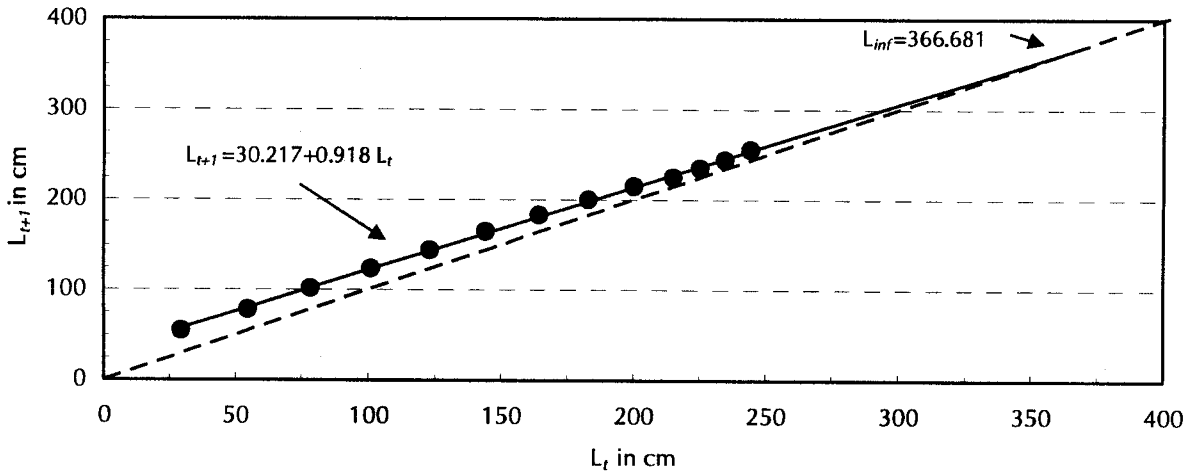


**Fig. 7** Back-calculated lengths plotted by Walford's (1946) method.

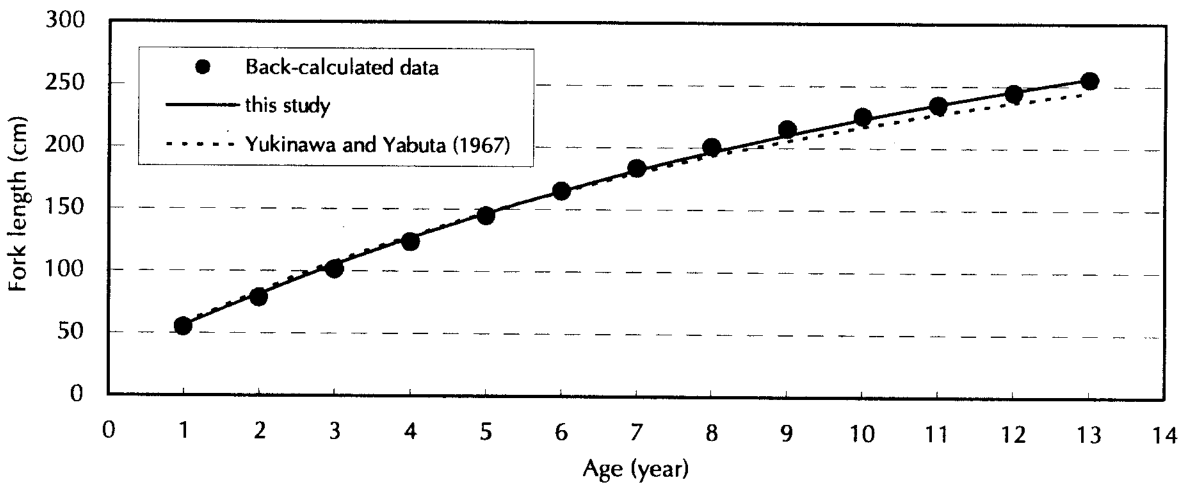


**Fig. 8** von Bertalanffy growth curves for North Pacific bluefin tuna derived from this study and from Yukinawa and Yabuta (1967).

