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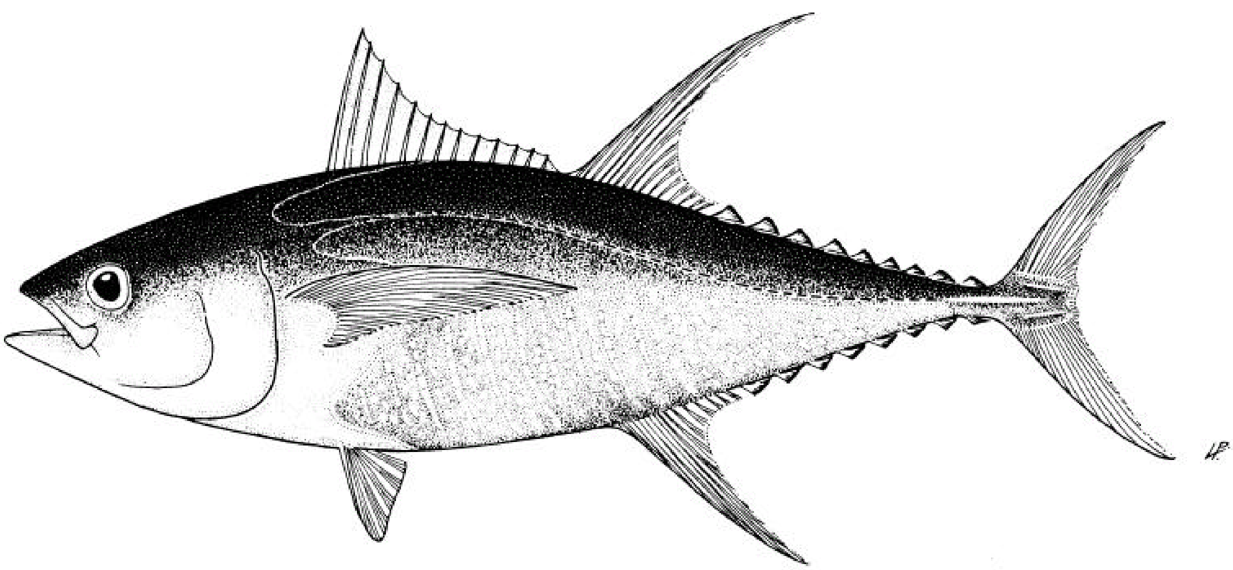
Growth of yellowfin tuna (*Thunnus albacares*) in the equatorial western Pacific Ocean



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Growth of yellowfin tuna (*Thunnus albacares*) in the equatorial western Pacific Ocean [1]

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Abstract

Monthly weight frequency distributions of yellowfin tuna (*Thunnus albacares*) landed by Taiwanese and Japanese coastal longliners in the Guam fresh tuna transshipment fishery were used in a mode progression analysis. The objective of this study was to investigate inter-annual variations in the parameters (K, L_∞, and recruitment age, r) in the von Bertalanffy model. Nine year classes (1989-2000) were tracked for 4-5 years. Recruitment occurred in the autumn and winter. The growth parameter, K, exhibited a low of 0.334 in 1993, but for the other years ranged from 0.511- 0.775, with an overall mean of 0.612 per year. L_∞ ranged from 152.5 - 173.1 cm fork length (FL). Age at the size of 100 cm FL ranged from 0.67 - 2.5 years, with an average of 1.28 years.

Introduction

Age and growth of yellowfin tuna (*Thunnus albacares*) in the Pacific Ocean has been studied for more than five decades by several different methods and with mixed results. Moore (1951) examined weight frequencies from two year classes of yellowfin tuna caught around the Hawaiian Islands to obtain a pooled estimate of the growth rate. Yabuta and Yukinawa (1959) tracked six year classes through mode analysis and reported alternating high and low growth year classes. Yabuta et al. (1960) aged longline-caught yellowfin tuna from scales and estimated the growth and asymptotic size parameters to von Bertalanffy (VB) model to be 0.33 per year and 190 cm fork length (FL), respectively. Other studies of yellowfin tuna growth based on the use of otoliths included Uchiyama and Struhsaker (1980) and Wild (1986). The former

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concluded that yellowfin tuna caught in the central Pacific were described by the VB parameters of L_∞ at 170 cm FL and *K* of 0.386; the latter determined that those caught in the eastern Pacific could be described by 188 cm FL asymptotic size and a 0.724 value for *K*.

