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Growth and Estimated Production of *Acanthogobius flavimanus* in an Eelgrass (*Zostera marina*) Bed and Unvegetated Tidal Flat of Dongdae Bay

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Abstract: The growth and estimated production of *Acanthogobius flavimanus* (1.9~24.7 cm TL) were investigated in an eelgrass bed and unvegetated tidal flat of Dongdae Bay, Korea from March 2006 to February 2007. Growth in fish total length was expressed by the von Bertalanffy's growth equation as: $L_t=43.238(1-e^{-0.3138(t+0.2507)})$. Estimated densities, biomass, daily and annual production, and P/B ratio were higher at eelgrass bed than those of at unvegetated tidal flat. Monthly variation in daily production was large; the peak numbers occurred in November 2006 (0.0014 g/m^2/day) at eelgrass bed, whereas was 0.002 g/m^2/day in July 2006 at unvegetated tidal flat. The eelgrass bed has been supported to maintain capacity of higher production of *A. flavimanus* than those of in unvegetated tidal flat.

Key words: *A. flavimanus*, growth, production, eelgrass bed, unvegetated tidal flat

INTRODUCTION

Zostera marina (eelgrass) is the most common seagrass species in temperate coastal areas and increases habitat complexity and provides living space and shelter for marine animals (Klumpp et al., 1989; Connolly et al., 1999; Hemminga and Duarte, 2000). *Acanthogobius flavimanus* (family Gobiidae) was distributed widely throughout the coastal water around Korean peninsula, and have been described one of common fish species in an eelgrass bed (Huh and Kwak, 1997; Go and Cho, 1997, Lee et al., 2000; Hwang, 2007). Recent studies of *A. flamivanus* have been concentrated on the characteristics of morphology and internal organs (Park et al., 2005; Lee, 2001), but few ecological studies was described except feeding habits in Kwangyang Bay (Huh and Kwak, 1999).

Shallow waters with rich eelgrass beds are located in Dongdae Bay where have never been influenced by human impacts until now provide a habitat for variety of invertebrates and small fish, particularly which in turn are the potential food of large fishes. Although some studies on fish have been conducted in Dongdae Bay, their interest was confined to feeding habits of particular fish species, *Pseudoblennius percoides* and *Hippocampus mohnikei* (Huh et al., 2008; Kwak et al., 2008). On the other hand, several studies of estimate production in gobiidae, for example, *Pomatoschistus minutus, Pomatoschistus microps, Gobius cobitis, Gobius paganellus,* and *Lesueurigobius friesii*, have been demonstrated in the coastal areas worldwide (Miller, 1961; Gibson, 1970; Gibson and Ezzi, 1978; Dolbeth et al., 2008).

The objectives of this study were to examine growth and estimated production of *A. flavimanus*, one of dominant fish species, inhabiting an eelgrass bed of Dongdae Bay, Korea and to compare with those in the unvegetated tidal flat in close to an eelgrass bed. It is a fundamental part of a wider study aimed at understanding the functional characteristics on fish assemblages, and also first approach for estimate production of fish species in coastal area including eelgrass beds in Korea.

MATERIALS AND METHODS

The eelgrass, *Zostera marina* is widespread in shallow areas, forming subtidal bends (800-1,000 m wide) along the shoreline of Dongdae Bay (Fig. 1). A total 296 *Acanthogobius flavimanus* were collected with a small beam trawl (1.9 cm mesh wing and body, 0.6 cm mesh liner) in an eelgrass bed and unvegetated tidal flat, and all fish samples were preserved immediately in 10% formalin after capture and measured their total length and body weight to the nearest

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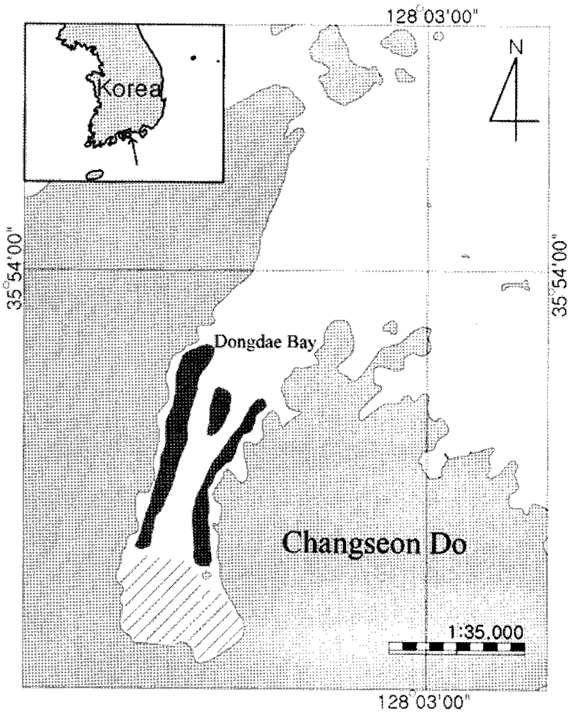

Fig. 1. Location of the study areas (The black area: eelgrass bed, the oblique area: unvegetated tidal flat).

millimeter and 0.01 g in the laboratory. Water temperature at the study site ranged from 6.2 to 24.2°C, and salinity ranged from 28.5 to 34.8‰ in the study area.

