

SIZE AND AGE AT RECRUITMENT AND SPAWNING SEASON OF SLEEPER, GENUS *ELEOTRIS* (TELEOSTEI: ELEOTRIDAE) ON OKINAWA ISLAND, SOUTHERN JAPAN

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ABSTRACT. – Prior to recruitment into streams, pelagic larvae of three *Eleotris* species (*E. acanthopoma*, *E. fusca* and *E. melanosoma*) occur in the surf zone along the coast of Okinawa Island. Their size and age at recruitment and daily growth rate during pelagic larval life were investigated in this study. Size at recruitment of *E. fusca* (16 - 19 mm standard length, SL) was larger than those of the other two species (10 - 13 mm SL). Pelagic larval durations were estimated to be between two and four months by assessing the age of the recruits. The recruits of *E. acanthopoma*, whose pelagic larval life was during the warmer season (July - September), were smaller and younger than those who spent pelagic larval life during the colder season (January - March). The larval daily growth rates of *E. acanthopoma* were larger during the warmer season. The spawning seasons of *E. acanthopoma* and *E. fusca* in the streams on Okinawa Island were from May to December, but the hatch dates of some *E. acanthopoma* recruits were estimated to be during the non-spawning season. It was suggested that a proportion of the larval recruits of *E. acanthopoma* (and perhaps the two other species), were born in regions further South and they traveled to the streams on Okinawa Island. Their relatively longer larval duration may enable greater dispersals, although there is no guarantee of successful recruitment to the appropriate streams. Some of these dispersed larvae will thus be able to settle somewhere else even if their habitats are changed, in cases such as ruination of the stream on an island or changes in oceanic current flows. Such strategies may be advantageous to allow the descendants to remain among tropical and subtropical small island regions where unstable small streams are sparsely distributed.

KEY WORDS. – Pelagic larval duration, recruitment, dispersal, otolith, spawning season, *Eleotris*.

INTRODUCTION

Three species of *Eleotris* (*E. acanthopoma*, *E. fusca* and *E. melanosoma*) are known to inhabit streams on Okinawa Island, Southern Japan and they have different instream distribution patterns. *Eleotris acanthopoma* is distributed from the tidal area to the lower reaches of the freshwater area and *E. fusca* is distributed mainly in the freshwater area. *Eleotris melanosoma* is distributed in the tidal area in relatively low abundance (Maeda & Tachihara, 2004). All the three species spend a pelagic larval phase in the sea habitat. The larvae recruit into the streams and settle at sizes of about 10 - 13 mm in standard length (SL) for *E. acanthopoma* and *E. melanosoma* and about 16 - 20 mm SL for *E. fusca* (Maeda & Tachihara, 2005).

The transparent pelagic larvae were found in the surf zone of the beaches on Okinawa Island just before recruitment into streams. The recruitment larvae of *E. acanthopoma* from the surf zone were collected throughout the year of 1999 (Maeda & Tachihara, 2005), but their spawning season remains unknown. Thus, some questions have arisen regarding the recruitment of the three *Eleotris* species, such as the length of time they spend in the pelagic marine phase. For example, we have wondered if *E. acanthopoma* spawn in streams on Okinawa Island throughout the year or the variation in pelagic larval durations was so great that the recruits occurred throughout the year despite no larval supply during the non-spawning season. Shen et al. (1998) reported from otolith analysis that the estimated age at recruitment of two specimens of *E. acanthopoma* collected in Taiwan was about four months. However, the sample size was small and

conspecific pelagic larval durations may vary with different localities (Victor, 1986a; Wellington & Victor, 1992) and seasons (McDowall et al., 1994; Bell et al., 1995). Furthermore, the pelagic larval durations of *E. fusca* and *E. melanosoma* are not known.

Many authors have determined the pelagic larval durations of reef fish and amphidromous fish by counting the total number of otolith increments of fish newly recruited into adult habitats and/or the number of otolith increments between the core and “settlement check mark” of settled fish (e.g., Brothers et al., 1983; Radtke et al., 1988; McDowall et al., 1994; Sponaugle & Cowen, 1994; Bell et al., 1995). The larvae of various gobioid species, including *Eleotris*, were abundant in the surf zone of beaches near the mouths of streams on Okinawa Island. The developmental stages were uniform to just before recruitment into the streams for most species (Yamasaki et al., 2004; Maeda & Tachihara, 2005). Their ages are believed to represent the age at recruitment and therefore, the pelagic larval duration.

In this study, the age at recruitment of the three *Eleotris* species was estimated from the counts of otolith increments of larvae collected from the surf zones. And the size at recruitment and the daily growth rates during pelagic larval life were determined. We also present the spawning seasons of *E. acanthopoma* and *E. fusca* determined by observing monthly changes in their gonad weight. Expanding on these results, their larval dispersals and migratory strategies are also discussed.

MATERIALS AND METHODS

Spawning season. – Adults of *Eleotris acanthopoma* and *E. fusca* were collected from 21 streams from the Northern to the Southern part (26°06'N 127°40'E to 26°50'N 128°19'E) of Okinawa Island, Southern Japan with hand nets (caliber: ca. 30 cm; mesh size: ca. 1.5 mm) from January to December 1997. These specimens were fixed in 10% formalin and brought to the laboratory and the SL and body weights were measured. Gonads were dissected from each fish, weighed and preserved in 10% buffered formalin.