Juvenile and adult yellowfin tuna exhibit wide latitudinal distribution throughout the tropical and temperate waters of the Pacific Ocean. The juveniles are found from about 30°N to 20°S (Higgins, 1967), whereas the adults occur from 40°N to 40°S in the western Pacific but with a narrower latitudinal range in the central Pacific (Suzuki, 1994). Juvenile and adults support several widely distributed fisheries; small yellowfin are commonly taken by artisanal, commercial pole-and-line, and purse seine fishermen, whereas the longline fishery takes larger and more valuable fish for the sashimi market.

In this study size frequency distributions of yellowfin tuna from 1989 to 2000 were analyzed through mode progression. Nine year classes or cohorts were identified and tracked from time of recruitment to near asymptotic size. Monthly size frequency distributions were developed from the landings of Taiwanese and Japanese longliners in Guam, which has become a major port for transshipment of fresh fish to Japan. Growth and time of hatching were determined through a modified VB growth model. This paper describes inter-annual variation in growth rates of yellowfin tuna from waters south of Guam in the Pacific Ocean.

Materials and Methods

The island of Guam since 1986 has become a major port for the Japanese coastal and Taiwanese offshore longliners that fish in the equatorial western Pacific (2-5°N latitude and 140-160°E longitude) (Fig. 1) and transship fresh fish to Japan. Most of the effort is centered directly south of Guam between the territorial waters of the Federated States of Micronesia and Papua New Guinea. Effort was determined as the number of offloading trips to the island of Guam.

The Guam Department of Commerce began a distant-water fishery monitoring program in late 1988 to determine the quantities of fish caught by small Japanese and Taiwanese longline vessels that were then offloaded and transshipped fresh to Japan. Fish were landed gilled and gutted, and individually weighed and graded for sashimi quality. Pooled percent weight frequency distributions were developed each month from the Taiwanese and Japanese yellowfin tuna landings from 1989 to 2000.

Nine year classes were tracked for 4 or 5 years from entry into the fishery until the modes overlapped and became indistinguishable (Fig. 2). Each of the year classes, the year of recruitment was used to assign year class; i.e., the yellowfin recruited 1989 was designated as the 1989 year class. Annual recruitment was assumed to occur as a single, discrete seasonal pulse (see Results, below) and each recruitment mode was assumed to be distributed normally. The technique of MacDonald and Pitcher (1979) for the distribution mixture model was used to define the modes by their means, standard deviations, and relative probabilities. A distribution fitting routine was used to describe the parameters of the individual modes (Somerton and Kikkawa, 1992).

Monthly weights-at-age were first converted to live weight and subsequently to FL's-at-age using conversion factors provided by Morita (1973), and Kamimura and Honma (1959), respectively, for yellowfin tuna from west of 170°E. Because this mode progression analysis was based on relative age (i.e., age relative to the time of recruitment) the VB growth model was modified by including an adjustment factor "*r*" for recruitment age to converting relative to real age. The modified model, VB', was:

$$L_t = L_\infty (1 - e^{-k((t+r)-t_0)});$$

where L_t = the length at age t,
L_∞ = the asymptotic size,
K = the growth constant,
t = the relative age,
t_0 = the age at length zero, and
r = the recruitment age .

During preliminary analyses with parameter values unrestricted, the model failed to converge on reasonable estimates of r and t_0. Therefore it was necessary to constrain one of the parameters in the modified VB growth model (VB'). Consequently, t_0 was determined algebraically (Lopez Veiga, 1979) from known hatching size of 2.3 mm (Mori et al., 1971). The data were again fitted to the VB' with a known t_0 to predict l_∞, K, and r.