numbers of rings clearly ranged from 8 to 13, and we estimated that those fish were 8~13 years old. However, there was a 0.4-mm ring located just outside the focus. According to the relationship between ring radius and fork length, if this ring was the ring representing 1 year old, then the fork length for this 1 year old fish was only 29.36 cm on average, which is far smaller than a previous estimation of 50 cm (Aikawa and Kato, 1938; Yokota *et al.*, 1961; Bell 1963; Yukinawa and Yabuta, 1967; Schultze and Collins, 1977). Therefore, we suspected this ring may be a "fry check" (Carander, 1974) or a larval mark (Tandon and Johal, 1996), which results from a feeding size change by the fry.

Table 1 shows the back-calculated results obtained from the relationship between ring radius and fork length. Accordingly, by the back-calculation, the relationship between $L_{t+1}$ and $L_t$ is $L_{t+1} = 30.217 + 0.918\, L_t$ (Fig. 7).

Consequently, the intrinsic growth rate is estimated from the slope (0.918) as 0.0860/year and the asymptotic length ($L_\infty$), interpreted as the mean length of infinitely old fish (Sparre *et al.*, 1989), is 366.68 cm fork length. Then, $t_0$ was estimated to be -0.926 years. The maximum fork length of northern bluefin tuna exceeds 300 cm (Collette and Nauen, 1983). Hsu *et al.* (2000) reported that the largest size of a Pacific bluefin tuna in their samples was 290 cm.