Sexes were usually distinguished by the morphology of the genital papillae and the gonads. However, the sexes of most specimens collected from January to April, especially for *E. acanthopoma*, could not be distinguished by the methods mentioned above. Therefore, thin sections of gonadal tissue stained with hematoxylin and eosin were prepared using routine histological procedures (Humason, 1979) for the specimens whose sex was not externally distinguishable and were observed with a light microscope to distinguish the sex.

The gonadosomatic index (GSI = gonad weight / body weight \times 100) was calculated for each specimen. In this study, only GSI values from specimens larger than 28.0 mm SL for *E. acanthopoma* (n = 310) and larger than 50.0 mm SL for *E. fusca* (n = 187) were used to determine the spawning season as they were considered to be mature at these sizes in spite

of their far larger maximum sizes (Maeda et al., 2005). Spawning seasons for *E. acanthopoma* and *E. fusca* were determined by monthly changes in the GSI. As *E. melanosoma* adults were rare, the GSI data for this species was not surveyed.

Size and age at recruitment. – The pelagic larvae of the three *Eleotris* species were collected along the surf zones of the sandy beach at Sedake (26°33'N 128°03'E) and the stony beach at Aritsu (26°35'N 128°08'E) on Okinawa Island using a small seine (1.0 mm mesh; 0.8 m in height; 3.5 m in width; cod end with a depth of 1 m and diameter of 0.7 m; sinkers attached along the bottom edge) at night from December 2003 to December 2004. All larvae were in a uniform phase just before recruitment into the streams (see description in Maeda & Tachihara, 2005). The larvae were sorted soon after collection and were brought to the laboratory packed in ice. The specimens were identified following the description of Maeda & Tachihara (2005). Their SL was measured using calipers under a stereomicroscope. The sagittal otoliths were extracted from the larvae and embedded on a glass slide using clear nail varnish. All otoliths which were investigated in the present study were sagittae. The number of increments in the otolith was counted from the core to the margin using a light microscope (Eclipse E600, Nikon) for age estimation.

To validate otolith increment periodicity, six pelagic larvae of *E. acanthopoma* collected in the surf zone of Sedake beach were brought to the laboratory and kept in sea water for one day and were then treated with otolith-marking methods using alizarin complexone (ALC). The larvae were transferred into a 4 L bucket containing ALC and salt solution (50 mgL⁻¹ ALC; salinity, 18 ppt) and kept there for 24 hours. The larvae were then reared in a 4 L tank containing salt solution (18 ppt) without ALC for 13 days before a second treatment with the ALC and salt solution for 24 hours. After an additional seven days of holding in the tank without ALC, the otoliths of the six larvae were extracted, embedded on a glass slide using clear nail varnish and observed under a fluorescence microscope (Microphot-FXA, Nikon). At that time, all the fish had already settled and measured 13.1 - 14.9 mm SL. The otolith increments between the two marks checked by ALC were counted using normal and ultra-violet light. The counts were compared with the number of days for the interval of ALC treatments (i.e. 13 days).

RESULTS

Spawning season. – Monthly changes in the GSI of *Eleotris acanthopoma* are shown in Figure 1. The GSI of specimens collected from January to April (n = 58) were below 0.5 for males and below 0.7 for females and their sexes were not distinguishable based on the morphology of the genital papillae and gonads. The GSI of females began to increase from May and remained high through to December (monthly average GSI value > 2.0). The GSI of males began to increase from May, peaked in July (mean \pm standard deviation = 1.6 \pm 1.1), then gradually decreased and dropped to 0.3 \pm 0.2 in December.

Monthly changes in the GSI of *E. fusca* are shown in Figure 2. Unlike *E. acanthopoma*, most *E. fusca* females had distinctive genital papillae, allowing visual identification of their sex throughout the year. The GSI of females was below 1.3 from January to March with the exception of a specimen collected in January having a GSI of 7.9. The GSI of one female (3.0) increased in April and the GSI was higher from May to November (monthly average GSI value > 4.0), after which the mean GSI decreased in December (1.8 ± 2.5), although one female had the highest GSI observed during this study (10.3). The GSI of males were quite low (< 0.4) from January to April and then began to increase from May with a peak in August (1.5 ± 0.2) and then gradually decreased with a mean value of 0.5 ± 0.8 in December.

General description of otolith microstructure. – Otoliths were plate-like ovals that are strongly warped (Fig. 3A). All the otoliths of the six larvae subjected to the ALC treatment had two bands stained with ALC (ALC checks) which were observed using ultra-violet light and one strong check mark which was seen using normal light after being synchronized with the inner ALC check. A faint check mark also occurred together with the outer ALC check in some specimens. They had many fine rings and those on the inside of the inner ALC check were clearer. Although these rings at the outside of the inner ALC check were somewhat more faint than those on the inside, 12 or 13 rings (mean: 12.7) were observed between the two ALC checks. The number of rings matches the number of interval days between the two ALC treatments

(i.e. 13 days). Hence, the results show that the rings were deposited daily, at least during from late pelagic to the early settling periods.

