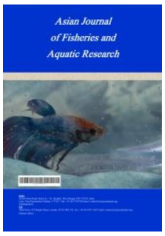

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Age and Growth Estimations of *Decapterus kurroides* Using Otolith in the Waters of Eastern Taiwan

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Redtail scad (*Decapterus kurroides* Bleeker, 1855) was once an economically important Carangidae species in Taiwan. This study determined age using otolith increments and re-evaluated the parameters of growth equations for this species.
Place and Duration of Study: Fish samples were collected monthly off the coast of Taitung, eastern Taiwan.
Methodology: A total of 367 specimens were observed in this study. To determine fish age, otolith age determination method was used. The largest and smallest otolith rings were seven and two, and their corresponding means of fork length (FL) were 29.2 and 12.2 cm, respectively.
Results: Most samples had six otolith rings with a mean FL of 27.2 cm. The von Bertalanffy growth equation is $FL_t = 30.44\ (1 - e^{-0.52\ (t - 1.50)})$ for females and $FL_t = 32.45\ (1 - e^{-0.39\ (t - 1.18)})$ for males. The otolith opaque zone annually formed from September to October. The relationship of body weight (BW) and Fork Length (FL) differed significantly between genders: $BW = 0.334 \times 10^{-2}\ FL^{3.463}$ for females and $BW = 0.469 \times 10^{-2}\ FL^{3.349}$ for males. The sex ratio was 0.56 over a whole year and varied among the age groups.
Conclusion: This study using the otolith method revises the estimations of age and growth parameters for the *D. kurroides*, which would be beneficial to manage and recover this species stock in the waters of Taiwan.

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Keywords: Body size; Carangidae; Growth equation; Otolith.

1. INTRODUCTION

Redtail scad *Decapterus kurroides* Bleeker, 1855 is a widely distributed Carangid fish in tropical and subtropical waters of the Indo-West Pacific and very common in all Taiwan waters [1]. *D. kurroides* feeds widely in the waters around Taiwan [2]. In Taiwan, *D. kurroides* was an economically important fish in the 1970s [3]. However, the annual production of *D. kurroides* decreased to about 7700 tons in 1998, further decreasing to about 40-598 tons in 2001-2010. *D. kurroides* specific listing in the Fisheries Statistical Yearbook of Taiwan has been omitted since 2011 and incorporated into the listing of *Decapterus spp*. due to the small production [4]. In addition, Yilan, once the leading fishing county, has been surpassed by the south eastern counties of Hualien and Taitung in the Fisheries Statistical Yearbook in terms of catching results.

Age information is essential, as it forms the basis for the calculations of growth, mortality rates, and productivity estimates [5], making it necessary for fisheries management [6], [7]. Scales have been used widely for age estimation in the past. However, the use of the scales method has been criticized in this recent years, mainly because the ages of older fish are frequently underestimated [8], [9]. Age estimation using otolith is thought to be more accurate because otoliths have a higher priority in the utilization of calcium [9]. Furthermore, unlike scales, otoliths continue to grow as the fish ages [6], [8]. Otolith sections provide accurate age estimation and back-calculated length estimation for young walleyes populations, and it is easier to determine the fish age. Consequently, otoliths are more accurate for determining the ages of older walleyes than are scales and dorsal spines [10].

The maximal total length (TL) of *D. kurroides* was 45.0 cm [11], recorded in the FishBase [12]. Three groups of age estimated by scales for the *D. kurroides* in the waters of Taiwan were reported in the 1970s [3]. The reproductive biology of *D. kurroides* indicated that the fish could spawn several times during a single spawning season and would migrate northward from southern Taiwan to the spawning grounds off Nafangao during the spawning season [13]. Based on the morphometric data, *D. kurroides* was considered a single population [14]. However, it appears that there are at least two morphologically distinguishable stocks of this species off Taiwan and need to be verified [15].

