AGE AND GROWTH OF THE DIVINE DWARF GOBY

EVIOTA EPIPHANES FROM OʻAHU, HAWAIʻI

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By
Reagan A. Grant

Thesis Advisor

Alan Friedlander

I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

THESIS ADVISOR

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Alan Friedlander
Department of Biology

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Abstract

I examined the age and growth of the divine dwarf goby *Eviota epiphanes*, a small, cryptic reef fish, in order to determine its role in the nearshore marine ecosystems of Hawaiʻi. Age was determined by counting presumed daily increments of transversely sectioned sagittae otoliths from 53 specimens captured on Oʻahu, Hawaiʻi between August and November 2012. Post-settlement growth was best represented by the von Bertalanffy growth function with a correlation coefficient of 0.53 and a residual sum of squares of 150.3. From examination of otoliths and counts of presumed daily increments, the mean pelagic larval duration (PLD) was found to be 26.5 +/- 0.22 days (SE) and the estimated maximum age was approximately 60.5 days. The proportion of total lifespan represented by the PLD was 43.8%, which corresponds to 34 days of post-settlement life. Estimated daily natural mortality was 3.6%. The age at sexual maturity calculated from the von Bertalanffy growth function was 40.9 days (or 14.4 days post-settlement). Mean generational turnover was 50.7 days. The rapid growth and short life span of *E. epiphanes* supports the hypothesis that small reef fishes are an important food source for piscivorous species and therefore plays an important role in the energetics and productivity of coral reef ecosystems.

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List of Abbreviations

g – gram

GBR – Great Barrier Reef

$\overline{\mathrm{GT}}$ – generational turnover

mm – millimeter

PLD – pelagic larval duration

UVC – underwater visual census

VBGF – von Bertalanffy growth function

TL – total length

Chapter 1. Introduction

Until recently the role of cryptobenthic fishes in coral reef ecosystems has been greatly underestimated due to the methodological bias associated with non-destructive underwater visual census (UVC) techniques (Willis, 2001). However, studies using ichthyocides and anesthetics have revealed that small cryptobenthic fishes comprise more than half of the numerical abundance of fishes observed on coral reefs in some locations (Depczynski & Bellwood 2005, Ackerman & Bellwood 2000). Small cryptobenthic fishes are defined as ‘adult fishes typically <50 mm that are visually and/or behaviorally cryptic, and maintain a close association with the benthos’ (Ackerman and Bellwood, 2000; Greenfield, 2003). Evidence suggests that they provide a substantial contribution to reef processes and trophodynamics disproportionate to their body size (Ackerman and Bellwood, 2000; Winterbottom & Southcott 2008; Depczynski & Bellwood 2003), yet little is known about their life history traits (e.g., longevity, mortality, etc.; Claro & Garcia-Arteaga 2001; Wilson 2004; Longnecker & Langston 2005).

Current knowledge categorizes reef fish life cycles into two groups of roughly similar diversity and abundance (Depczynski & Bellwood 2006). The first group consists of primarily medium to large (>100 mm total length [TL]) conspicuous species whose common life history traits include asymptotic growth trajectories, late maturation, low adult mortality, and life spans numbering in the years that lead to high lifetime reproductive output (Thresher 1984; Sponaugle & Cowen 1994; Choat & Axe 1996) . The second group consists primarily of small fishes (<100 mm TL) whose common life history traits include steep continuous growth trajectories, early maturation, high adult mortality, and short life spans (<1 yr; Miller 1984; Thresher 1984; Roff 1992; Munday & Jones 1998; Hendry et al. 2001; Neff 2003; Wilson 2004). This second group is dominated by species primarily from the families Gobiidae (gobies), Blenniidae (blennies), Tripterygiidae (triplefin blennies), and Pseudochromidae (dottybacks; Depcyzynski & Bellwood 2006). The short generation times, high susceptibility to predation and often high densities of these small species, suggest that their contribution to coral reef trophodynamics may be more important than one might predict based on their body size alone (Munday & Jones 1998; Depcyzynski & Bellwood 2006). These small fishes likely serve as an important trophic link between the algae and/or invertebrate fauna found on coral reefs and larger fish species that feed primarily on smaller fishes (Greenfield 2003).

Species of the genus *Eviota* (Teleostei: Gobiidae) fall within the smaller fish group. Very little is known about these small tropical marine gobies, as demographic studies on small cryptic fishes have focused primarily on the upper size range (50-120 mm TL) of this group, while *Eviota* tend to be <20 mm TL. Depczynski & Bellwood (2006) found fishes of the genus *Eviota* to be some of the smallest and most abundant fishes on the Great Barrier Reef (GBR), comprising more than half of all cryptic fish abundance on the reefs surrounding Lizard Island, GBR. The complete life cycles of the three most abundant species of *Eviota* found on these reefs, *Eviota sigillata*, *E. queenslandia*, and *E. melasma*, were documented and they were found to be some of the shortest-living and earliest-maturing vertebrates known to date. These studies have greatly broadened the scope of our knowledge of vertebrate life histories. Major shifts in patterns of growth, reproductive strategy, and timing of sexual development were observed, suggesting that maximum size and age in these short-lived reef fish species strongly influence their life history traits (Depczynski & Bellwood 2006).