Results

Both the total numbers and tonnage of yellowfin tuna landed in Guam were highly correlated ($r= 0.972$, $N = 12$, $p<0.00$) (Fig. 3) and varied by >3 fold. The Japanese and Taiwanese landings ranged from 636 to 4287 t per year and 422 to 6164 t per year, respectively. It was noteworthy that the Japanese and Taiwanese landings varied out of phase with one another from 1990 until 1996, whereas the trends were very similar from 1997 through 2000.

Pooled weight frequency distributions of yellowfin tuna in the 5-68 kg size range were developed from the landings of Japanese and Taiwanese longline vessels. Annual recruitment was concentrated in the first quarter of the year. Within each monthly size frequency distribution there were 4 or 5 identifiable modes. Each of these could be tracked from the time of recruitment for about 4-5 years before the modes overlapped near the asymptotic size (Fig. 2). However, many of the apparent modes within the 25-40 kg size range were not clearly defined and broad based, which made it more difficult to identify and track growth within age groups.

Among the nine age groups, the 1991 year class recorded the highest K value (0.775 per year) but the lowest asymptotic size (L_∞ = 152 cm FL). In contrast, the 1993 year class was characterized by a much lower K value (0.335 per year) and higher L_∞ (173.1 cm FL) than all other years. The average parameter values of L_∞ and K for the remaining year classes were 0.613 per year and 157.5 cm FL, respectively. The t_0 ranged from -0.004 to -0.002 for the nine year classes. Size at recruitment for the nine year classes ranged from 89.4 to 107.6 cm FL with an overall mean of 98.2 cm FL; correspondingly, the recruitment age (*r*) ranged from 1.2 - 2.6 yr and averaged 1.6 yr (Table 1).

Discussion

The effectiveness of any mode progression analysis on a series of size frequency distributions is the ability to identify and track patterns in the age groups as they progress from time of recruitment to near asymptotic size and unlike length-based mode progression analysis, the use of weight as the measured variable permits greater resolution of the individual modes before these become indistinguishable approaching the asymptotic size. Factors influencing the shapes of the size frequency distributions are recruitment, growth, mortality, and fishing and sampling biases. The recruitment of yellowfin tuna in the Guam tuna transshipment fishery was highly defined and occurred yearly in the first quarter. Growth was relatively fast and there was little overlap between sizes of individuals in successive age groups; such that, size could be used with certainty to which age group a fish belongs and basic statistics can be computed for each group. However, the occurrences of the broader based and indistinct modes within the 25-40 kg size range appear to be the result of having the data pooled data in addition to the possibility of a slight misaligned time frame in the landings. The high correlation between the number of fish and catches, and mean sizes of yellowfin landed by the Japanese and Taiwanese vessels suggest that there was very little if any fishing bias during this time period that could affect the shape of size frequency distributions. However, beside making it necessary to combine the landings from both the Taiwanese and Japanese longline vessels, the disparity in Taiwanese vessels landing larger proportion of the larger sized tuna (Fig. 4) and the possibility of high-grading could have an affect on the shape of the distribution by truncating the lower sizes for some of the year classes.

To overcome one of the major shortcomings in determining fish growth through mode progression analysis, size at hatching was used as a way of anchoring the growth curve to the real time scale. Although, with the use of a single estimate, the assumption that the variation between year classes was very small and the impact on the VB model would be minimum.

Estimated values of *K* for each of the year classes were well within the range (0.20-0.66 per year) from previous age and growth studies of yellowfin tuna in the Pacific (Table 2) through various techniques. Works by Yabuta and Yukinawa (1957 and 1959) on yellowfin caught by longliners around Japan and in the western Pacific were very similar. However, unlike latter study, results from this study did not exhibit alternating high and low values of *K* between the year classes. Estimated growth was extended (0.334-0.775 per year) and variable between year classes; however, correlation to environment conditions (i.e.; SOI) could not be detected. Unlike bigeye tuna (*T. obesus*) that demonstrated a good correlation with the SOI and growth (Kikkawa et al. In prep.) yellowfin tuna that normally inhabit waters above the thermocline (Suzuki, 1994) appear to be less sensitive to these episodic events that occur in the Pacific Ocean. This conjecture can be supported by Nishikawa et al. (1985) study on the distribution of tuna larvae in the Pacific Ocean. Although both the yellowfin and bigeye tuna exhibit huge spawning potential