Compared to similar species in the genus *Decapterus*, *D. kurroides* is deep-bodied [16]. *Decapterus russelli* and *Decapterus tabl* are two species with similar appearances to *D. kurroides* in the waters of eastern Taiwan. However, three features can easily distinguish the latter from the two formers [16], [12]. First, *D. kurroides* has relatively big eyes, an essential characteristic differing from *D. russelli* and *D. tabl*. Second, the caudal fin of *D. kurroides* is bright red, which differs from hyaline to dusky on *D. russelli*. Third, there is no scale on the straight part of the lateral line of *D. kurroides*, which differs from 4–12 scales on *D. tabl*. By understanding the difference mentioned above, it is easy to distinguish *D. kurroides* from *D. russelli* and *D. tabl* when collecting samples in the waters of eastern Taiwan.

Although a number of valuable studies on the *D. kurroides* in the waters of Taiwan were documented in the 1970s, successive studies and applications of advanced age estimation technologies have been sparse over the last forty years. In addition, the production and fishing areas of this species have changed significantly since the 1970s, and the scale method has mostly been replaced by the otolith method for fish age estimation since the 21st century. Therefore, this study aims to determine age using otolith readings and to evaluate growth patterns for this species in the waters of eastern Taiwan.

2. MATERIAL AND METHODS

2.1 Data Collection and Samples Measurement

In usual, *D. kurroides* were commercially caught by the pole and line fishery in the waters of Taiwan. At least 30 specimens were randomly collected from the commercial catch each month from May 2010 to April 2011 in the waters of Changbin and Chenggong, Taitung County, Taiwan (Fig.1). In August 2010, the monthly specimens were randomly collected from the catch of *D. kurroides* caught only occasionally by set net in the same waters since no *D. kurroides* was caught by the pole and line fishery. The total number of the *D. kurroides* specimens was 367 in this study. Specimens were measured to the nearest millimeter in fork length (FL) and the nearest gram in body weight (BW).

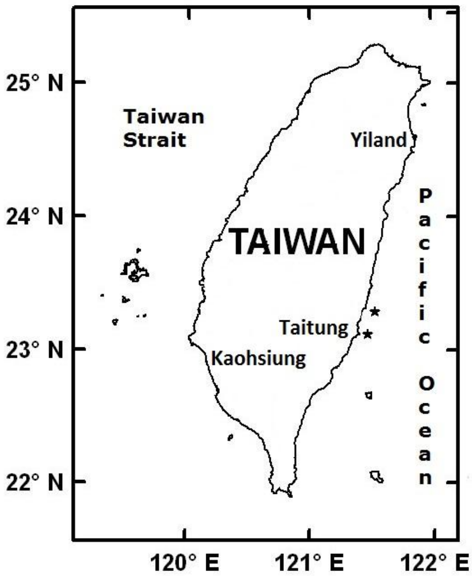

Fig. 1. Map of the waters around Taiwan showing the two collection locations, Changbin and Chenggong, Taitung County (★), of *D. kurroides* from May 2010 to April 2011

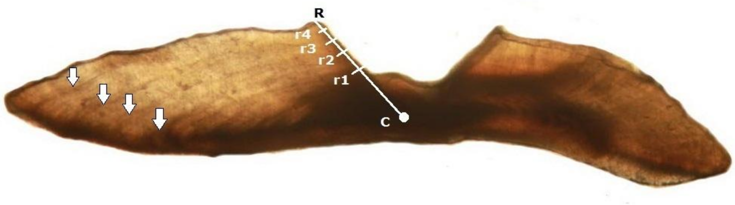

Fig. 2. Otolith section of a *D. kurroides* with four ring marks. White arrows indicate ring marks. C: core, R: otolith radius (distance from C to the otolith margin), r_n: ring radius of the boundary from a translucent zone to an opaque zone (n = 1-4)

2.1.1 FL - BW relationship and sex ratio

The relationship between FL and BW was expressed by the function $BW = a\,FL^b$, or $\ln(BW) = \ln(a) + b\ln(FL)$, where b is the slope of the fitted line when the logarithm of the weight is plotted against the logarithm of the length [17]. A single multiple regression model with one dummy variable was adopted to assess the gender (Gd) effect on the length-weight relationship with logarithmic transformations of FL and BW [18]. The statistic model was $\ln(BW) = b_0 + b_1 \ln(FL) + b_2\,Gd + b_3\,Gd \ln(FL) + \varepsilon$, where b_0 - b_3 are regression coefficients, Gd is the dummy variable, and ε is the error in the model. Sex ratio was determined following the equation [19]:

$$Sex\ ratio = \frac{Number\ of\ females}{Number\ of\ females + Number\ of\ males}$$