Ichthyoplankton samples taken offshore from Oʻahu found *Eviota* spp. to be the most abundant taxon off this coast, outnumbering the next most abundant taxon by fivefold (Boehlert & Mundy 1996). This suggests that even as larvae this genus may provide a significant food source for pelagic predators. Despite their prevalence, the three documented *Eviota* species in the waters surrounding Oʻahu, *E. epiphanes*, *E. rubra*, and *E. susanae*, are rarely observed by divers due to their small size and cryptic nature. Their sheer numbers combined with their presumed role as an important trophic link suggest that their virtual exclusion from investigation of reef ecology thus far has resulted in a distorted and fragmented picture of reef fish ecology, biased towards larger species (Depczynski & Bellwood 2003; Greenfield 2003). An essential first step in accurately assessing the significance of *Eviota* species in Hawaiian coral reef ecosystems is to gain basic knowledge about their life history traits.

Important early life history and aging data can be obtained from the examination of fish otoliths, which are hard, calcified internal structures, located within the otic vesicle at the base of the brain, that assist in orientation and sound perception (Carlström 1963; Gauldie 1988). Otoliths grow throughout an individual's life through continuous precipitation of endolymph, an organic fluid retained within the otic vesicle (Green et al. 2009). The proteins contained within the endolymph mediate the size, shape, and orientation of these aragonite crystal formations (Degens et al. 1969; Morales-Nin 1986). Biological mediation by these proteins result in incremental accretion of the otolith by production of alternating bands of mineral-deficient (less dense, lighter) and mineral-rich (denser, darker) zones, known as L-zones and D-zones respectively, as the structure is formed (Green et al. 2009). Each pair of light and dark zones together is referred to as a growth increment. Counting these increments gives an estimate of age, once the period of formation is known (Green et al. 2009). Daily periodicity of increments has been confirmed in several species of tropical gobies, including species in the genus *Eviota*, using injection of, or immersion in, chemicals such as tetracycline, calcein and strontium chloride (Hernaman et al. 2000; Depczynski & Bellwood 2006).

Fish settlement from the planktonic larval phase to the benthic, relatively sedentary phase is reflected in the increment pattern in otoliths, known as a settlement check mark (Dunkelberger et al 1980; Green et al. 2009). This microstructural feature is used for age estimation prior to or after settlement (Panella 1971; Green et al. 2009). By counting the increments deposited prior to the settlement check mark the pelagic larval duration can be calculated (Green et al. 2009).

The combination of age data and fish length can be used to calculate growth rates of average individuals in a population. Fitting age-length data to the von Bertalanffy growth equation (VBGF) allows for an estimation of maximum asymptotic length and calculation of the VBGF growth constant (Pauly & Morgan 1987). These parameters are then used to estimate natural mortality rates and other important population dynamics parameters. The incorporation of sex and reproductive condition with growth data can be used to determine age at maturity and mean generational turnover (a conservative averaged estimate of the time taken for a new generation to be generated).

Histological examinations and laboratory experiments on *Eviota epiphanes* (Fig 1.1) have confirmed that they are protogynous hermaphrodites, meaning they mature as females and at some point in their life they change to males. Gonad morphology also suggests that they are capable of bidirectional sex change (Cole 1990). The goals of this study were to build upon the current knowledge of the life cycle of *Eviota epiphanes,* so that their influence and importance in the coral reef ecosystem can be better understood. This study investigated the age-length relationship, length-weight relationship, pelagic larval duration, age at maturity, generational turnover, natural mortality rate and approximate life span of *Eviota epiphanes*.

Figure 1.1 Photograph of *Eviota epiphanes.*

The goals of this study were to:

1. Calculate age-at-length relationship
2. Calculate length-weight relationship
3. Determine mean pelagic larval duration
4. Determine age and size at maturity
5. Calculate mean generational turnover
6. Estimate daily natural mortality
7. Approximate maximum lifespan

Chapter 2. Methods

Specimens of *Eviota epiphanes* were collected in three day intervals between August 30 and October 29, 2012 at Kahala Beach on Oʻahu, Hawaiʻi (21° 15' 44.39" N, 157° 46' 55.488" W; Fig 2.1). A total of 153 *E. epiphanes* were collected, ranging in size from 9 to 19mm. Individuals were captured by agitating loose rocks found among the coral reef (at approximately 1 m depth; Fig 2.2) in a five gallon bucket. After the rocks were removed from the bucket, the remaining contents were filtered through a fine mesh (1 mm) bag and inspected for *E. epiphanes.* Captured specimens were immediately transferred to a container with a mixture of MS-222 (an ichthyocide) and water for transportation to the laboratory.

Back in the laboratory wet weight (g) and total length (TL), measured to the nearest 0.5 mm were recorded for each individual (Appendix A). The specimens were sexed based on genital papilla under a dissecting microscope. However, because *E. epiphanes* are protogynous hermaphrodites (Cole 1990), sex was later verified by histological examination. The whole fish trunk was then sectioned longitudinally into three parts, anterior of the pectoral fin, posterior of the anal fin, and the section between the pectoral and anal fins. Saggital otoliths were extracted from each fish and mounted on a microscope slide with thermoplastic glue (Crystalbond 509™) and stored for aging at a later date. The anterior and posterior sections of the fish were placed in Dietrich's Solution (30% ethanol, 10% formalin, and 2% acetic acid) for later histological examination.