There was one oblong spot and a single strong ring (core ring) closely surrounding the spot at the core of the otolith (Fig. 3B). The mean diameter at the longest axis of this core ring was 0.014 mm for all species (*E. acanthopoma*, 0.014 ± 0.001 mm, $n = 155$; *E. fusca*, 0.014 ± 0 mm, $n = 12$; *E. melanosoma*, 0.014 ± 0.001 mm, $n = 4$). In the present study, we assumed that the number of increments between the core ring and the margin of the otolith represents the age (in days) since hatching.

Size and age at recruitment. – Pelagic larvae of *E. acanthopoma* were collected in every month surveyed, while those of *E. fusca* occurred in March, August, November and December and those of *E. melanosoma* only occurred in November and December. The SL of pelagic larvae of *E. fusca* collected in the surf zones (15.5 - 19.1 mm, $n = 13$, Table 1) were larger than those of *E. acanthopoma* (9.8 - 13.4 mm, $n = 315$, Fig. 4) and *E. melanosoma* (12.0 - 12.4 mm, $n = 4$, Table 1). The data correspond with the results of Maeda & Tachihara (2005). The monthly sizes of *E. acanthopoma* larvae at recruitment are shown in Figure 4. The sizes of most larvae collected from January to May were larger than 11.0 mm, while the SL of more than half the larvae collected in August and September were smaller than 11.0 mm.

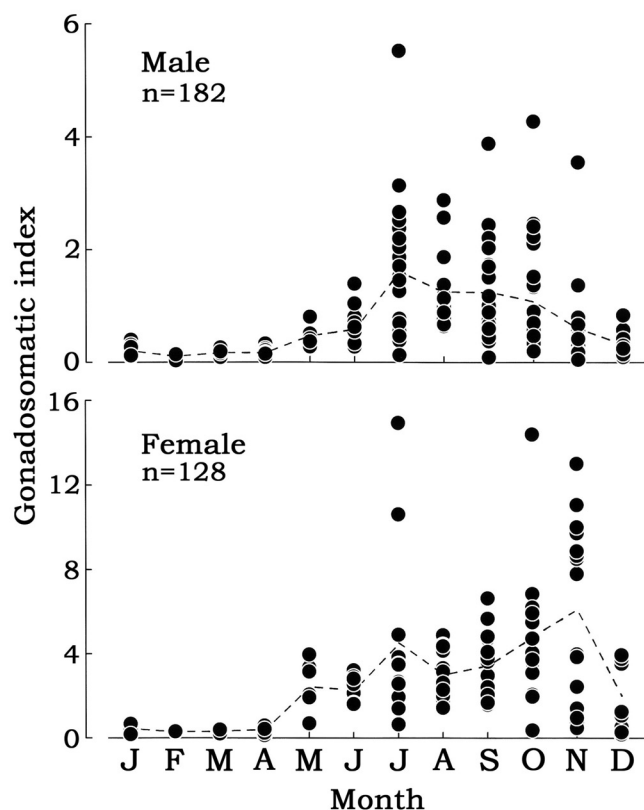


Fig. 1. Monthly changes in the gonadosomatic index (GSI) of *Eleotris acanthopoma* larger than 28 mm SL, collected from streams on Okinawa Island in 1997 (broken line represents trend passing through monthly mean values). n = sample size.

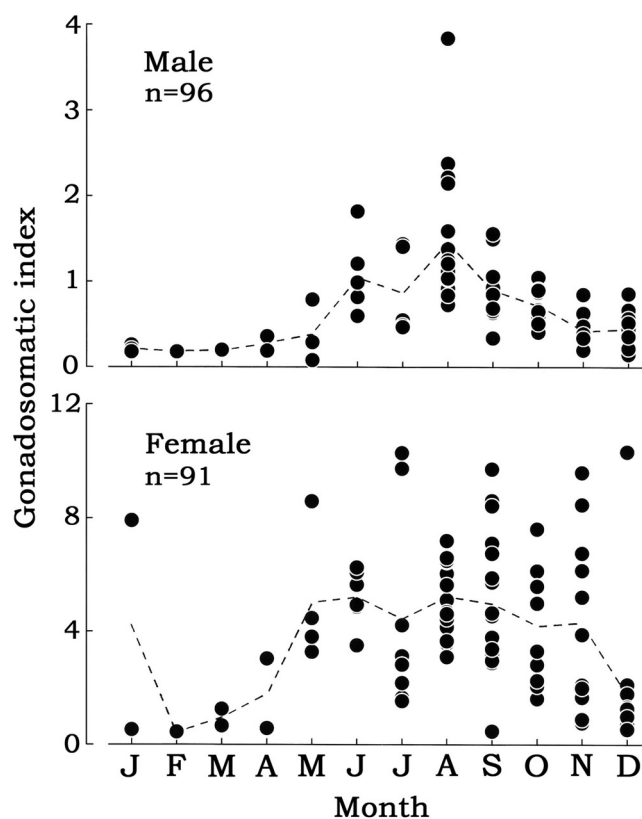


Fig. 2. Monthly changes in the gonadosomatic index (GSI) of *Eleotris fusca* larger than 50 mm SL, collected from streams on Okinawa Island in 1997 (broken line represents trend passing through monthly mean values). n = sample size.

