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Growth of Buccaneer Anchovy (*Encrasicholina punctifer*) During Juvenile Stage in the Waters off Southwestern Taiwan

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ABSTRACT

The buccaneer anchovy (*Encrasicholina punctifer* Fowler, 1938) is one of the major species caught by the coastal larval anchovy fisheries around Taiwan. The morphology of buccaneer anchovy is similar to that of its congener *E. heteroloba* (Rüppell, 1837), which is always caught simultaneously or subsequently by the same fisheries. Most previous studies of the species have focused on the larval stage, that is, when the fish are younger than 30 days old, because the study samples were collected from fishery catches that were caught with gear that selectively targets larval anchovies. However, for the purpose of conservation and management, understanding the growth of the population after early-life stage exploitation is necessary. Therefore, in order to explore the growth parameters after the larval stage, 258 specimens of juvenile buccaneer anchovy (>30 days old) were collected from the waters off southwestern Taiwan (Fang-liao) during 2002 and 2006. For each specimen, the standard length (SL) was measured, the sexual maturity stage was determined, and the otoliths (sagittae) were extracted for microstructure analysis. The length composition of the juvenile anchovy caught in the waters off southwestern Taiwan ranged from 31.1 to 78.7 mm SL, while their ages ranged from 30 to 77 days. The growth rate, estimated from the von Bertalanffy growth function, of the buccaneer anchovy was 0.56 mm d^{-1}, which is similar to those of other tropical anchovies. These data provide critical information regarding management strategies for the larval anchovy fisheries in Taiwan.

Key words: anchovy, *Encrasicholina punctifer*, otolith, age, growth, juvenile

INTRODUCTION

The larval anchovy fisheries of Taiwan are located in the neritic waters around Taiwan. A number of fishing gears have been developed to harvest anchovy populations during their early-life stages. The total production of Taiwan's larval anchovy fisheries is about 700 to 1,250 tons per year (Fisheries Agency, 2016). There are four major fishing grounds around Taiwan with the following associated landing ports: I-lan (northeast fishing ground), Tan-shui (northwest), Wu-chi (west-central), and Fang-liao (south-western) (Yu and Chiu, 1994). However, the production levels for I-lan and Fang-liao have been the highest. The catches of the larval anchovy fisheries in the coastal waters of Taiwan are mainly composed of fish species belonging to the families Engraulidae and Clupeidae, which accounted for 80-95% of the total catches (Chiu *et al.*, 1997; Young *et al.*, 1992; Lee, 2004).

Previous studies have indicated that three anchovy species dominated the catch composition, namely, *Encrasicholina punctifer* (buccaneer anchovy), *E. heteroloba*, and *Engraulis japonicus* (Lee *et al.*,, 1990; Young *et al.*, 1992). The catches fluctuated irregularly,

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while their species compositions varied seasonally and temporally (Chiu *et al*., 1997; Lee, 2004). Traditionally, larval anchovy was harvested in Taiwan by small-scale fisheries using purse-seine nets with torchlight to attract the fish or using fyke nets set along tidal fronts in estuaries. Indeed, the scale of larval anchovy fisheries was small in early years and their impact on the resource was assumed to be limited. The scale of larval anchovy fisheries was increased in 1977, however, when high-efficiency pair-trawlers were introduced to the bay area. Pair-trawlers quickly replaced the other less efficient fishing gear, and local fish populations have since become threatened (Chen, 1980). The life-history traits of a fishery resource, such as its growth parameters and age composition, are crucial basic information for efficient fishery management. In Taiwan, because previous study samples were collected from fishery catches that were caught with gear that selectively targets larval anchovies, most previous studies have focused on samples less than 30 days of age (Young *et al*., 1992; Chiu *et al*., 1999; Wang and Tzeng 1999; Chiu and Chen, 2001). However, for the purpose of conservation and management, understanding the growth of the population after early-life stage exploitation is necessary, in spite of the fact that is has been seldom studied. In this study, therefore, we examined the growth of buccaneer anchovy, one of the major species in the fisheries, through otolith microstructure analysis.