Calibration of fish density data using box drop trap

In order to allow data collected by small beam trawl to be expressed per unit area of seafloor, 1 m^2 box drop trap with 700 mm high sheet-metal sides were used in an eelgrass bed and unvegetaed tidal flat. Similar box drop trap have been used effectively with quantitative survey of fishes, and their virtues and efficiencies discussed in other studies of seagrass fishes (Huh, 1984; Sogard et al., 1987, 1989; Holmquist et al., 1989). Seven replicate traps were dropped onto the substratum in ≈0.3 m water depth from the front of a small boat as it drifted with the current across the study site. Fishes were removed from the trap using small hand nets which were moved form side to side within the trap until no further animals. Mean numbers of fish collected in box drop trap were considered to represent absolute densities for small demersal fish species, and these densities used to calibrate numbers collected per beam-trawl haul.

Growth

Growth was deduced by tracking recognizable cohorts along size-frequency distributions (1-mm TL classes) from successive sampling occasions. All fish were born during the same reproductive period were assigned to the same cohort (Fernandez and Rossomano, 1997). Length-age was modeled using three key parameters of von Bertalanffy growth model (Bertalanffy,1938) described as $L_t = L_\infty[1-e^{-k(t-t0)}]$, where L_t is the length-at-age t, L_∞ the maximum theoretical length, K is the body growth coefficient synonym to the rate at which L_∞ is attained and t_0 is the age of zero length fish (Ricker, 1975).

Estimation of production

Production of *Acanthogobius flavimanus* was calculated using information on mean daily length increments provided to Bertalanffy growth model according to cohort analysis method of this study. The production was estimated using a newly-derived general equation $P = 0.0848 \times B^{0.5043} T^{0.2664}$ which relates daily fish production P (g AFDW/day) to ash-free dry weight, Biomass (g), and water temperature T (°C). Water temperatures measured on each sampling occasion, and these were ranged 6.2~24.2°C. To measure ash-free dry weight of each specimen, individuals were dried for 2-3 weeks at 80°C and weighted to the nearest 0.0001 g. Individuals were then burned to ash at 500°C for a minimum of 4 h. The weight of the remaining ash was measured and subtracted from the dry weight measurement to get the ash-free dry weight of each individual. Where multiple specimens of the same length were used to determine a mean ash-free dry weight, only one resulting data point was used in the regression analysis. Regression analysis of natural log-transformed data was used to determine the equations describing the relationship between length and ash-free dry weight for each species or species group (Gould, 1965; Burton, 1998).

RESULTS

Calibration of fish density data

The area was pulled by small beam-trawl was 180 m^2. The mean abundance was sampled by small beam-trawl was difference between eelgrass bed and unvegetated tidal flat (respectively 4.135±2.99 and 4.417±0.847) (Table 1). For 1 m^2 box drop trap, the value was 0.299±0.205 in an eelgrass beds, while 0.19±0.074 in the unvegetated tidal flats. When the numbers of *A. flavimanus* collected per small beam-trawl were compared with those were in 1m^2 box drop trap, the mean efficiency of the net in an eelgrass bed was 7.7% compared to 12.9% in the unvegetated tidal flat.

Growth

The total length was differed significantly with body weight ($P<0.00001$, Fig. 2). For example, body weight was plotted against length over the ranges 1.9-24.7 cm for total length and 0.06-100.79 g for weight. The variation in total length demonstrated remarkable differences with months (Fig. 3).