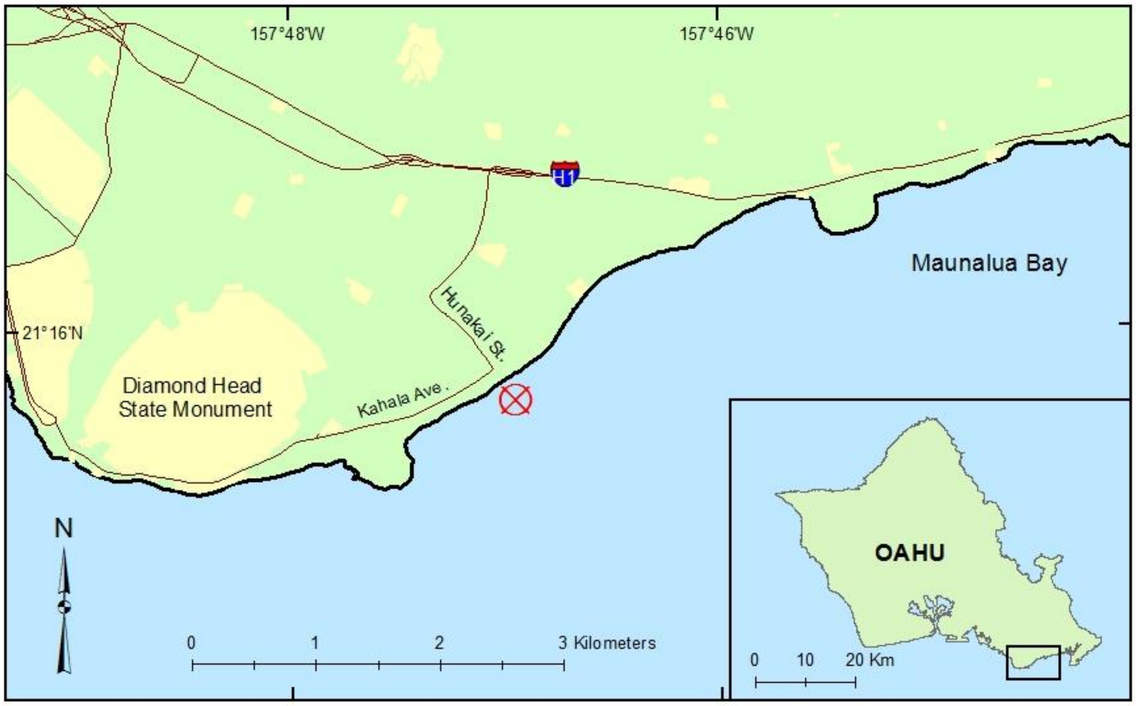

Figure 2.1 Map of Kahala Beach area indicating fish collection site.

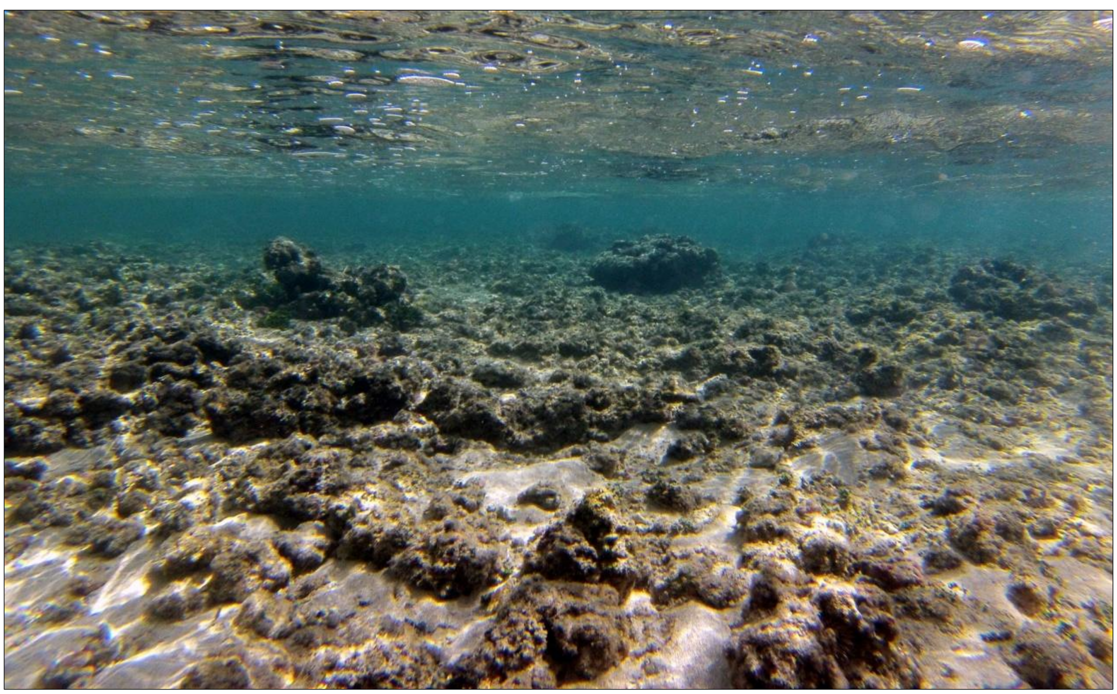

Figure 2.2 Photograph of *Eviota epiphanes* habitat and collection site.