2.1.2 Age and growth estimations

The sagittal otolith was removed, washed in freshwater, and dried. The left otolith was burned at 200 °C for 30 min in a drying oven, embedded in resin, then sectioned transversely (0.2-0.3 mm thickness). Sectioned otolith was observed under a digital microscope (Lieca, DM 2500) with transmitted light to count the opaque rings. Measurement of the ring radius was done using a computerized electronic measurement system. Each otolith was examined three times, with a minimum of two weeks between examinations, by two independent readers. If two or more examinations per otolith agreed on the number of ring marks, this number was recorded and used for the analysis. The right otolith was prepared as the above-left otolith if its paired left otolith was missing. No significant difference in ring mark numbers was found between the left and right otolith in ten *D. kurroides* selected randomly from the specimens (paired t = -0.25, p = 0.809). Ultimately, a total of 226 otoliths were used for age estimation. The above method was modified from Ohshimo et al. (2006) [20] and Shiraishi et al. (2010) [21].

The distance from the core (C) along a straight line to the inside margin of the first opaque zone was defined as the first ring radius (r_1), the sum of the distance between the inside edge of each adjoining opaque zone was defined as the ring radius (r_2, r_3, …r_n) and the distance from C to the otolith margin was defined as the otolith radius (Fig. 2). The formation month of otolith ring marks was determined by the monthly changes of the marginal increment (MI). The MI was defined according to the equation:

$$MI = \frac{(R - r_n)}{(r_n - r_{n-1})}$$

R is the distance from the core to the otolith margin.
r_n is the distance from the core to the outer edge of the formed annulus.

Age was determined for each fish based on the number of ring marks (annuli) on the sectioned otolith. In order to describe the growth of males and females, von Bertalanffy growth equations were fitted to the observed FL values at age t (size-at-age) in the FiSAT II. FiSAT II, the Windows version of FiSAT (FAO-ICLARM Stock Assessment Tools), is a program package developed mainly to analyze length-frequency data and enables related analyses of size-at-age catch-at-age, selection, and other analyses. The growth equation is:

$$FL_t = FL_\infty\,(1 - e^{-K(t-t_0)})$$

FL_t represents the fork length (cm) at age t, and FL_∞, K, and t_0 represent the asymptotic fork length, growth coefficient, and hypothetical age at FL equal to zero.

3. RESULTS AND DISCUSSION

3.1 Age and Growth Estimations

Ranges of FLs and BWs of the redtail scad specimens were 12.4 – 30.4 cm and 19.3 – 447.9 g for females (n = 207), 11.7 – 32.1 cm and 21.0 - 492.2 g for males (n = 160) respectively. Modes in the frequency distributions of FLs and BWs for both genders were the same at the intervals of 26.0 - 27.9 cm and 280.0 – 309.9 g, respectively. Monthly mean FLs ranged between 23.6 - 28.7 cm for males and 24.3 - 28.2 cm for females in the regular collections, which were not included in the fish collected on August 2010 by set net with FL range of 11.7 – 16.1 cm. The oldest and youngest individuals in this study had seven and two otolith rings (Fig. 3). Their corresponding mean (± standard deviation) and range of FLs were 29.2 (± 1.0) cm and 27.6 - 32.1 cm, and 12.2 (± 0.4) cm and 11.7 - 12.4 cm, respectively. Most samples had six otolith rings with the mean and range FLs of 27.2 (± 0.6) cm and 25.6 – 28.6 cm. In the regular collections of the specimens caught by the pole and line, four to seven otolith rings were found, and their corresponding FLs ranged from 22.3 to 32.1 cm. Two to three otolith rings were found only in the specimens caught by the set net, and their corresponding FLs ranged from 11.7 to 16.1 cm (Fig. 3).