MATERIALS AND METHODS

1. Sample collection

Samples of buccaneer anchovy were collected between 2002 and 2006 from fishing vessels operated in Fang-liao Bay (22.38˚N 120.58˚E), a bay containing a tropical estuarine with inflow from the Fang-liao River, in southwestern Taiwan. Pair-trawling expeditions with a cod-end mesh of 1×1 mm^2 were conducted at a depth of ca. 30 m and a distance of ca. 500 m from the coast. All fish samples were preserved in 95% ethanol.

2. Growth analysis

The samples used for age determination ranged in maturity from the larval stage to the adult stage. For each fish, a measurement of standard length (SL) was taken to the nearest 0.01 mm and the development of the gonad organs was checked. The otoliths (sagittae) were removed from the semi-circular canals of each specimen using fine forceps. Age was determined from counts of primary growth increments in the sagittae. Specifically, the left sagitta from each sample was cleaned and mounted on a microscope slide with thermoplastic cement (epoxy kit), and the sagittal plane was grounded with 600-2000 grade wet carborundum paper. The sagitta was ground until the nucleus was visible and then polished with 0.05 µm alumina powder. The sagitta parameter was estimated by the method described in a previous study by Chen and Chiu (2003): The mounted slides were observed under a compound microscope at 200×, and a clear image of the sagitta was obtained using a hard copier connected to the image analysis system. Furthermore, all distinctive increments were reasonably identified as daily rings from the larval to adult stage and marked with a pen. The coordinates of the sagittal perimeter and increment position were obtained using a digitizer (MM1201 Data Tablets Summasketch III Summagraphics Seymour, CT, USA) and then stored in a computer file. Because the position of the increments was first examined and marked on the hard copier output, and then digitized, the number of increments was exactly determined, and the increment sizes were precisely calculated. The daily ages of the fish were directly determined from the number of increments without adjusting for yolk sac duration, because the number of increments of tropical herrings and anchovies were assumed to be deposited daily after hatching (Thorrold and Williams, 1989; Hoedt, 2002).

3. Growth curve fitting

Length was plotted against the number of primary growth increments (age) for all the samples. To describe the relationship between the age and length of the juvenile buccaneer anchovies, the von Bertalanffy growth function (VBGF, Francis 1988) was fitted to length-at-age data. For small tropical anchovies, this function produces biologically meaningful estimates of the VBGF parameters, L_∞

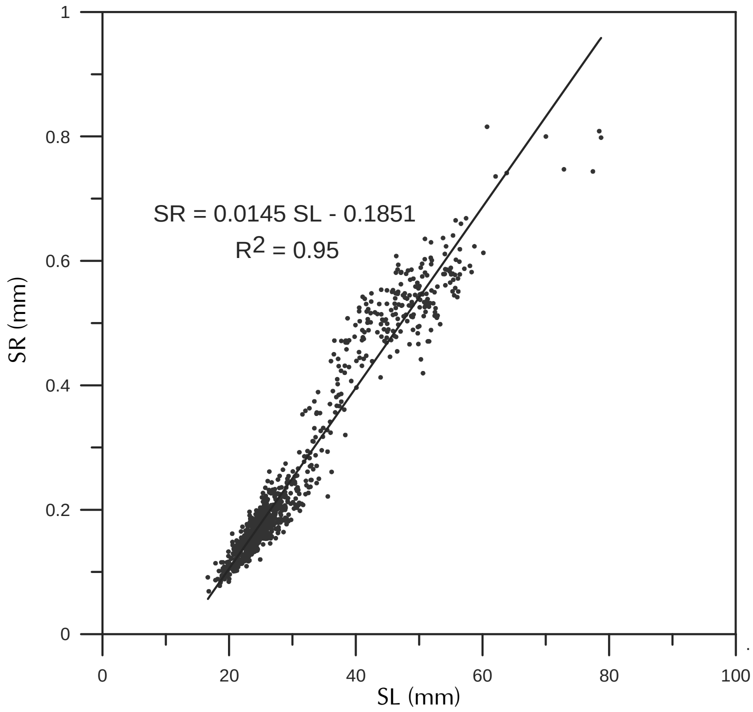

Fig. 1 The relationship between sagitta radius (SR) and standard length (SL) for buccaneer anchovies in the waters off southwestern Taiwan.