For ageing analysis 53 individuals were selected to include a full range of available sizes. One sagitta otolith from each specimen was mounted, sulcus side down, on the edge of the microscope slide so that the core remained on the inner edge of the slide and the anterior end protruded off the edge of the slide. The anterior end was removed by holding the slide perpendicular to the lapping film (9 and 3µm) and wet ground until flush with the edge of the slide. The thermoplastic glue was then reheated and the otolith was repositioned to the center of the slide with the ground surface face down. The posterior end was hand ground using 3 and 1µm lapping film in water, until a thin section was obtained that showed the sequence of growth increments from the core to the outer edge. Progress was monitored and photographed at 60x magnifications on a computer monitor using an Olympus camera model DP72 mounted on an Olympus BX41 compound microscope.

The observed increments are assumed to be deposited daily as studies have confirmed daily increment deposition in three *Eviota* spp. (Depczynski & Bellwood 2006) as well as in an additional six species of reef-associated gobies (Hernaman et al. 2000; Shafer 2000). Using ImageJ 1.46r the otoliths were counted from the core to the edge along the longest axis. Each otolith was counted twice and the average of the two counts was used provided they agreed within 10%. When the two counts did not agree within 10%, a third count was taken and the average of the two closest counts was used.

E. epiphanes, like most reef fishes, have complex bipartite life cycles including a pelagic larval dispersal phase before beginning the sedentary benthic phase of their lives. The transition between the two phases is clearly shown on the otolith as a shift from more widely spaced increments to narrower increments, as well as a change in color and focal plane (Fig 2.3; Wilson and McCormick 1999). Pre settlement age was determined by counting the number of increments between the core and the distinct check mark indicating settlement. Histological samples were cross-referenced with aging data to determine size and age at first maturity (Schemmel unpublished).

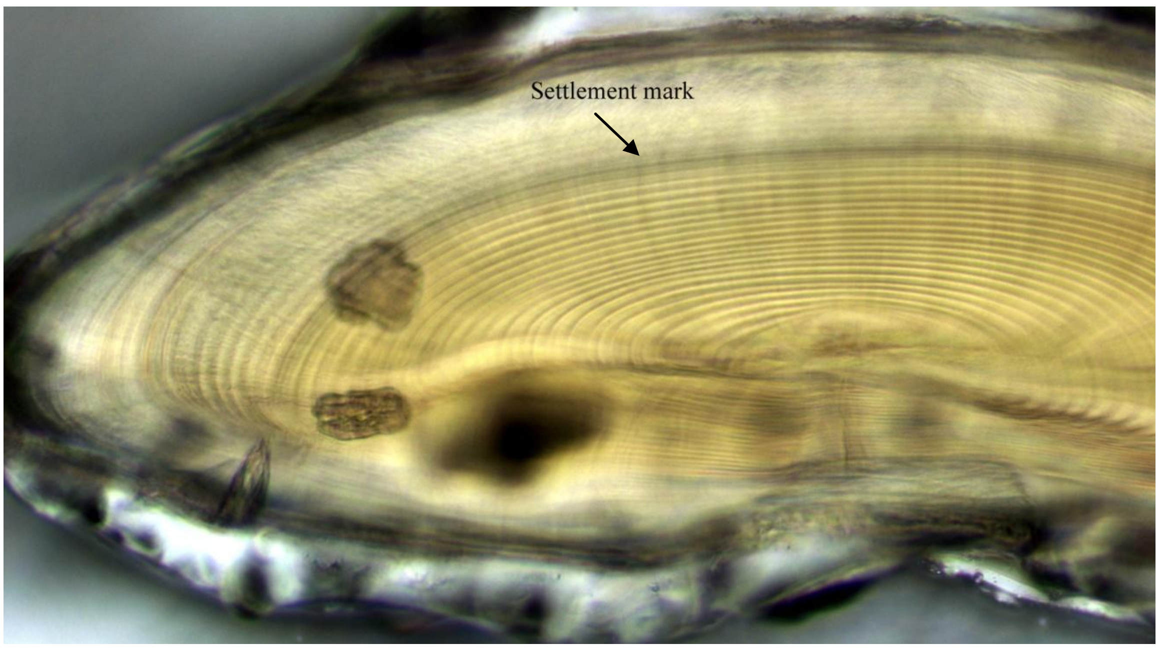

Figure 2.3 Transversely sectioned *Eviota epiphanes* sagitta otolith showing daily increments. Arrow denotes settlement mark indicating the transition from the pelagic larval phase to the benthic reef-associated phase. Not all increments are visible in this focal plane (40x magnification).

Growth trajectories from age-at-length data were fitted to three growth models: the von Bertalanffy growth function (VBGF), least-squares linear regression, and power curves. Goodness of fit of each model was tested by the residual sum of squares (RSS) and the coefficient of determination (r^2) calculated from the RSS and the total sum of squares (TSS).