(Miyabe, 1994, and Suzuki, 1994), the broad distribution yellowfin tuna larvae, unlike bigeye tuna, throughout the tropical Pacific Ocean supports the assumption that biologically, the spawning, larval growth and survival properties were less influenced by episodic conditions such as the El Niño/SOI. Arguably, the individual year class estimates to the VB parameters can significantly change dynamic population models as estimates of inter-annual variations were never developed before. Thus it is imperative that we resolve this first study and consider to include other population parameters such as mortality and year class strength.

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Table 1. Summary of the growth of yellowfin tuna (*Thunnus albacares*) by the Taiwanese and Japanese coastal longline vessels in the Guam fresh tuna transshipment fishery from 1989-2000. The recruitment age adjustment factor (r), von Bertalanffy parameters of L_∞, k, and t_0, and the coefficient of determination r^2 values are presented for each of the nine year classes. Standard error are shown in parenthesis.

Year Class	**Age (yr) at recruit-ment size of 100 cm fl**	**r**	**$L\infty$ (cm)**	**k**	**t_0 (yr)**	**r^2**
1989	1.78	1.367 (0.107)	157.1 (1.294)	0.609 (0.0401)	-0.0024	97.4
1990	1.59	1.507 (0.123)	157.4 (1.217)	0.648 (0.0461)	-0.0023	97.2
1991	1.36	1.194 (0.089)	152.5 (0.838)	0.775 (0.0448)	-0.0019	97.9
1992	2.22	2.051 (0.243)	156.7 (2.251)	0.535 (0.0649)	-0.0027	95.5
1993	2.61	2.605 (0.289)	173.1 (5.248)	0.334 (0.047)	-0.004	97.8
1994	1.60	1.346 (0.156)	158.7 (2.515)	0.604 (0.0634)	-0.0024	96.6
1995	1.30	1.302 (0.159)	153.8 (1.862)	0.688 (0.07)	-0.0022	96.5
1996	1.92	1.666 (0.444)	159.8 (5.633)	0.533 (0.1307)	-0.0027	91.5
1997	1.51	1.431 (0.225)	164.1 (3.943)	0.511 (0.071)	-0.0027	97.6

Table 2. Summary of von Bertalanffy growth parameters for yellowfin tuna (*Thunnus albacares*) caught in the central and western Pacific Ocean.

Fishing Gear	Max. Size (cm)	K	t_0	Method	Author(s)
Longline	192	0.44	-0.22	Weight Modes	Moore (1951)
Longline and baitboat	168	0.55	-0.35	Length Modes	Yabuta and Yukinawa (1957)
Longline	150	0.66	-0.4	Length Modes	Yabuta and Yukinawa (1959)
Longline	190	0.33	0.0	Scales	Yabuta et.al. (1960)
Troll	170	0.386		Otolith	Uchiyama and Struhsaker (1981)
Longline	195	0.36	0.27	Scales	Yang et. al. (1969)
Baitboat	181	0.29	-	Length modes	Wankoski (1981)
Various	175 173	0.30 0.32	- -	Length modes	Yesaki (1983) -Male -Female
Longline	195	0.36	0.27	Scales	Yang et. al. (1969)