(theoretical maximum length), and K (value of the growth rate). The non-linear function was fitted to the data using the least square optimization method in Microsoft EXCEL. To calculate the growth rate (dL/dt) at $L_\infty/2$, the following equation was used (Milton *et al*., 1991, 1993): $dL/dt = K \times L_\infty/2$. This equation takes into account some of the wide variation in growth parameter values between populations and reduces the effect of the strong negative relationship between K and L_∞. The age-length data in the juvenile samples was also described by a linear relationship.

RESULTS

1. Size and age of samples

A total of 258 samples were collected, among which the standard lengths (SL) ranged from 31.09 to 78.72 mm and the ages ranged from 30 to 77 d. Two of the specimens of buccaneer anchovy, aged 70 d (78.43 mm) and 73 d (78.72 mm), respectively, were found to have developing ovaries.

2. Relationship between standard length and sagitta radius

The distance between continuous features such as otolith increments is proportional to fish growth on the basis of empirical correlations between sagitta size and fish size (Campana, 1985). The sagitta radius (SR) values of the buccaneer anchovy specimens exhibited a linear relationship with their standard lengths (SL), $SR = 0.0145 \times SL - 0.1851$, $R^2 = 0.95$, indicating a high correlation between the two growth parameters (Fig. 1).

3. Growth function and growth rate

The VBGF parameters were fitted to the standard length-at-age (growth increments) data of the buccaneer anchovy specimens caught in the waters off southwestern Taiwan (Fig. 2). The function is:

$L_t = 176.43\ (1 - e^{-2.32t})$, ($R^2 = 0.84$, n = 258)

The value of the growth rate (K) was 2.32 (yr^{-1}), and the theoretical maximum length (L_∞) was 176.43 mm SL. The growth rate of the juvenile buccaneer anchovies was thus calculated to be $176.43 \times 2.32/2 = 204.66$ ($mm\ yr^{-1}$), which was converted to a growth rate per day of 0.56 ($mm\ d^{-1}$). The linear relationship of the standard length and age in these juvenile individuals was thus $SL = 0.80 \times Age\ (d) + 7.79$ ($R^2 = 0.72$, n = 258).