The standard von Bertalanffy growth function models mean length at age using the following equation:

$$L_t = l_\infty[1 - e^{-k(T-t_0)}]$$

where L_t is the mean length in mm, T is the age in days, l_∞ is the mean asymptotic maximum length in mm, k is the rate at which L_t reaches l_∞ with units of yr^{-1}, and t_0 is the theoretical age at which the fish would have a length of zero assuming that the larval fish growth followed the post settlement growth pattern (Beverton & Holt 1957).

The length-weight relationship was determined from 138 specimens. The exponential equation in the commonly used form was fitted to the data:

$$W = a\,TL^b$$

where W is the total wet weight (g), TL is the total fish length (mm) and a and b are parameters in the allometric growth equation. Length-weight parameters were initially derived from the linearized version of this model (ln W = ln a + b ln L) and back transformed to fit to the actual data.

Mean generational turnover ($\overline{GT}$) estimates were calculated using the following equation:

$$\overline{GT} = AM + \left[\frac{T_{max} - AM}{2}\right]$$

where AM = age at maturation and T_{max} = maximum age. Assuming that a stable population exists, this gives a conservative averaged estimate for the time taken for a new generation to be generated (see Gaillard et al. 2005).

Natural mortality estimates were calculated using Pauly's (1980) M empirical equation:

$$\log(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543 * \log(K) + 0.4634\log(T)$$

where L_∞ is the asymptotic total length in cm, K is the VBGF growth constant, and T is the mean annual habitat temperature in ˚C (Pauly 1980).

Chapter 3. Results

Post-settlement growth was best described by the von Bertalanffy growth function. The growth parameters derived from the VBGF were L_∞ = 25.14 mm, K = 7.68 yr^{-1}, t_0 = 0, with an RSS=150.3 and r^2= 0.53 (Fig 3.1). However, of the three models tested there was not a significant difference between the VBGF and least-squares linear regression (F=2.55, p>0.25), nor between the VBGF and power curve (F=2.28, p>0.27; Figure 3.2; Table 3.1). The mean length (TL) at sexual maturity was 14.5 mm (Schemmel unpublished), while the age at sexual maturity, calculated from the mean length at sexual maturity, was 40.9 days, or 14.4 days post settlement.

From otolith analysis the mean pelagic larval duration (PLD) was found to be 26.5 (± 0.22 SE) days, representing 43.8% of the total life span. This corresponds to 34 days of post-settlement life and a maximum life span of 60.5 days.

For the length-weight relationship the values of parameters a and b of the allometric power equation were $W = 0.0024 * TL^{2.742}$, with an r^2= 0.89 (Fig 3.2). Maximum length recorded was 19 mm TL and mean generational turnover was 50.7 days. Daily natural mortality estimation from Pauly’s empirical equation was 3.6%.

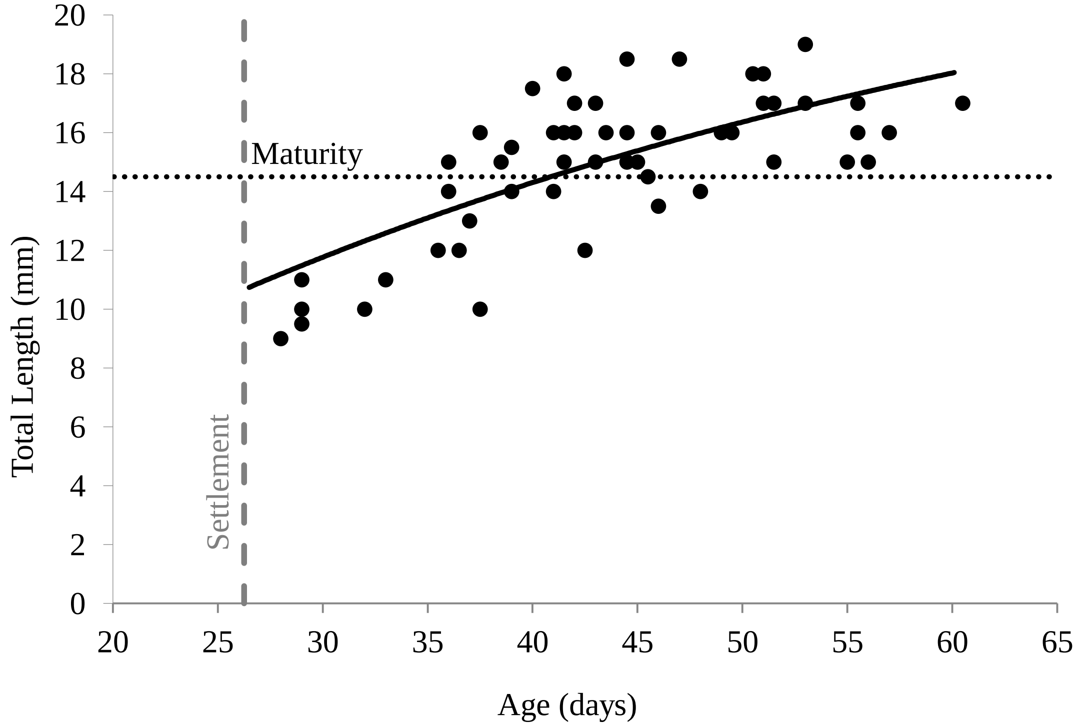

Figure 3.1 *Eviota epiphanes* age (days) versus total length (mm) showing the von Bertalanffy growth function, r^2= 0.53 (L_∞=25.14, K=7.68, t_0=0). Settlement line denotes the mean age at which the pelagic larval phase ends and the benthic reef-associated phase begins. Maturity line denotes mean size at maturity. N=53.