Parameters of the equation differed significantly between genders ($p \leq 0.05$), evaluated by 95% confidence intervals (CIs) (Fig. 4). These parameters indicated that the female scad had a larger K and grew faster while had a smaller asymptotic FL than the male scad. The von Bertalanffy growth equation of the redtail scad was estimated as follows:

$$FL_t = 30.4(1 - e^{-0.52(t-1.5)})$$

$$FL_t = 32.5(1 - e^{-0.39(t-1.2)})$$

3.1.1 Time of otolith ring formation

The largest monthly mean of MI was at the value of 0.93 in September, then abruptly decreased to the smallest value of 0.24 in the next month, October (Fig. 5). From October to December, the MI monthly mean apparently did not increase until January. After that, from January to April, a steady increase was found, and then a steeper increase continued from May to September. The most significant drop in the mean of MI occurred in October (Fig. 5). Therefore, it is determined that the otolith's opaque zone annually formed from September to October for the redtail scad in the waters off eastern Taiwan.

3.1.2 FL-BW relationship

Results from ANOVA for the multiple regression model with one dummy variable indicated that gender has a significant effect on the slope ($F_{1,}$

$_{363}$ = 7.12, p = 0.008) and adjusted mean ($F_{1, 363}$ = 5.81, p = 0.016) for the FL-BW relationship of the redtail scad. Thus, the relationships between FLs and BWs of *D. kurroides* were estimated as:

$$BW = 0.334 \times 10^{-2} FL^{3.463} \text{ for females}$$

$$BW = 0.469 \times 10^{-2} FL^{3.463} \text{ for males (Fig. 6)}$$

3.1.3 Sex ratio based on age classes

The sex ratio was 0.56, which differed significantly from 0.5 (χ^2 = 6.02, p = 0.014), with 207 female and 160 male specimens identified in this study. The sex ratio varied among the age groups. In the age five group, age six group, and age seven group the sex ratios were 0.65 (χ^2 = 5.25, p = 0.022), 0.61 (χ^2 = 4.94, p = 0.026), and 0.33 (χ^2 = 7.00, p = 0.008), respectively, which differed significantly from 0.5, while in the age two to four groups they insignificantly differed from 0.5 (p < 0.05) (Fig. 7). Based on the sex ratio, the female proportion in the age two to four groups insignificantly differed from the males. Still, the females were significantly different in the age five to six groups and small in the age seven group.

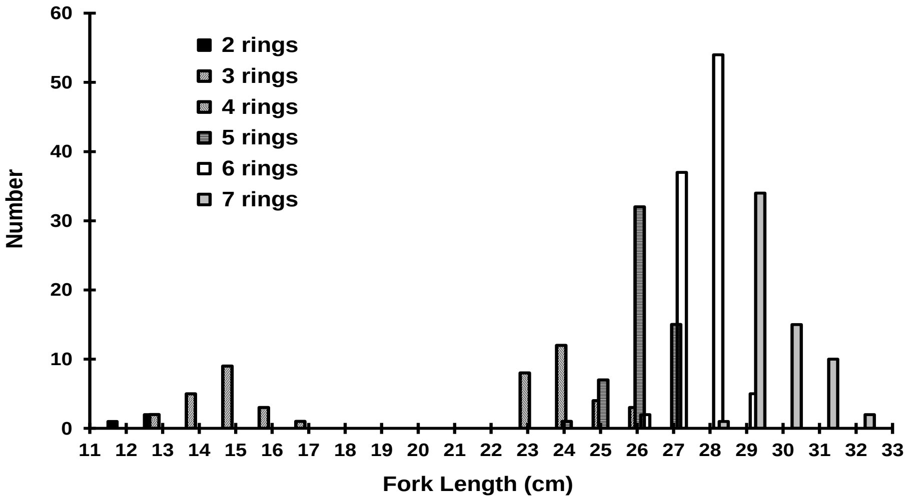

Fig. 3. Fork length distribution of *D. kurroides* with two – seven ring marks in otolith