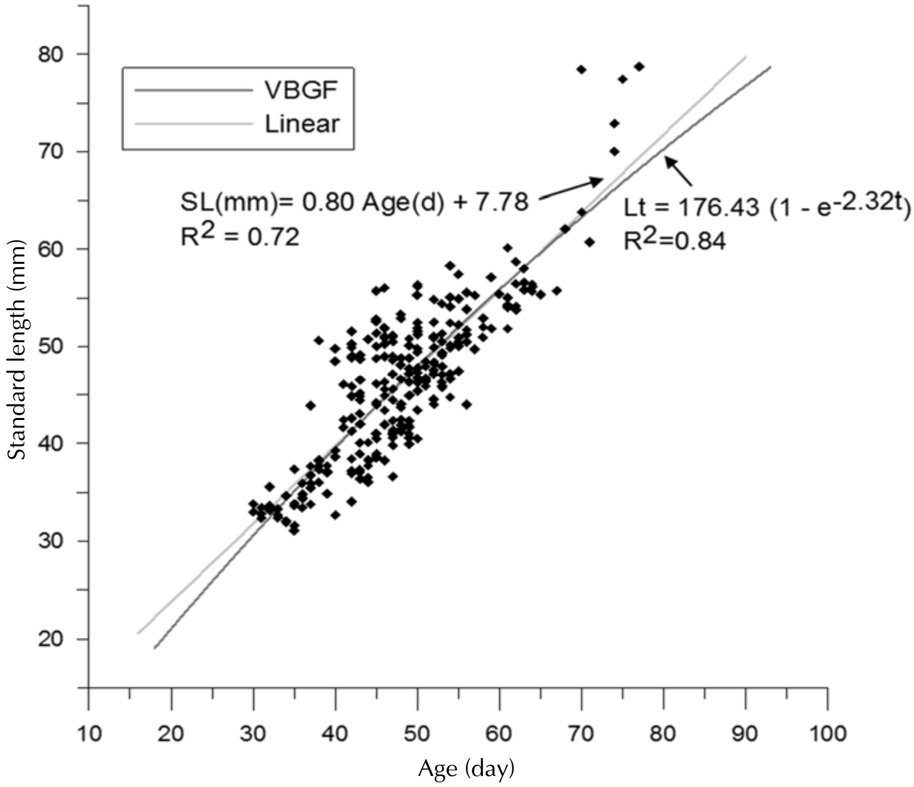

Fig. 2 VBGF and linear regressions were fitted to the standard length-full age data.

DISCUSSION

1. Conservatism of growth parameters in small tropical anchovy species

The growth of tropical anchovy species before sexual maturity has been found to show very similar patterns, with the length-at-age data of larval buccaneer anchovy and *E. heteroloba* in the waters off northeastern Taiwan having been found to be capable of being fitted with linear regressions (Wang and Tzeng, 1999) or a linear-like Gompertz curve (Chiu *et al*., 1999). The growth of tropical *Encrasicholina*, *Stolephrous*, and *Thryssa* species in Australia also exhibited a linear function in the juvenile stage (Hoedt, 2002). In this study, the growth of buccaneer anchovies in the waters off southwestern Taiwan could be fitted with the VBGF which was linear-like during the juvenile stage (Fig. 2).

Little inter-species variability in growth parameters was previously found for tropical anchovies before sexual maturity, with growth ranging from 0.4-0.71 mm d^{-1} with a mean of 0.58 mm d^{-1} (Hoedt, 2002) (Table 1). In this study, the mean growth rate of the buccaneer anchovy specimens was found to be 0.56 mm d^{-1}. Moreover, the growth rates of other tropical clupeoids, such as *Anchoa mitchilli* (Zastrow *et al*., 1991), genus *Spratelloides* (Milton *et al*., 1991), and *Amblygaster sirm* and *Herklotsichthys quadrimaculatus* (Milton *et al*., 1993), have also showed similar levels. Hoedt (2002) suggested that the growth rates of young tropical anchovies are reasonably conservative across species. The growth parameters of the buccaneer anchovy specimens in this study also supported this conclusion.

Like other tropical *Encrasicholina* and *Stolephorus* species (Whitehead *et al*., 1988), the buccaneer anchovy is a small-sized and early-maturing species with a maximum size-at-maturity of 85 mm SL (Andamari *et al*., 2002). In this study, two specimens of buccaneer anchovy aged about 70 d were found to have developing ovaries. The age-at-maturity of buccaneer anchovy in Indonesia was previously found to be 65-75 d (Andamari *et al*., 2002), which is similar to the age-at-maturity for small tropical anchovies, such as *Encrasicholina devisi*, *Stolephorus insularis*, *S. carpentariae* (Hoedt, 2002) in Australia, and genus *Spratelleoides* spp. in