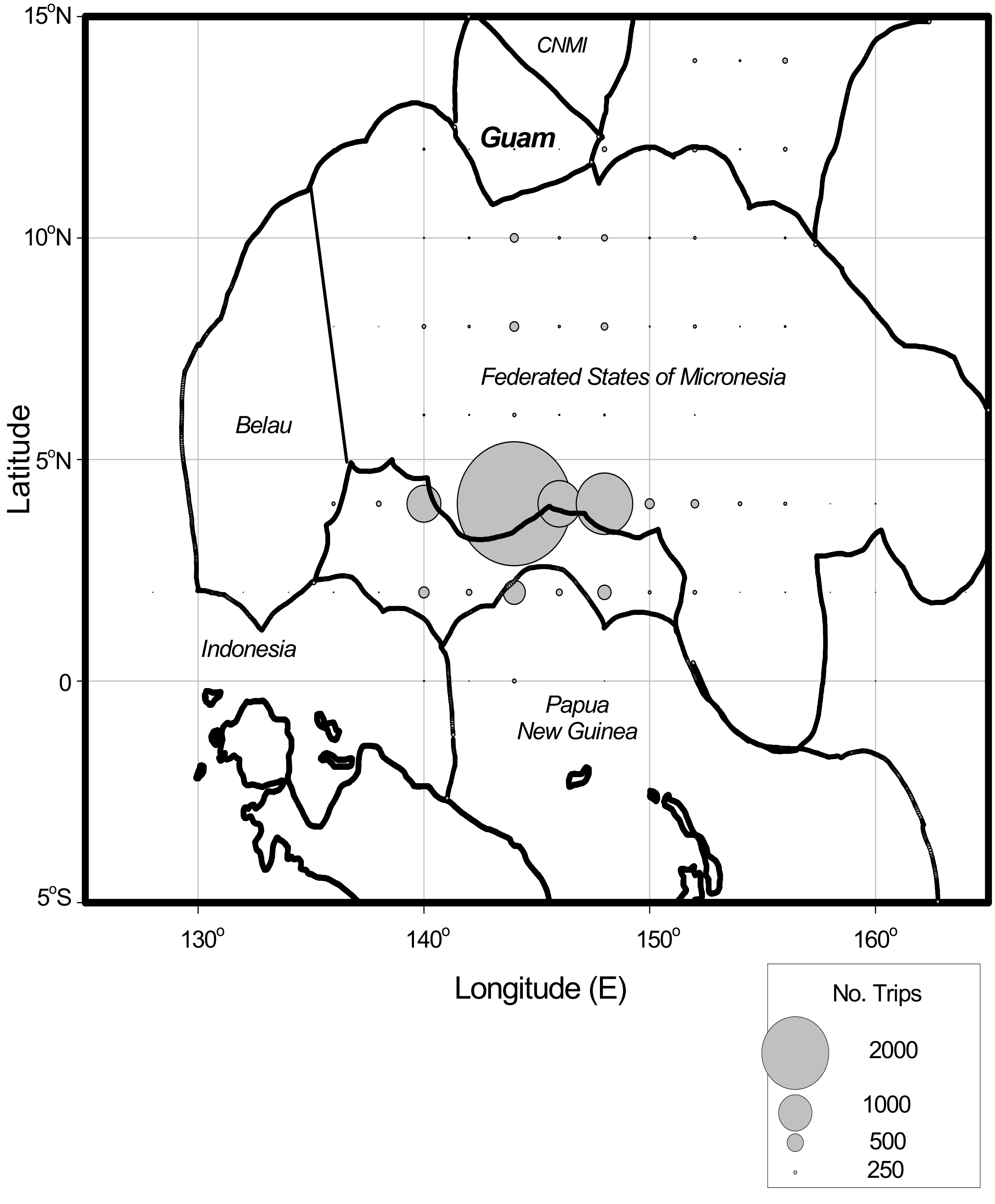

Figure 1. Reported fishing area and estimated number of trips by the Taiwanese and Japanese longline vessels in the Guam fresh tuna transshipment fishery from 1989 to 2000.