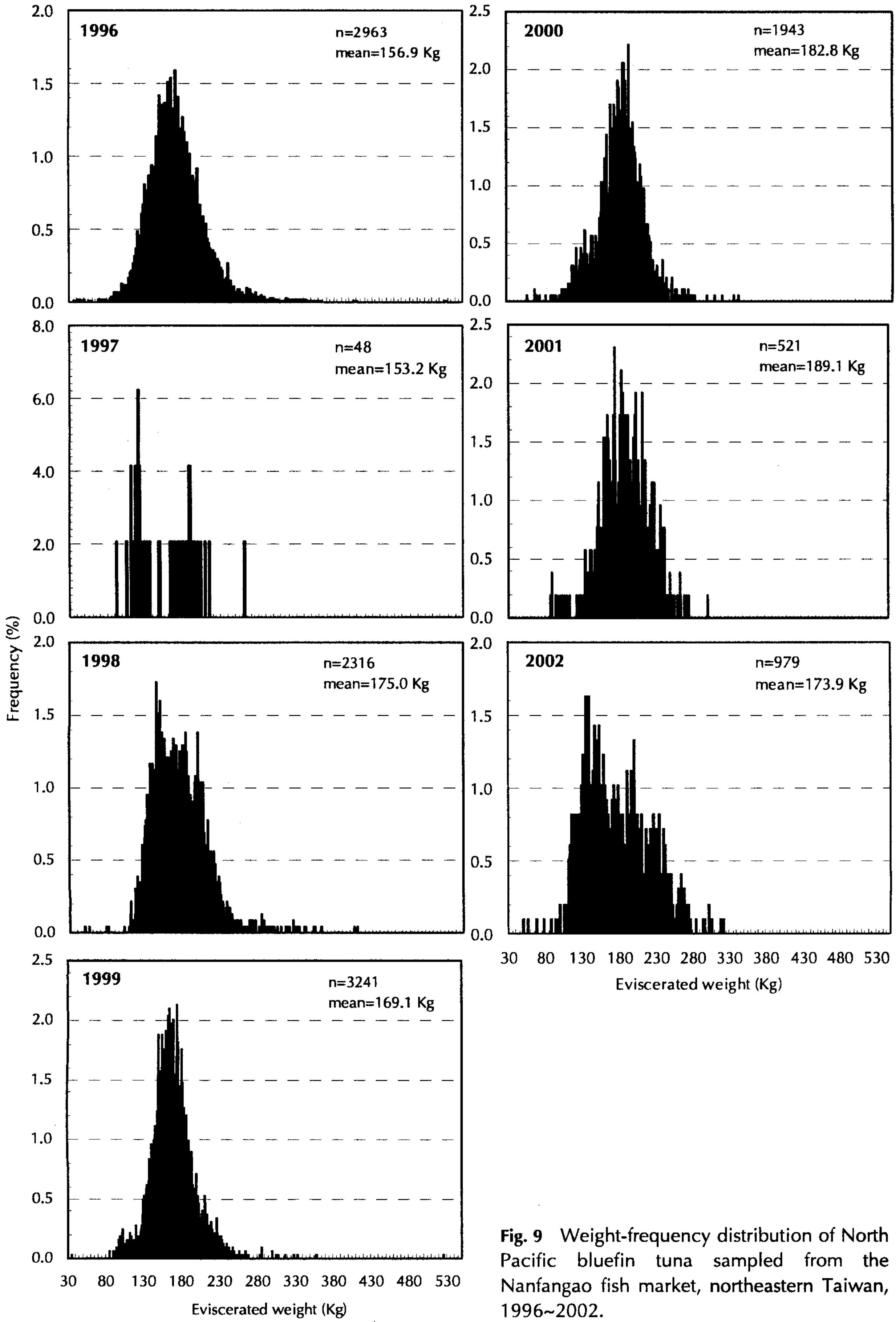


**Fig. 9** Weight-frequency distribution of North Pacific bluefin tuna sampled from the Nanfangao fish market, northeastern Taiwan, 1996~2002.

The $L_\infty$ derived in our studies is somewhat greater than the observed fork length. Figure 8 illustrates the comparison between von Bertalanffy's growth rates obtained by Yukinawa and Yabuta (1967) and by the present study. Both growth curves show that there appear to be discrepancies from about age 7 (183 cm in fork length), and they seem larger than what was obtained in the present study.

### *5. Variation of annual landing sizes*

Figure 9 illustrates the weight distribution of landings at Nanfangao fishing port from 1996 to 2002, indicating that the eviscerated weight of landed bluefin tuna showed a single mode of from 60 to 410 kg (with the majority between 80 and 300 kg) equivalent to 155~295 cm in fork length (by the following equation: $Wt = 0.000023058Fl^{2.9342}$; which was estimated by Hsu *et al.*, 2000). In addition to the distribution in 1997 with few samples, the size distribution varied yearly. Among those values, the smallest mean weight occurred in 1996 at about 157 kg (equivalent to 8 years old), and the largest values were found in 2000 and 2001 at about 183 and 189 kg, respectively (10~11 years old).

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# 北太平洋黑鮪成長參數的估計

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## 摘要

於每年四月至七月間，北太平洋黑鮪洄游至中西太平洋海域產卵，並為我國近海鮪延繩釣漁船所捕獲。而我國於 1999 年的太平洋黑鮪產量 3089 mt，創歷史高量，已超過美國僅次日本。經由分析 1996 年至 2002 年宜蘭縣南方澳籍漁船所漁獲的黑鮪體長、體重等資料顯示，黑鮪尾叉長主要分布範圍在 160 ~ 270 cm，體重（去內臟）在 80 ~ 300 kg 間，而年別間的體重頻度分布呈現變動。於 2001 年 5 月至 6 月間，至東港、蘇澳等魚市場採集 228 尾黑鮪左側第二背鰭下方至側線部位的鱗片進行輪紋判讀，其中僅有 133 尾體長分布為 204 ~ 255 cm 的黑鮪鱗片可以判讀。基於黑鮪鱗片輪紋一年形成一紋的假設，推估樣本魚的年齡分布為 8 ~ 13 齡。尾叉長和鱗片半徑的線性關係不顯著，惟隨著鱗片輪紋數增加，魚體呈現增長。以鱗片為年齡形質推估太平洋黑鮪產卵群的成長方程式為：$L_t = 366.681 \times (1 - e^{-0.086\times(t + 0.926)})$。

關鍵詞：北太平洋、黑鮪、年齡、成長

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