Table 1 Growth rates of the tropical clupeoids based on otolith analysis

Species	Growth rate (mm day^{-1})	Reference
Anchoa mitchilli	0.44-0.50	Zastrow *et al.* (1991)
Encrasicholina devisi	0.71	Hoedt (2002)
E. punctifer	0.56	This study
Herklotsichthys quadrimaculatus	0.30-0.75	Milion *et al.* (1993)
Spratelloides delicatulus	0.39-0.87	Milion *et al.* (1993)
S. gracilis	0.45-0.77	Milion *et al.* (1991)
Stolephorus insularis	0.56	Hoedt (2002)
S. carpentariae	0.68	Hoedt (2002)
S. nelsoni	0.4	Hoedt (2002)
S. commersonii	0.68	Hoedt (2002)
Thryssa aestuaria	0.43	Hoedt (2002)
T. hamiltoni	0.61	Hoedt (2002)
T. setirostris	0.55	Hoedt (2002)

Kiribati (Milton *et al*., 1993). More information is needed to predict the accurate longevity of buccaneer anchovies around Taiwan, but documented data indicate that the longevity of tropical clupeoids can be estimated to be about twice the age, in days, as the age at first maturity (Table 2). The buccaneer anchovies in the waters off southwestern Taiwan thus might live up to about 5 months given that their age-at-maturity is about 10 weeks according to our observations.

In tropical environments, anchovies showed phylogenetic conservatism in their life-history traits (Milton *et al*., 1993), and thus the traits of body growth rate, ages at maturity, and longevities may be reasonably comparable across species (Hoedt, 2002). The results of our studies of buccaneer anchovy have also showed similar growth parameters to those mentioned above. Hoedt (2002) also suggested that these anchovies are typically planktivores and that perhaps the metabolic constraints of this mode of diet limits growth and, consequently, does not allow large variation in growth histories for similar sized clupeoid fishes.

2. Limitation of VBGF in smaller tropical anchovy species

The von Bertalanffy growth function (VBGF) has been widely used to describe growth in aquatic animals, but Hoedt (2002) suggested that the equation is not always suitable for small tropical fish that do not always exhibit an asymptotic growth phase at larger sizes. The calculated value of $L\infty$ in the buccaneer anchovy specimens in this study was unreasonably high, being 176.43 mm, which is much higher than the maximum recorded length of 130 mm (Whitehead *et al*., 1988). A similar situation was also found in previous research in which the $L\infty$ of *Stolephorus commersonii* was calculated to be 381 mm even though the maximum recorded length of the species was only 158 mm (Hoedt, 2002). When most of the samples ages were small, resulting in a linear growth pattern, this appeared to have biased the fitted curve (Hoedt, 2002). Thus, adding more growth data from older samples might improve the results of our growth examination, but it was not easy to get enough older samples because anchovies larger than 5-6 cm are not a major fishery target in Taiwan. However, the widths of increments in the sagittae decreased and the growth of the sagitta radius (Fig. 1) seemed to slow down after 60 days of age (about 60 mm SL). These thinner and unclear increments may increase the difficulty of growth analysis. Using advanced micrograph technologies, like using a scanning electron microscope (SEM) to assess juvenile anchovy otoliths

Table 2 Lifespans and ages at maturity of the tropical clupeoids

Species	Length of the oldest fish (mm)	Lifespan	Age_m	References
Encrasicholina devisi	54	102 d	63 d	Hoedt (2002)
Herklotsichthys quadrimaculatus	110	About 1 y	–	Milion *et al.* (1993)
Spratelloides delicatulus	75	4-5 month	60-65 d	Milion *et al.* (1993)
Stolephorus insularis	62	126 d	71 d	Hoedt (2002)
S. carpentariae	67	158 d	72 d	Hoedt (2002)
S. nelsoni	90	285 d	160 d	Hoedt (2002)
S. commersonii	139	240 d	160 d	Hoedt (2002)

Age_m: age at maturity

(Cermeño *et al.*, 2003), may thus be an alternative approach to improve the accuracy of age determination and growth curve fitting.