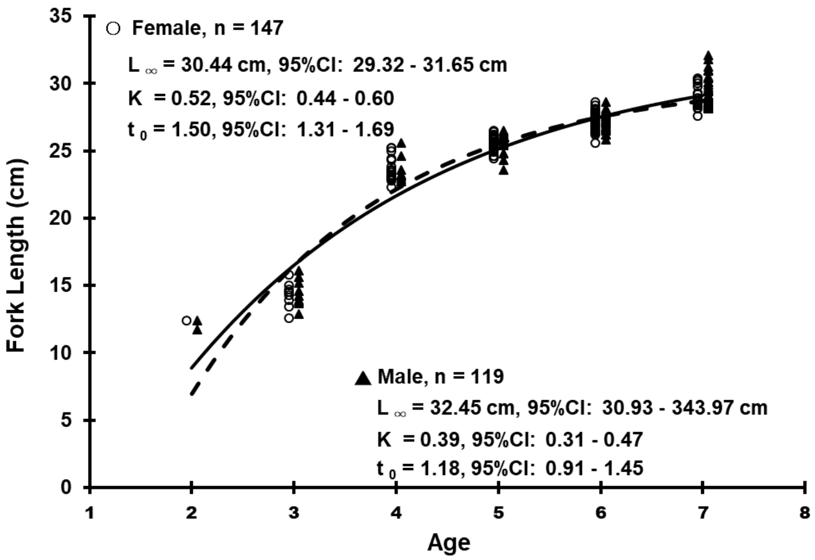

Fig. 4. The von Bertalanffy growth curves of *D. kurroides*. The fitting curve and observations were shown by a dotted line and open circles for females, and a solid line and solid triangles for males

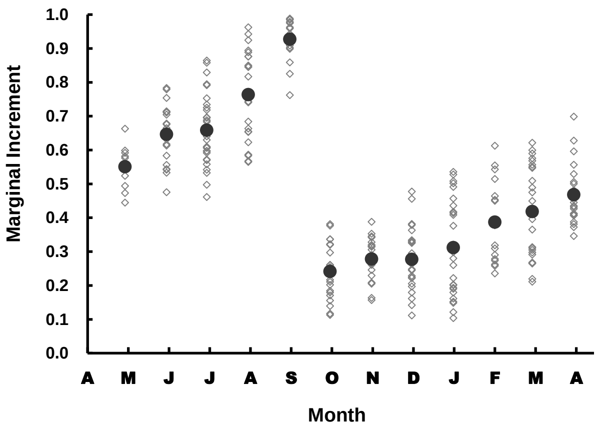

Fig. 5. Monthly changes in the marginal increment of the otolith for *D. kurroides* from May 2010 to April 2011. Solid circles and open rhombuses show monthly means and observations

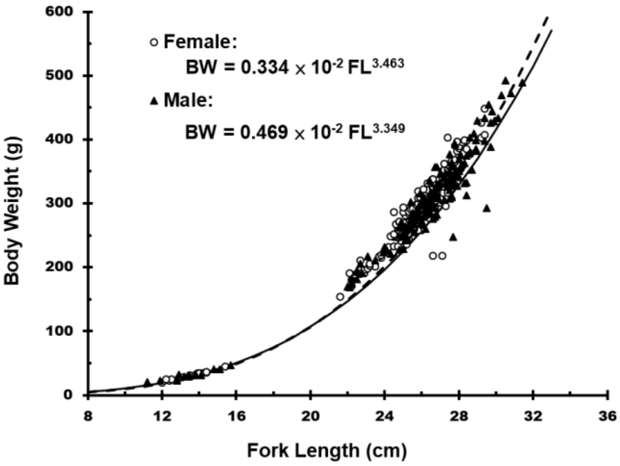

Fig. 6. Relationships of fork lengths and body weights for *D. kurroides*. The fitting curve and observations were shown by a dotted line and open circles for females and a solid line and solid triangles for male

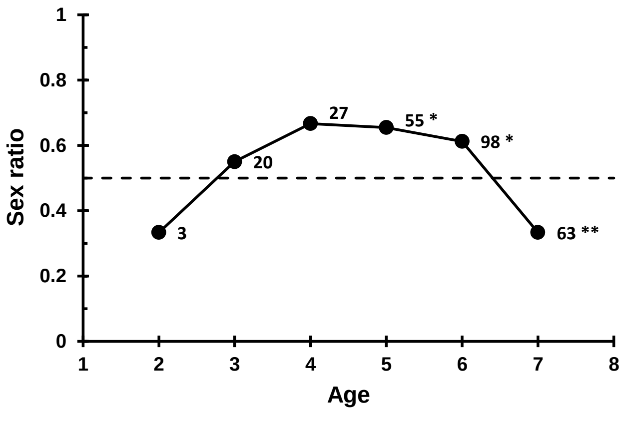

Fig. 7. Variations of the sex ratio among 2-7 age classes of *D. kurroides*. Numbers indicate sample sizes. *, significant at 5%; **, significant at 1%