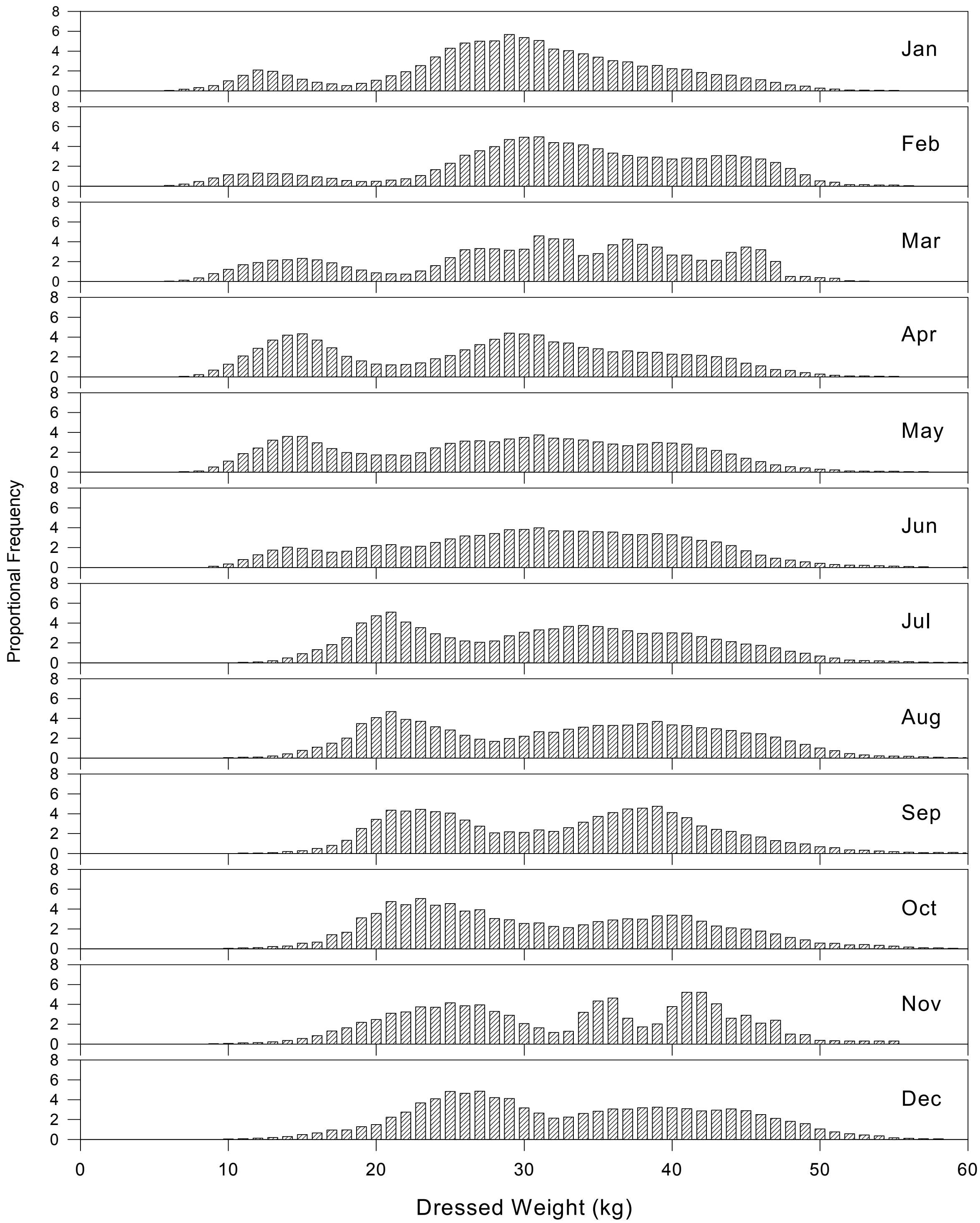

Figure 2. Monthly proportional dressed weight frequency distribution of yellowfin tun (*Thunnus albacares*) landed by Taiwanese and Japanese longline vessels in the Guam fresh tuna transshipment fishery in 1992.