Table 1. Data for *Eleotris fusca* and *E. melanosoma* larvae collected at the surf zones along the coast of Okinawa Island in 2004. Data for *E. fusca* in December are shown as mean \pm standard deviation. The number of otolith increments and the daily growth rate of one specimen of *E. fusca* could not be determined.

	March	August	November	December
<i>Eleotris fusca</i>				
No. of specimens	1	3	1	8
Standard length (mm)	16.4	15.5, 15.7, 17.2	16.9	16.8 \pm 1.0 (N = 8)
No. of otolith increments	108	111, 98, 101	84	93.9 \pm 8.9 (N = 7)
Daily growth rate during pelagic larval life (mm/day)	0.14	0.13, 0.15, 0.16	0.19	0.17 \pm 0.01 (N = 7)
<i>Eleotris melanosoma</i>				
No. of specimens	0	0	1	3
Standard length (mm)	-	-	12.1	12.0, 12.3, 12.4
No. of otolith increments	-	-	83	81, 84, 81
Daily growth rate during pelagic larval life (mm/day)	-	-	0.13	0.14, 0.13, 0.14

The number of daily growth increments of larval otoliths ranged from 62 to 125 for *E. acanthopoma* (n = 155, Fig. 5), from 84 to 111 for *E. fusca* (n = 12, Table 1) and from 81 to 84 for *E. melanosoma* (n = 4, Table 1). These numbers were considered to represent their age at recruitment. The age of larval *E. acanthopoma* collected changed monthly (Fig. 5). Most larvae collected from January to May were older than 90 days and some were over 120 days, while most larvae collected from August to November were younger than 90

days with some below 70 days. The difference of ages between the oldest and youngest recruits was 64 days, but the differences within each month were from 11 to 42 days (Fig. 5). The mean ages of *E. fusca* (94 days, n = 7) collected in December 2004 (the month when more than half the specimens of *E. fusca* and *E. melanosoma* were collected) were slightly older than those of *E. acanthopoma* (88 days, n = 12) and *E. melanosoma* (82 days, n = 3) collected during December 2004, but the differences were not significant ($P > 0.05$).

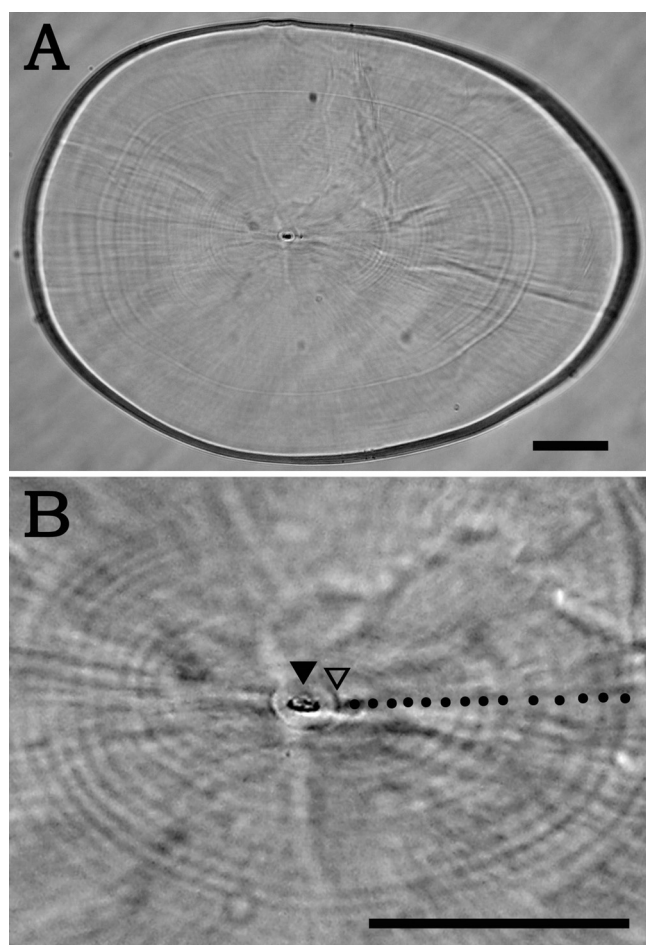


Fig. 3. Sagittal otolith of an *Eleotris acanthopoma* larva (11.1 mm SL) collected at Sedake Beach on Okinawa Island in October 2004. A) entire picture focused at the core, B) magnified picture around the core. Scale bar = 50 μ m. Solid triangle = core spot; open triangle = core ring; dots = otolith increments.