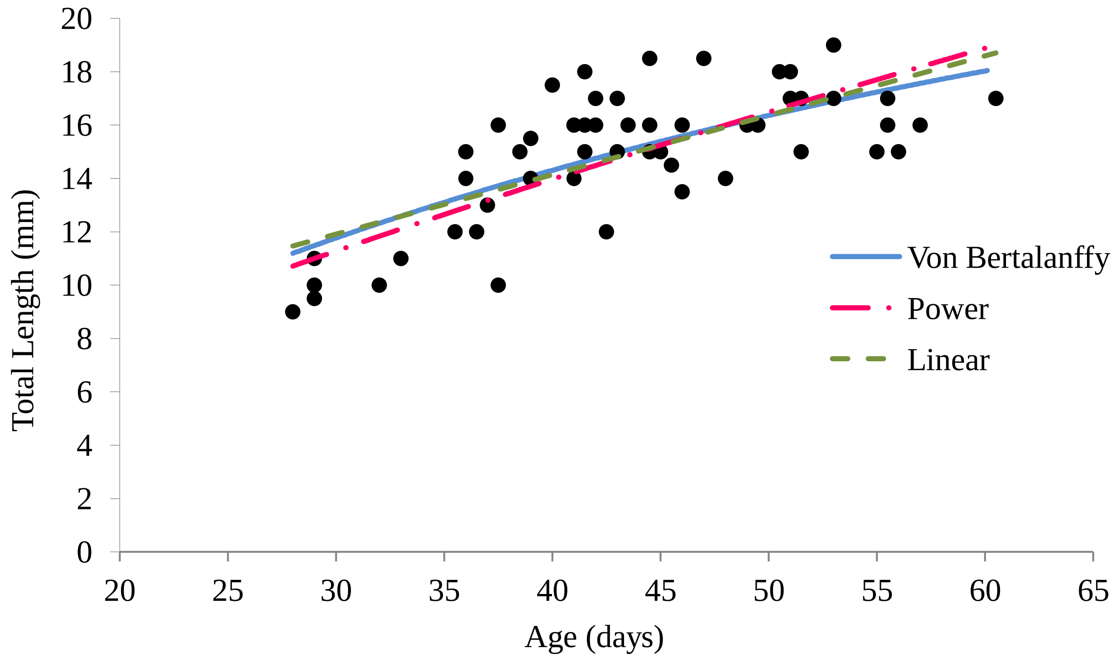

Figure 3.2 *Eviota epiphanes* age (days) versus total length (mm) showing the von Bertalanffy growth function (r^2= 0.53, L_∞=25.14, K=7.68, t_0=0), least-squares linear regression (r^2= 0.49), and power curves (r^2= 0.49). N=53

Table 3.1 Residual sum of squares (RSS) and the coefficient of determination (r^2) of each model tested. Although the models were not significantly different, the VBGF had the lowest RSS and highest r^2.

Model	**RSS**	**r^2**
Von Bertalanffy Growth Function	150.31	0.5354
Power curve	163.49	0.4947
Least-squares linear regression	165.08	0.4897