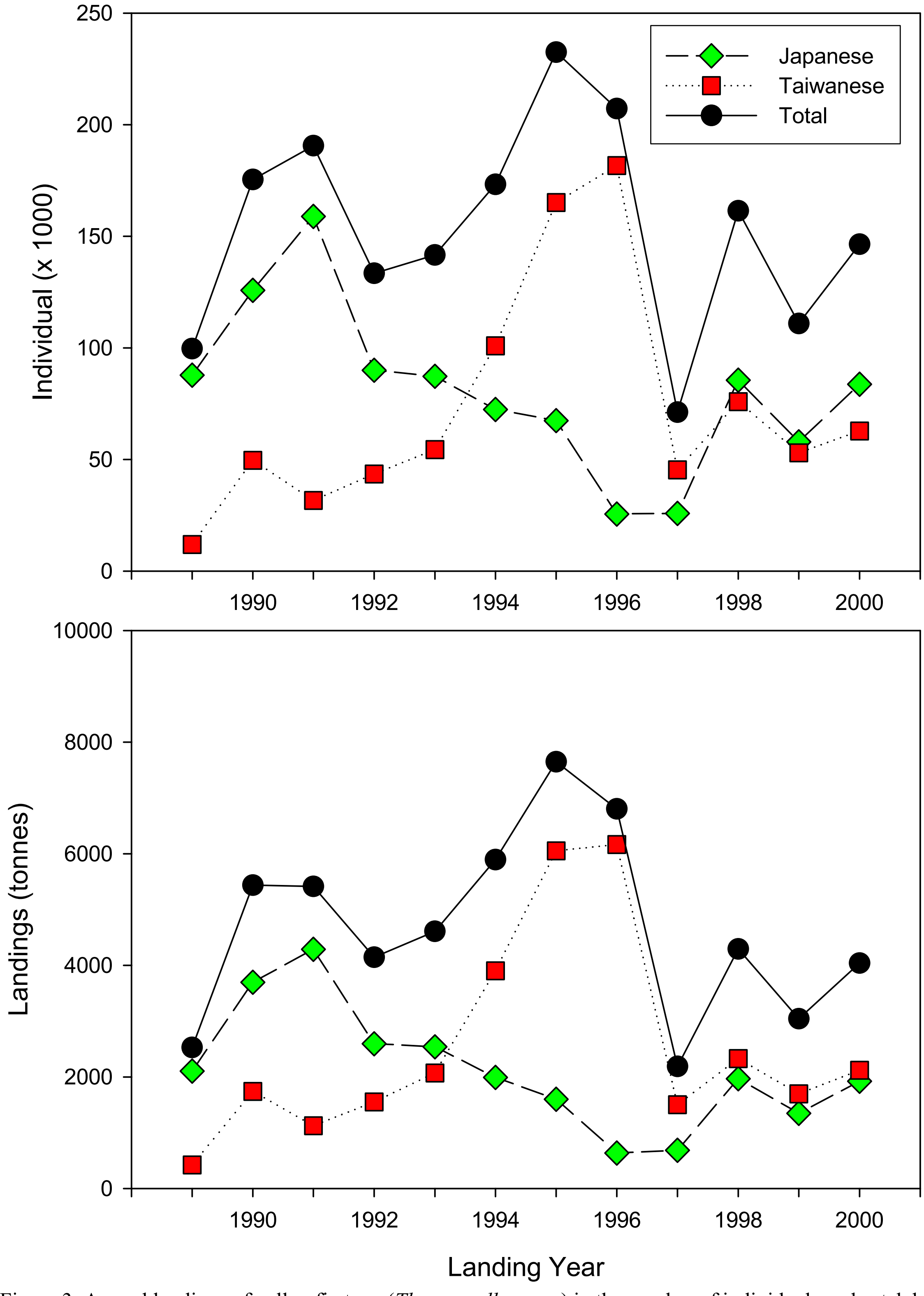

Figure 3. Annual landings of yellowfin tuna (*Thunnus albacares*) in the number of individuals and catch by the Taiwanese and Japanese longline vessels in the Guam fresh tuna transshipment fishery from 1989 to 2000.