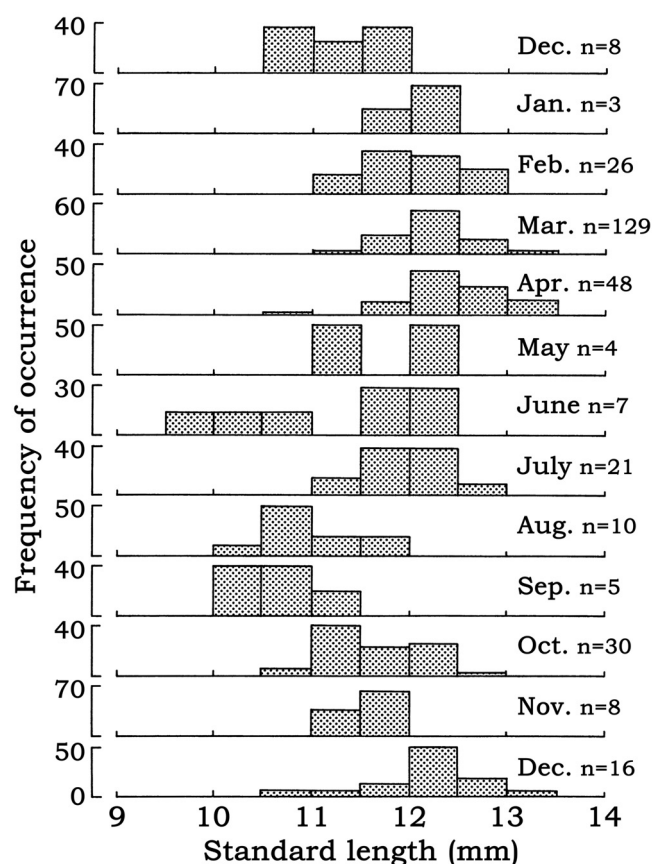


Fig. 4. Monthly distributions of the standard lengths of *Eleotris acanthopoma* larvae collected at the surf zones along the coast of Okinawa Island from December 2003 to December 2004. n = sample size.

Monthly changes in mean size and age at recruitment of *E. acanthopoma* are shown in Figure 6, with mean water temperature measured at a 10 m depth at three typical survey stations off Okinawa Island (25°50'N 127°50'E to 26°00'N 128°00'E) for an average year (from Shimojo, 2005: 60). The water temperature during the present investigation for size and age (largely in 2004) was similar to that of the average year (Shimojo, personal communication). Monthly changes in recruitment size and age appeared to be synchronized and both were larger from winter to spring (January - May) than from summer to autumn (August - November) (Fig. 6). The months with maximum recruitment size and age (April and May) were two to three months away from the coldest month (February) and the month with minimum recruitment size and age (September) was one month away from the warmest month (August). There was a significant positive correlation between size and age at recruitment ($r = 0.46$, $n = 155$) ($p < 0.01$), with larger larvae being older (Fig. 7).

Mean daily growth rates of individual larvae collected in each month were calculated as $[(\text{SL at recruitment} - 1 \text{ mm}) / \text{number of increments}]$ and are shown in Figure 6 and Table 1. Since the notochord length of newly hatched larvae of both *E. acanthopoma* and *E. fusca* were 1.0 - 1.4 mm (Maeda et al., 2005), "SL - 1 mm" was considered to indicate the growth during pelagic larval life. The size at hatching of *E. melanosoma* larvae is not known, but we assumed that they

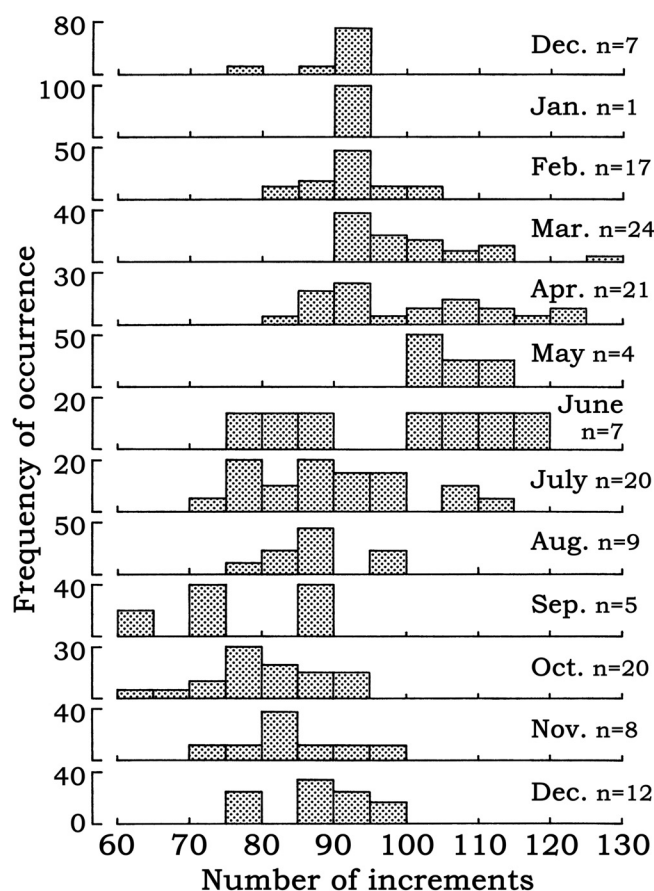


Fig. 5. Monthly distributions of the number of otolith increments of *Eleotris acanthopoma* larvae collected at the surf zones along the coast of Okinawa Island from December 2003 to December 2004. n = sample size.

were similar to those of the other two species. The growth rates ranged 0.094 - 0.179 mm/day for *E. acanthopoma* ($n = 155$), 0.131 - 0.189 mm/day for *E. fusca* ($n = 12$) and 0.134 - 0.141 mm/day for *E. melanosoma* ($n = 4$). Monthly changes in daily growth rates of *E. acanthopoma* appeared to be the inverse of those of size and age at recruitment and synchronized with water temperature with a delay of two to three months (Fig. 6). The month with the minimum growth rate (May) was three months away from the coldest month (February) and the month with the maximum growth rate (October) was two months away from the warmest month (August). The mean growth rates of *E. fusca* larvae collected in December 2004 (0.169, $n = 7$) were significantly larger than those of *E. acanthopoma* (0.128, $n = 12$) and *E. melanosoma* (0.137, $n = 3$) (both $p < 0.01$) while difference between the two latter species was not significant ($p > 0.05$).