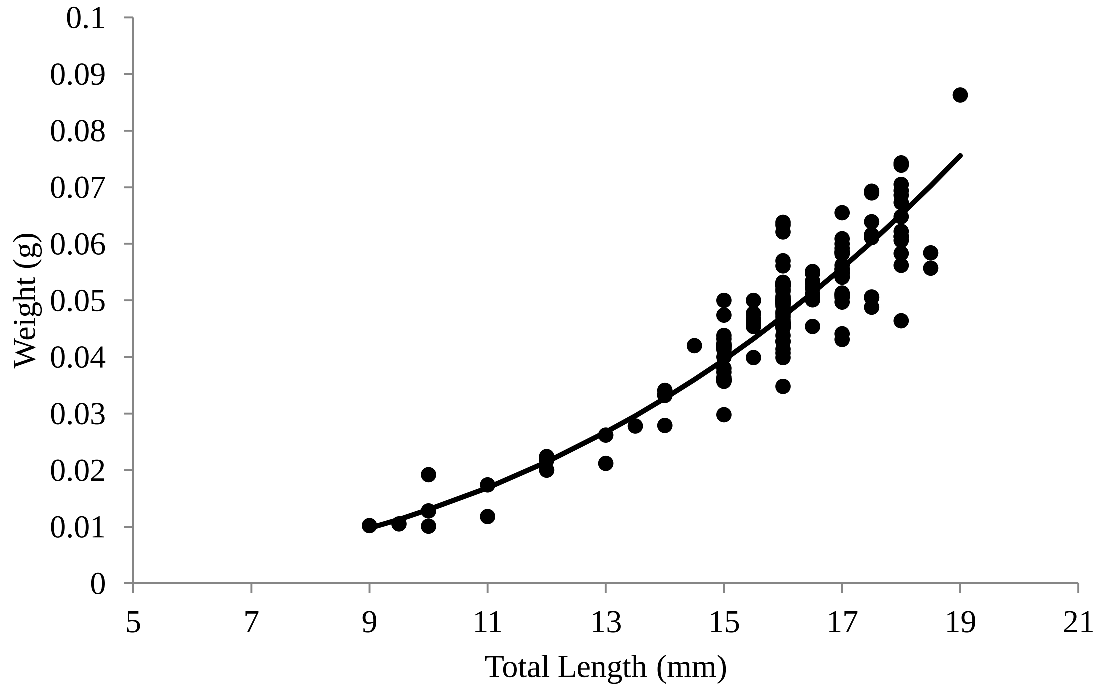

Figure 3.3 Length-weight relationship of *Eviota epiphanes*. The values of parameters a and b of the allometric power equation were $W = 0.0024 * TL^{2.742}$, with an r^2= 0.89. N=138.

Chapter 4. Discussion

Eviota epiphanes, along with three other *Eviota* species, represent some of the shortest-living and earliest maturing vertebrates known to date (Depczynski & Bellwood 2006). However, *E. epiphanes* growth patterns are not consistent with the linear growth observed in the other three species, but instead exhibits a curve-linear trajectory indicating a trade-off between somatic growth and reproduction.

Age-at-length data were not divided into male and female categories because *E. epiphanes* are known to be protogynous hermaphrodites and gonad morphology suggests that they are capable of bidirectional sex change (Cole 1990). Individuals were sexed based on the presence of sperm (male-acting) or secondary-stage oocytes (female-acting). Several individuals used for aging analyses had neither sperm nor secondary stage oocytes present, suggesting they were either not spawning and in a resting phase or were in the process of changing sex (Schemmel unpublished).

The pelagic larval duration *of E. epiphanes* is typical for many gobies (Brothers et al. 1983). However, the proportion of their total lifespan spent in the pelagic larval phase is extraordinarily long. The vast majority of reef fishes for which data exist spend <1% of their total life in the pelagic larval phase (Depczynski & Bellwood 2006), yet the PLD of *E. epiphanes* constitutes 43.8% of their entire life. The PLDs lack of response to extremely short life span supports an increasing amount of data indicating that there may be a minimum level of development (i.e. condition or size) required for pelagic young to be capable of settling, maturing and surviving on the reef (Depczynski & Bellwood 2006; Winterbottom & Southcott 2008; Searcy & Sponaugle 2000) .

Eviota epiphanes experienced a daily natural mortality of 3.6%. Natural mortality is expected to be primarily due to predation and is equal to total mortality since *E. epiphanes* is not exploited by humans. Theory suggests that a high mortality rate selects for early maturation and high reproductive effort (Miller 1996), and experiments show that high extrinsic mortality throughout prey life selects for earlier maturation and faster growth (Reznick & Endler 1982), but the extent to which it shapes the early life history traits of small fishes is not well understood (Depczynski & Bellwood 2006). Size at maturity typically happens at 65% of average asymptotic size in most fishes (Charnov 1993), however for *E. epiphanes* maturity occurred at 58%. This reduction is consistent with life history theory, and possibly is influenced by the high mortality rate.

Miller (1984) proposed that there may be a functional body-size threshold for gobiid fishes of 10 mm below which the teleost frame is unable to support reproduction. The delay in maturity observed in *E. epiphanes* until 14.5 mm may be explained by size specific predation. It has been hypothesized that other small prey species of fishes delay maturity so that they may focus on growth until they have outgrown the size class preferred by specific predators (Reznick & Endler 1982).

The asymptotic maximum size calculated by the VBGF was 24.96 mm, however 19 mm was the maximum length observed. This suggests that *E. epiphanes* do not live long enough to reach asymptotic size, likely due to high mortality rates, a trend often observed in small prey fishes (Depczynski & Bellwood 2006). The mean generational turnover rate of *E. epiphanes* is extremely high at 50.7 days, suggesting up to seven generations per year. High mortality rates, earlier maturation, and exceedingly high generational turnover rates all support the hypothesis that *E. epiphanes* plays an important role as a food source for larger piscivorous fishes that feed on smaller species, as these shifts in life history traits are often seen in prey species.

Chapter 5. Conclusion

This study lays the foundation for further research on *Eviota epiphanes* and their role in coral reef ecosystem function and trophodynamics. Density estimations, field mortality calculation and dietary analyses would tremendously increase our understanding of their importance in the coral reef ecosystem. Dietary composition studies that included *Eviota* spp. from the GBR found that they are capable of utilizing a wide variety of food items including amorphous organic matter, sediment, decapods, amphipods, and copepods, with the majority of their diet consisting of carnivorous items. If *E. epiphanes* does indeed feed primarily on crustaceans, as *Eviota* spp. did in the GBR studies, their short generation times, high susceptibility to predation, and fast turnover rates combined with their role as a trophic intermediate suggests that they may have a substantial affect on trophodynamics out of proportion with their size. This would support the argument for ecosystem-based management as opposed to management on a species-by-species basis. *E. epiphanes* may be an important prey species for larger fish that are exploited by fishermen. Due to the shy nature of these small cryptobenthic fishes it is very likely that there are numerous other important species of which we know little to nothing about.