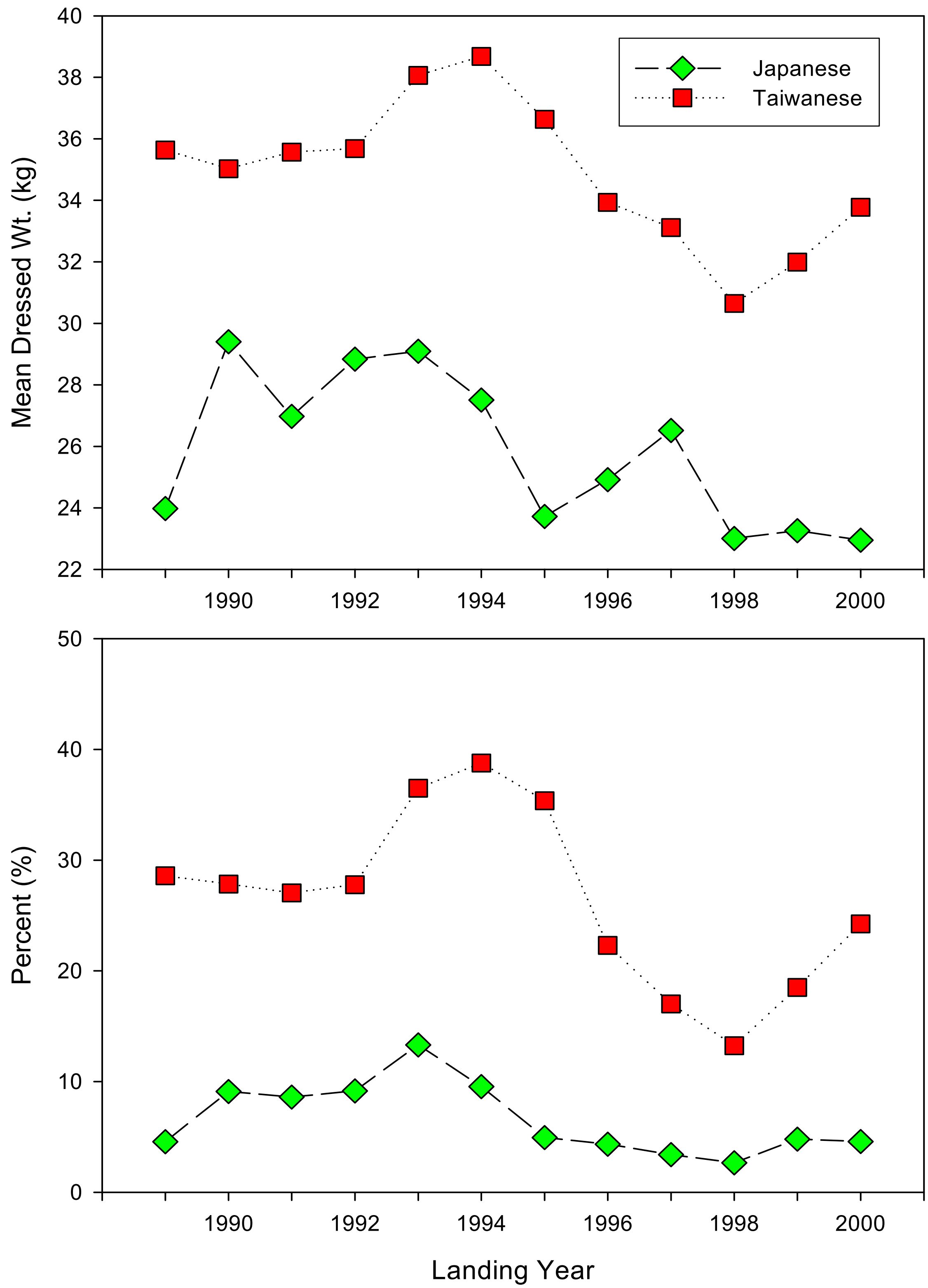

Figure 4. Annual mean dressed weight (top) and proportion of the landings >40 kg (bottom) of landed yellowfin tuna (*Thunnus albacares*) by the Taiwanese and Japanese longline vessels in the Guam fresh tuna transshipment fishery from 1989 to 2000.