3. Anchovy resource conservation in Taiwan

Larval anchovies are one of the most important resources of the fisheries around Taiwan. Due to their high commercial value, the larval anchovy fisheries were scaled up in 1977, when high-efficiency pair-trawlers were introduced to contend with local fishermen (Chen, 1980). However, due to large catches along with the generally small size-at-catch of the fish, the pair-trawlers likely had a strong and threatening impact on this fish resource. Due to its high commercial value, the fish stock was evaluated as being overfished in the 1990s, during which time the catch weights declined (Fisheries Agency, 2016). There are two reasons that the fisheries should be subject to stringent management. First, a shortage of young anchovies may suggest the starvation of fishes at higher trophic levels in the coastal marine ecosystem, because anchovies are an important food resource (bait fish) for dominant commercial fish species, such as mackerels and scads. In addition, non-anchovy species might be influenced by the pair-trawlers, which operate with a tiny mesh size (2 mm stretched) and a lack of selectivity.

Since 2001, there has been a 3-month closed fishing season during the summer in Taiwan for the purpose of anchovy resource conservation. However, the stock status of larval anchovies has not recovered to an obvious degree (Fisheries Agency, 2016). Meanwhile, since 2008, the Fisheries Agency has been conducting control and verification of catches at the time of landing and collecting information from catch logbooks for provision to scientists for scientific analysis, with the aim of updating the status of fish resources (Chiu, 2016). In 2011, the Regulatory Guidelines for the Competent Local Authorities to Manage Larva Fishery were established. The control measures include the restriction of the business scale, the establishment of closed areas, annual total allowable catches, the obligation of filling in and submitting catch logbooks, and coordination with the Coast Guard Administration for conducting surveillance and control of the larval anchovy fisheries.

Our examination of growth parameters in juvenile anchovies collected from 2002 to 2006 provides important information regarding management strategies for the larval anchovy fisheries in Taiwan. The effects of long-term marine environment changes on anchovy growth and fishery resources could also potentially have been clarified if a sampling period of ten years or longer had been applied in this study. Despite the buccaneer anchovy being a species that is fast growing and probably has a short life span, recruitment overfishing is also a major concern in terms of resource conservation. Currently measure of 90 days banning season ensures minimal escapements to go through juvenile stage (less than 80 days) during summertime. On the other hand, under the government's management, the bycatch percentages of larval anchovy fisheries in

2015 decreased to 5.3%, which is close to the allowance level of 5.0%, and based on the time series data of historical catches, the larval anchovy resource is expected to recover to a moderate level (higher than 1000 tons per year) in the near future (Chiu, 2016). However, more information such as growth (Plaza *et al.*, 2006, Wang *et al.*, 2012, Yamamoto *et al.*, 2018), spawning migration (Tu *et al.*, 2012), and molecular systematics (Lavoue *et al.*, 2017) data is still necessary to improve anchovy resource management policies in Taiwan.

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臺灣西南水域刺公鯷稚魚之成長

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摘　要

刺公鯷 (*Encrasicholina punctifer* Fowler, 1938) 為臺灣沿岸水域常見的小體型魚類，並為魩鱙漁業主要漁獲物種之一。刺公鯷的外型與異葉公鯷 (*E. heteroloba* Rüppell, 1837) 相似，二物種經常於同地先後或同時出現。先前對於刺公鯷日齡及成長的研究多限於 30 日齡內的仔魚階段，而 30 日齡以上之稚魚階段，因為並非漁業之主要利用對象及受漁具選擇性影響，使其在沿岸水域之成長狀態並不瞭解。本研究應用耳石 (矢狀石) 定日齡，探察 2002 年至 2006 年臺灣西南水域 (枋寮) 刺公鯷稚魚之成長情形。共分析 258 標本，其體長 (standard length) 範圍為 31.1 – 78.7 mm，日齡分布為 30 – 77 日。由套適之 von Bertalanffy 成長方程式推算，刺公鯷之成長率為 0.56 mm d^{-1}，與其他熱帶鯡亞目之成長率相近。本研究相關結果可提供魩鱙漁業管理措施規劃之參考。

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