Birth months of *E. acanthopoma* larvae ($n = 155$) estimated by collection date and age, was throughout the year (Fig. 8). Birth months for *E. fusca* larvae ($n = 12$) were estimated to be in April, May, August, September and December and those of *E. melanosoma* larvae ($n = 4$) to be in August and September.

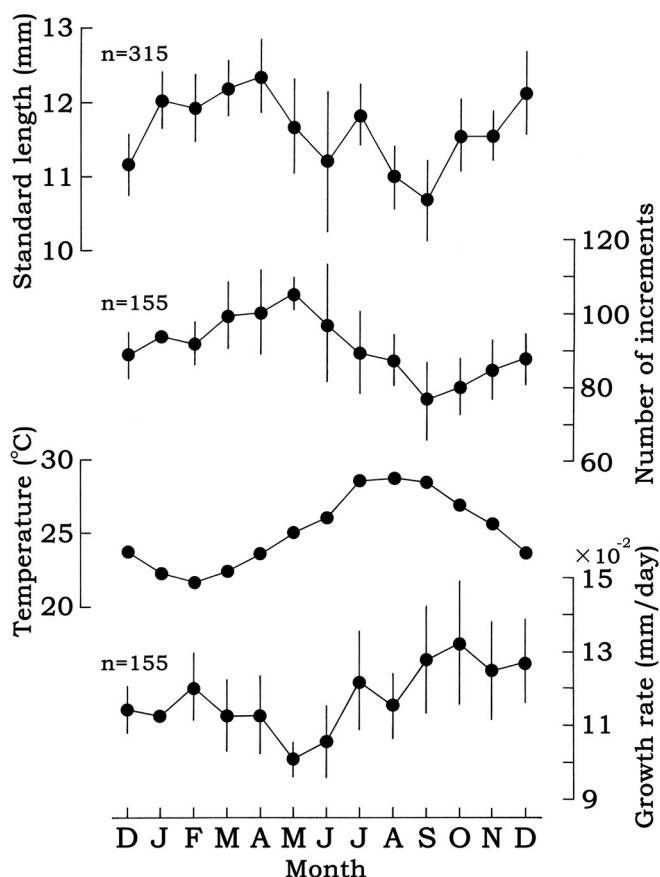


Fig. 6. Monthly changes in standard length, number of otolith increments and daily growth rate during pelagic larval life (mean \pm standard deviation) of *Eleotris acanthopoma* larvae collected at the surf zones along the coast of Okinawa Island from December 2003 to December 2004. Mean water temperature was measured at 10 m depth at three typical survey stations off southern Okinawa Island (25°50'N 127°50'E to 26°00'N 128°00'E) in an average year (Shimojo, 2005: 60). n = sample size.

DISCUSSION

Spawning season. – The spawning season of *Eleotris acanthopoma* in streams on Okinawa Island, based on the GSI fluctuations, was determined to be from May to December. It was not possible to determine if *E. fusca* spawned in the winter season due to insufficient collections from January to April. However, the fact that the newly-hatched drifting larvae of *Eleotris* spp. occurred in streams on Okinawa Island mainly from May to December and were never caught in February and March (our unpublished data), suggested that the spawning season of *E. fusca* was largely from May to December.

Pelagic larval dispersals. – The pelagic larval habitat of *Eleotris* is not known. Based on their absence, however, it has been suggested that larvae do not spend the bulk of their pelagic life in freshwater, estuaries and surf zones of coastal areas. This is with the exception of newly hatched drifting larvae and larvae just before recruitment (Maeda & Tachihara, 2005). Generally, the vertical distribution of the pelagic larvae of reef fish in oceanic waters is confined primarily to the upper depths of 100 m (Leis, 1991: 209). We assumed that the *Eleotris* larval habitat is the upper layer of offshore and/or near shore water. Relationships between size and age at recruitment of *E. acanthopoma* and sea water temperature at a 10 m depth (Fig. 6) show that the recruits that spent their pelagic larval phase during the warmer season were smaller and younger. Conversely, the recruits that spent their pelagic larval phase during the colder season were larger and older. Fluctuations of daily growth rates documented that they grew faster during the warmer season. Similar trends of size, age and temperature have been reported for the diadromous galaxiid, *Galaxias maculatus* in New Zealand (McDowall et

al., 1994) and the Hawaiian amphidromous goby, *Lentipes concolor* (Radtke et al., 2001). On the other hand, Bell et al. (1995) reported different trends with sicydiine gobies, *Sicydium punctatum* and *S. antillarum* in Dominica, where age at recruitment varied seasonally and was inversely-related to the seasonal variation in size at recruitment and growth rate.