Eviota epiphanes has many of the life history characteristics of small reef fishes: short lifespan, relatively long pelagic larval duration, early maturation, high adult mortality, and rapid generational turnover; *E. epiphanes* thus takes its place among several other gobiid fishes at the extreme small end of vertebrate body length scale, that live on the evolutionary and ecological fringe of current life history possibilities for vertebrates.

Appendix A: Individual Fish Length Weight and Age Data

Total Length (mm)	Standard Length (mm)	Weight (g)	PLD (days)	Age (days)
9	8	0.0102	27.5	28
9.5	9	0.0105	27.5	29
10	9.5	0.0128	29	29
10	12	0.0192	27	37.5
10	9	0.0101	26	32
11	9.5	0.0118	25.5	29
11	10	0.0174	26.5	33
12	10	0.0218	29.5	42.5
12	11	0.0224	27	35.5
12	10.5	0.02	27.5	36.5
13	10.5	0.0262	29.5	52
13	11	0.0212	27.5	37
13.5	12	0.0278	24.5	46
14	12.5	0.0341	27	48
14	12.5	0.0332	26.5	41
14	11.5	0.0334	28	39
14	12	0.0279	26.5	36
14.5	13	0.042	25	45.5
15	12	0.05	24.5	51.5
15	12.5	0.04	26	44.5
15	12.5	0.042	24.5	45
15	13.5	0.0364	26	36
15	12.5	0.038	25	41.5
15	13	0.0432	26	56
15	13.5	0.036	26.5	38.5
15	13	0.0373	27	43
15	13	0.0424	26	55
15.5	13.5	0.05	21.5	39

Continued on the following page.

Total Length (mm)	Standard Length (mm)	Weight (g)	PLD (days)	Age (days)
16	14	0.0621	23.5	49.5
16	14	0.057	23	41.5
16	13	0.0465	27.5	49
16	14	0.0527	25	37.5
16	14	0.05	26.5	41
16	14.5	0.0471	25	42
16	14.5	0.0527	25.5	43.5
16	14	0.05	24.5	46
16	13	0.0561	24	55.5
16	14	0.0399	26	44.5
16	13	0.05	29.5	57
17	13.5	0.0541	22.5	43
17	14	0.0431	26	51.5
17	14	0.0513	26.5	42
17	15	0.0509	26.5	55.5
17	15	0.0555	27.5	53
17	14	0.06	27	60.5
17	13.5	0.0497	27	51
17.5	14.5	0.0505	26	40
18	15	0.0694	26	51
18	14	0.0562	24.5	41.5
18	15	0.0705	27.5	50.5
18.5	16	0.0584	26	47
18.5	15	0.0557	27.5	44.5
19	16.5	0.0863	29	53

Glossary

Core – The area surrounding the primordium and bounded by the first prominent D-zone.

Cryptobenthic fishes − Fishes that are visually and/or behaviorally cryptic, and maintain a close association with the benthos.

D-zone – That portion of an otolith micro-increment that appears dark when viewed under transmitted light. This component of a micro-increment contains a greater amount of organic matrix and lesser amount of calcium carbonate than the L-zone.

Daily increment – An increment formed over a 24 hour period. In its general form, a daily increment consists of a D-zone and L-zone. The term is synonymous with "daily growth increment".

Generational turnover − Gives a conservative averaged estimate for the time taken for a new generation to be generated, assuming that a stable population exists.

Genital papilla − A small, fleshy tube behind the anus in some fishes, from which the sperm or eggs are released; the sex of a fish often can be determined by the shape of its papilla.

Ichthyocide − A chemical or organic substance which kills fishes.

Ichthyoplankton − The eggs and larvae of fish found mainly in the upper 200 meters of the water column, also called the near-surface waters.

L-zone – The portion of an otolith micro-increment that appears light when viewed under transmitted light. The component of the micro-increment that contains a lesser amount of organic matrix and a greater amount of calcium carbonate than the D-zone.

MS-222 – (Tricaine mesylate) A white powder used for euthanasia of fish.

Natural mortality – (M) The removal of fish from the stock due to causes not associated with fishing. Such causes can include disease, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish.

Otic vesicle – Epithelial sac that forms the semicircular canals dorsally and the otolith organs ventrally.

Otolith − consist of three pairs of small carbonate bodies that are found in the head of teleost (bony) fish. Otoliths are used by fish for balance, orientation and sound detection. They function similarly to the inner ear of mammals.

Pelagic larval duration – The amount of time a larva spends in the plankton; time between spawning of pelagic eggs (or hatching from demersal eggs) and settlement.

Protogynous hermaphrodite − Refers to organisms that are born female and at some point in their lifespan, based on internal or external triggers, changes sex to male.

Saggitae – (singular sagitta) The largest of the three pairs of otoliths found in teleost fish and the structure most often used for age determination.

Settlement − the permanent transition from the pelagic environment to the benthic environment.

Settlement check mark – A point or line of clear change in the appearance of the macrostructure or microstructure of the otolith indicating settlement.

Underwater visual census – (UVC) A non-destructive census method used in estimating the abundance of coral reef fishes. Examples include the transect method and the point and count method.

Von Bertalanffy growth function – (VBGF) The three parameter model of growth in length most commonly used in fisheries.

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