Table 1. Comparisons of ranges and monthly means of fork lengths for *D. kurroides* collected in this study with the 1970-80s data

Fishing gear	Fork length (cm)		Sampling waters	Reference
	Range	Monthly means		
Pole and line	22.3 - 32.1[a]	23.6 - 28.7[a]	Taitung	This study
Pole and line	21.3 - 31.6		Yilan	[3]
	21.9 - 34.0		Kaohsiung	
Pole and line	23.4 - 32.2	26.2 – 30.7	Yilan	[14]
	23.6 - 34.3	27.6 – 30.7	Kaohsiung	
Pole and line		26.5 - 30.9	Yilan	[13]
		27.0 - 30.8	Kaohsiung	

4. DISCUSSION

4.1 Body Size and Age

The largest specimen of *D. kurroides* collected in this study was 32.1 cm FL, corresponding to 35.5 cm TL. This FL was close to the largest FLs of this species collected in the waters around Yilan, northeast Taiwan, but about two cm smaller than those collected in the waters around Kaohsiung, south Taiwan, using the same fishing gear, pole, and line, in the 1970s (Table1). In addition, the common FL of this species was 30.0 cm [22]. In the 1970s of Taiwan, the monthly mean FLs of *D. kurroides* ranged between 26.2 - 30.9 cm in the waters around Yilan and Kaohsiung [2], [14], which were about two cm larger than those of 23.6 - 28.7 cm in this study (Table 1). These comparisons indicated that the maximum body size of *D. kurroides* might vary in the different waters around Taiwan, but the mean body size of this species has decreased since the 1970s in the waters around Taiwan. Moreover, *D. kurroides* with 11.7 – 16.1 cm FL collected by the set net in our study updated the minimal size of this species exploited by fisheries in Taiwan.

The oldest specimens of *D. kurroides* found in this study had seven otolith rings, and most samples had six otolith rings (Fig. 3). Age estimation using scales in the 1970s reported that there were three age groups for this species, with mean of FLs for the 1, 2, and 3-year-old groups in the waters around Yilan and Kaohsiung were 21.3 and 24.8 cm, 26.2 and 28.5 cm, and 30.5 and 31.3 cm, respectively [3]. Currently, determining fish age using otolith is the most reliable way [10], [23], [24]. Age estimation using otolith is more accurate and suitable than using fish scales because estimating the age of fish using the scales method tends to underestimate the age of the older fish [7]. In comparison with FL at the oldest group of age, seven years old, with a mean of 29.2 cm FL in this study, if the decrease of body length was considered, it was roughly close to the 30.5 cm FL in the waters around Yilan in the 1970s, which was corresponding to three years old [3]. Thus, there is a probability of underestimating age for the older *D. kurroides* in the 1970s. The age estimation using otolith proves that the oldest group of age for *D. kurroides* is at least seven years old, more than double compared with the result of the 1970’s study.

The formation time of the opaque zone in the otolith of *Decapterus* fish might be relative to their reproductive seasons. The formation period of the opaque zone in the otolith was started from the climax until the end of the reproductive season for shortfin scad *D. macrosoma* and mackerel scad *D. macarellus* [21]. At the same time, it was in January, with the high gonadosomatic index for Japanese scad *D. maruadsi* [20]. The result of our study for the monthly variations of the MI rate indicated that the opaque zone of the otolith annually formed from September to October for *D. kurroides* (Fig. 5). However, the primary reproductive season for *D. kurroides* was from April to July. Thus, the time of the opaque zone formation for *D. kurroides* occurred after the reproductive season.