McDowall et al. (1994) reported that the age at recruitment of *Galaxias* species with larger recruits was older than congener species with smaller recruits. Although we had presumed that the larger size of *E. fusca* recruits required longer pelagic larval durations, the pelagic larval durations of *E. fusca* were not significantly longer than those of *E. acanthopoma* and *E. melanosoma*. Therefore, it is suggested that the larger size of *E. fusca* recruits is a result of a faster growth rate rather than of a longer pelagic larval duration.

In the present study, pelagic larval recruits of *E. acanthopoma* were collected throughout the year in 2004. However, estimated hatch dates for all the larvae which were recruited from May to June, were dated to their non-spawning season (January to April). And hatch dates of more than half the larvae collected in April and July were also estimated as being January or April (Fig. 8). Maeda & Tachihara (2005) documented that the larvae also occurred at the surf zone of Sedake beach throughout the year in 1999 and the number of recruits caught from April to July cannot be ignored. Therefore, it is suggested that considerable portions of recruits observed from April to July were born on other islands and drifted to Okinawa Island. This is possible if they spawned from January to April in regions further South of Okinawa Island.

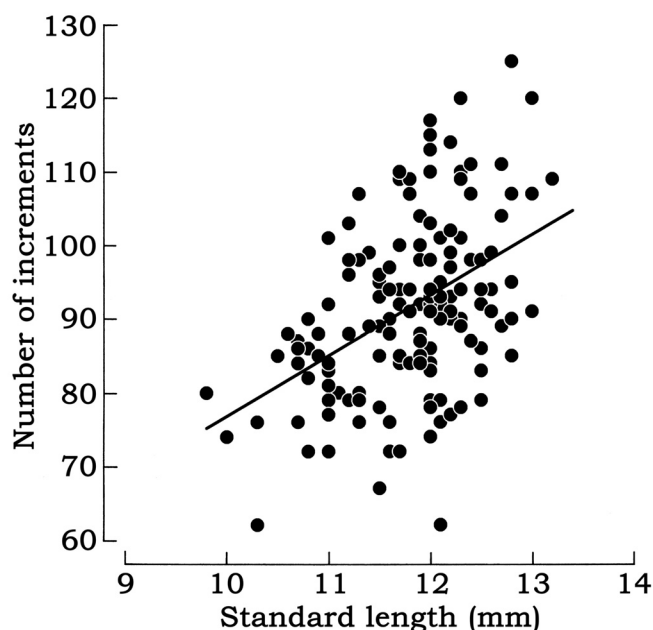


Fig. 7. Correlation between standard length (X-axis) and number of otolith increments (Y-axis) of *Eleotris acanthopoma* larvae collected at the surf zones along the coast of Okinawa Island from December 2003 to December 2004. The regression equation is $Y = 8.21X - 5.30$; regression coefficient, $r = 0.46$; sample size, $n = 155$.

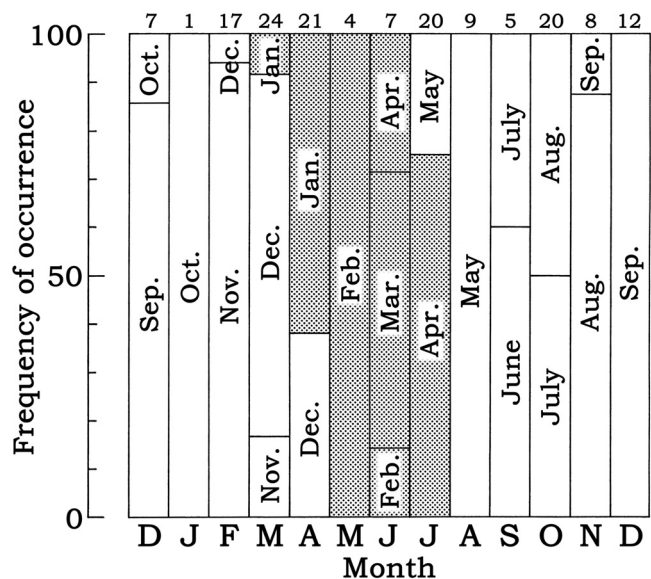


Fig. 8. Estimated birth month composition of *Eleotris acanthopoma* larvae collected at the surf zones along the coast of Okinawa Island from December 2003 to December 2004. Numbers above blocks show the number of specimens examined. Shaded blocks represent larvae whose birth months are dated in the non-spawning season on Okinawa Island (i.e. January to April).

For *E. fusca* and *E. melanosoma*, the data concerning spawning seasons and estimated hatch dates were not sufficient to discuss their relationships. However, their larger or similar size and age at recruitment compared with *E. acanthopoma* and similarity of larval morphologies and recruitment patterns (Maeda & Tachihara, 2005) suggested that at least a proportion of their recruits were also born on other islands and traveled across the ocean.

Thus, the origin of such foreign larvae of the three *Eleotris* species remains to be answered. We suspect that most of them come mainly from the Yaeyama Islands, located approximately 400 km Southwest of Okinawa Island. This is because the Islands are located upstream of the Kuroshio Current and has many streams with an abundance of *Eleotris* spp. (Suzuki & Senou, 1981, 1982). In addition, the Philippines may also be source islands of foreign larvae. There were no genetic differences among some island populations of Hawaiian amphidromous gobioids, suggesting that their pelagic larvae have transferred between Islands within Hawaiian Archipelago (Fitzsimons et al., 1990; Zink et al., 1996; Chubb et al., 1998). Genetic studies might give some suggestions for the exchange of larval gobioids in the Ryukyu Archipelago.

Pelagic larval durations of the three species of *Eleotris* examined here were about two to four months long, although the number of specimens of *E. fusca* and *E. melanosoma* collected might not be enough to represent the entire range of durations. Estimated larval durations of two specimens of *E. acanthopoma* collected in Taiwan were also reported as being four months (Shen et al., 1998). Age at recruitment of *E. pisonis* (n = 21) in Dominica was estimated to be around three months, but two specimens showed older ages of up to five and a half months (Bell et al., 1995). Reared *E. oxycephala* in Japan settled at 61 days after hatching in water temperatures of 22 - 29°C (Dotsu et al., 2004). Those with longer durations than the one to two months reported for typical coastal marine gobies (Brothers et al., 1983; Sponaugle & Cowen, 1994), corresponded to the two to six months reported for some amphidromous sicydiine gobies and their relatives, such as *Lentipes concolor*, *Stenogobius hawaiiensis* and *Awaous guamensis* in Hawaii (Radtke et al., 1988, 2001; Radtke & Kinzie, 1996), *Sicydium punctatum* and *S. antillarum* in Dominica (Bell et al., 1995) and *Sicyopterus japonicus*, *A. melanocephalus* and *Stenogobius genivittatus* in Taiwan (Shen et al., 1998). Kinzie (1997: 32) noted in discussions on the long larval life of Hawaiian amphidromous goby that he lacked data for pelagic larval durations of amphidromous gobioids from large island systems such as Japan, Taiwan, the Philippines and from continental streams. Hence, he could not speculate whether long larval life is related to the isolation of oceanic islands or is common to amphidromous gobioid fish. Recent works showed that some Taiwanese (Shen et al., 1998) and Okinawan (Yamasaki et al., 2004) amphidromous gobioids have a shorter pelagic larval life (about one month). Thus, all amphidromous gobioids in these regions may not have a long pelagic larval duration. Only some species (including *Eleotris* and sicydiine gobies) are considered to have relatively longer larval

durations. These longer pelagic larval durations may enable wide-range dispersal. The larvae of the eleotrid, *Dormitator latifrons* were found about 400 km offshore of Baja California (Watson, 1996) and their larval morphology resembled *Eleotris* larvae. This supports our hypothesis that some eleotrid larvae disperse widely in offshore sea regions.

Miller (1998) discussed the possibility of transatlantic larval dispersal in a study of amphiatlantic affinities in the genus *Eleotris*. He noted that their larval duration may be too short for the estimated transatlantic drift (96 days) but necessary information about their postlarval biology was lacking. The present study suggested that the pelagic larval durations of at least some *Eleotris* species were long enough and they would have the ability for wider dispersal if transported by adequate current.

Radtke et al. (1988), Radtke & Kinzie (1996) and Keith (2003) considered that longer pelagic larval durations of the Hawaiian amphidromous gobies may increase the likelihood of finding an appropriate stream in which to recruit. We speculate that the longer pelagic larval duration enables wider dispersal and the likelihood of finding streams may be increased by a greater variability of larval duration rather than only by the obligate long larval duration. The potential of longer larval life enables a delay in metamorphosis (sensu Victor, 1986b; Wellington & Victor, 1989, 1992). However, our results showed that the difference of age at recruitment was restricted to within about 30 - 40 days and these were not as significant as the results of Bell et al. (1995) (about two months for *Sicydium punctatum* and *S. antillarum* and two and a half months for *E. pisonis*).

We conclude that the long larval durations and expected wide larval dispersals of Okinawan *Eleotris* may cause high mortality among pelagic larvae and suspect that large numbers of larvae cannot recruit to the appropriate streams. These dispersals seem to be wasteful but some dispersed larvae will be able to settle at new habitats even if their natal habitats are changed, such as by ruination of streams on an island. These dispersals will also be significant when oceanic current flow is changed. Members of the genus *Eleotris* are found worldwide in tropical and subtropical fresh and brackish waters (Bussing, 1996). *Eleotris acanthopoma* is widely distributed in the Western and Southern Pacific regions and *E. fusca* and *E. melanosoma* have an even greater distribution throughout the Western and Southern Pacific and Indian Oceans (Akihito et al., 2000). The sicydiine gobies, which share some aspects of their life history such as large size and age at recruitment with *Eleotris*, are also distributed in tropical and subtropical insular and coastal streams (Parenti & Maciolek, 1993). Okinawan amphidromous gobioid species with shorter pelagic larval duration typically do not have such wide distributions (Yamasaki et al., 2004). In tropical and subtropical small island regions, there are no large stable freshwater habitats comparable to major rivers on large islands or continents. Life cycles repeated in restricted areas (such as a small island) would only result in destruction of all their descendants when habitats are lost. The strategies of long larval duration and wide larval dispersals may be advantageous to allow the descendants to remain among

tropical and subtropical small island regions where unstable small streams are sparsely distributed.

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