There are two records of the asymptotic body length (L_∞) and the growth coefficient (K) for *D. kurroides* analyzed using Electronic Length Frequency Analysis (ELEFAN) in the Fishbase [12]. One is 25.0 cm TL, and 0.80 from Davao Gulf, Philippines [25], and the other is 33.0 cm FL and 0.63 from Guimaras Strait, Philippines [26], respectively. In the 1970’s data from Taiwan, the L_∞ and K for *D. kurroides* aged using scales method were reported as 39.1 cm FL and 0.3, respectively [3]. Differences among these three historical records were apparent. In addition, the L_∞ and K for the two scads, *D. russelli* and *D. macrosoma*, which have similar appearance to *D. kurroides*, were estimated to be 23.2 cm and 23.8 cm , and 0.16 and 0.08, respectively, on the Karnataka coast, India [27]. However, the L_∞ (female: 30.4 cm, male: 32.5 cm) and the K (female: 0.52, male: 0.39) estimated in our study were close to but smaller than those in the study of Guimaras Strait [26]. In addition, if the age was underestimated and the L_∞ and t_0 were assumed to be constant, K would be larger than it is in the von Bertalanffy growth equation. Therefore, there would have been an overestimation of K for *D. kurroides* in the 1970's Taiwan study.

There is a high increase of FL from the age of three to four in our study (Fig. 4). The minimum biological size of maturation for *D. kurroides* was 22.0 – 24.0 cm FL [13], close to the range of FLs, 22.3 – 25.4 cm, in the group of four years old in this study. This indicates that *D. kurroides* is not adult until four years old, and after this age, the fish growth will tend to get slow.

In addition, due to selection limitations of the fishing gear (set net) and small sample size in this study, only three in the two-year age group, the minimum limit of the FLs range could be overestimated (Fig. 4). In contrast, the maximum limit of the FLs ranges in the three-year age group could be underestimated due to the selection limitations.

4.2 FL - BW Relationship

The common power value, b, of the FL-BW relationship for fish, ranges from 2.5 – 4.0, and it is affected by environmental factors, gender, and growth stages [28]. If the fish body length, body depth, and body width were isometric growth, the power value of b would be three or close to 3. The b value for the redtail scad in the Guimaras Strait, Philippines was 3.110 [26]. In contrast, the b value of the relationship between FL and BW of *D. kurroides* collected in Yilan and Kaohsiung in the 1970s was 1.054 and 1.289, respectively, and there was no significant difference between gender [3]. However, in this study, the FL-BW relationship of *D. kurroides* was found to be different between genders, and the b values were 3.463 and 3.349 for females and males (Fig. 6), identical to the b values in general [28] and in the study of Guimaras Strait [26]. The body size ranged from 11.7 – 32.7 cm FL in this study (Fig. 3), while it went from 21.3 – 34.0 cm FL [3]. Thus, the b value is far below three in the Chang and Shaw (1975) [3] study could be caused by the body size range of the specimens was too small to evaluate the general population.

4.3 Sex Ratio

In the age of two to four-year age groups of *D. kurroides*, proportions of females and males were the same, but the females were larger in number for the five to six-year age groups (Fig. 7). This is a typical finding in many temperate freshwaters and marine fish that, in the early years of a year class's existence, males are either more numerous or equal in number compared with females. As the fish age, the males suffer a higher mortality rate, so that older fish are nearly always female [29]. However, the sex ratio of the seven-year age group was significantly smaller than 0.5 (Fig. 7). This might be caused by the females growing faster (Fig. 4) and then dying earlier than the males for this species, which need to be verified in the future.

The sex ratio of *D. kurroides* was 0.5 over a whole year while significantly larger than 0.5 in the reproductive season in Yilan, which is close to the spawning ground in northern Taiwan, in the 1970s [13]. In this study, the sex ratio was 0.56 over a whole year (Fig. 7). The high proportion of females in the population ensure reproductive capacity [30]. Compared to the 1970's data, a higher sex ratio of *D. kurroides* found in this study might imply that the population structure has changed to ensure its reproductive capacity.

5. CONCLUSION

Results of age and growth estimations using otolith for *D. kurroides* indicate that the lifespan of this species is seven years at least, and the body size decreases. The underestimation of the fish age in 1970 and the decrease of the fish body size from 1970 are unfavorable for the sustainability of this species. However, this study using the otolith method revises the estimations of age and growth parameters for the *D. kurroides*, which would be beneficial to manage and recover this species stock in the waters of Taiwan.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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