Table 1. Densities (±SE) of *A. flavimanus* collected by beam trawl, box drop traps, correction factors (i.e. beam trawl abundance/drop net density) and net efficiencies (i.e. correction factor/mean area) at eelgrass bed and unvegetated tidal flat in Dongdae Bay

Habitats	Beam trawl density	Box drop traps density (m^2)	Correction factor	Net efficiency (%)
Eelgrass bed	4.135±2.990	0.299±0.205	13.8	7.7
Unvegetated area	4.417±0.847	0.19±0.074	23.2	12.9

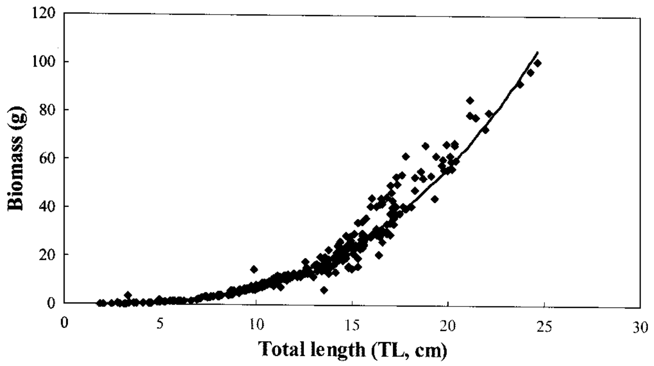

Fig. 2. Relationships between biomass (g) and total length (TL, cm) of *A. flavimanus* in Dongdae Bay. This figure represented by the power function $W=\alpha L^{\beta}$, where $\alpha=0.0083$, $\beta=2.9498$; the fit is significant at $P<0.00001$ with a coefficient of determination (R^2) of 0.9727.

For example, *Acanthogobius flavimanus* occurred as smaller individuals (<7 cm TL) with 14-20 cm TL in July 2006, and these groups remained until January 2007. The growth data were used to calibrate a growth model proposed by von Bertalanffy (1938) with seasonal variations into consideration, and two and three main cohorts were tracked during the sampling period, and the fit was compared on r^2 values. The growth-data-fitted von Bertalanffy' model well predicted the results for *A. flavimanus* (r^2=0.86 for twelve data points) although those of *A. flavimanus* were not significant differed with two habitats (P>0.05). The model parameters of this group were estimated as follows: L_∞=43.238 cm SL; t_0= −0.2507; k=0.3138 (Fig. 4).

Estimation of production

The relationships between total length and ash free dry weight (AFDW) was estimated as $W=0.0007\,L^{3.314}$ (Fig. 5), and this value was not varied significantly with two habitats (P>0.05). Overall estimated densities (0.299/m^2), biomass (7.754 g/m^2), daily (0.006 g/m^2/day) and annual (2.149 g/m^2/yr) production, and P/B ratio (0.277) were higher at eelgrass bed than those of at unvegetated tidal flat (Table 2). The density differed substantially between different months and habitats (ANOVA, Fig. 6-a). Higher numbers occurred at eelgrass bed than unvegetated tidal flat with the highest value in November (0.68/m^2) 2006, July 2006 (0.46/m^2) and January 2007 (0.42/m^2). Significant difference was observed between months and habitats for biomass (ANOVA, Fig. 6-b). The biomass at eelgrass bed was higher in November, October and August 2006 (18.54, 10.61, and 10.54 g/m^2), however, at unvegetated tidal flat, highest biomass was in October 2006 (3.57 g/m^2). The two-way ANOVAs revealed that the daily production differed significantly between months and habitats with the largest production occurring at eelgrass bed (ANOVA, Fig. 6-c). At eelgrass bed, daily production was higher in November 2006 (0.014 g/m^2/day), while was 0.002 g/m^2/day in July 2006 at unvegetated tidal flat.

DISCUSSION

The present study is first to provide density and estimates production of *A. flavimanus* in an eelgrass bed and unvegetated tidal flat. The major source of error in density estimates probably resulted from the difficulty in calibrating fish numbers per haul with absolute fish density. The box drop trap density used to calibrate small beam trawl numbers were presumably themselves subject to error, although for small, relatively immobile species this error should not be great (Sogard et al., 1987; Edgar and Shaw, 1995). A systematic error would also have been introduced into calculations if the capture efficiency of small beam trawl differed substantially between eelgrass bed and unvegetated tidal flat. The difference of net efficiency between eelgrass bed and unvegetated tidal flat was ignored because it was relatively small and these efficiency values were based on a limited sampling programs carried out at a single pair of sites over a short time periods. Edgar and Shaw (1995) demonstrated that most of the error in estimates of production at different sites was probably caused by error in the calculation of fish densities, and production estimates provide better insight into the biological properties of fish communities including each fish species.

Monthly variations of growth rate appear to be considerable for *A. flavimanus* utilizing our study sites in cohort analysis (Fig. 7). Smaller individuals were occurred in July 2006, and then most of individuals were larger from October to January 2007 with growth. Probably these patterns did over again next year with predicted value. Thus *A. flavimanus* have been inhabited within wide range of temperature, and then these results might it explained *A. flavimanus* would be dominated over other fish species at our study sites. Also the growth rate of *A. flavimanus* was influenced by spawning periods. The smallest individuals of *A. flavimanus*

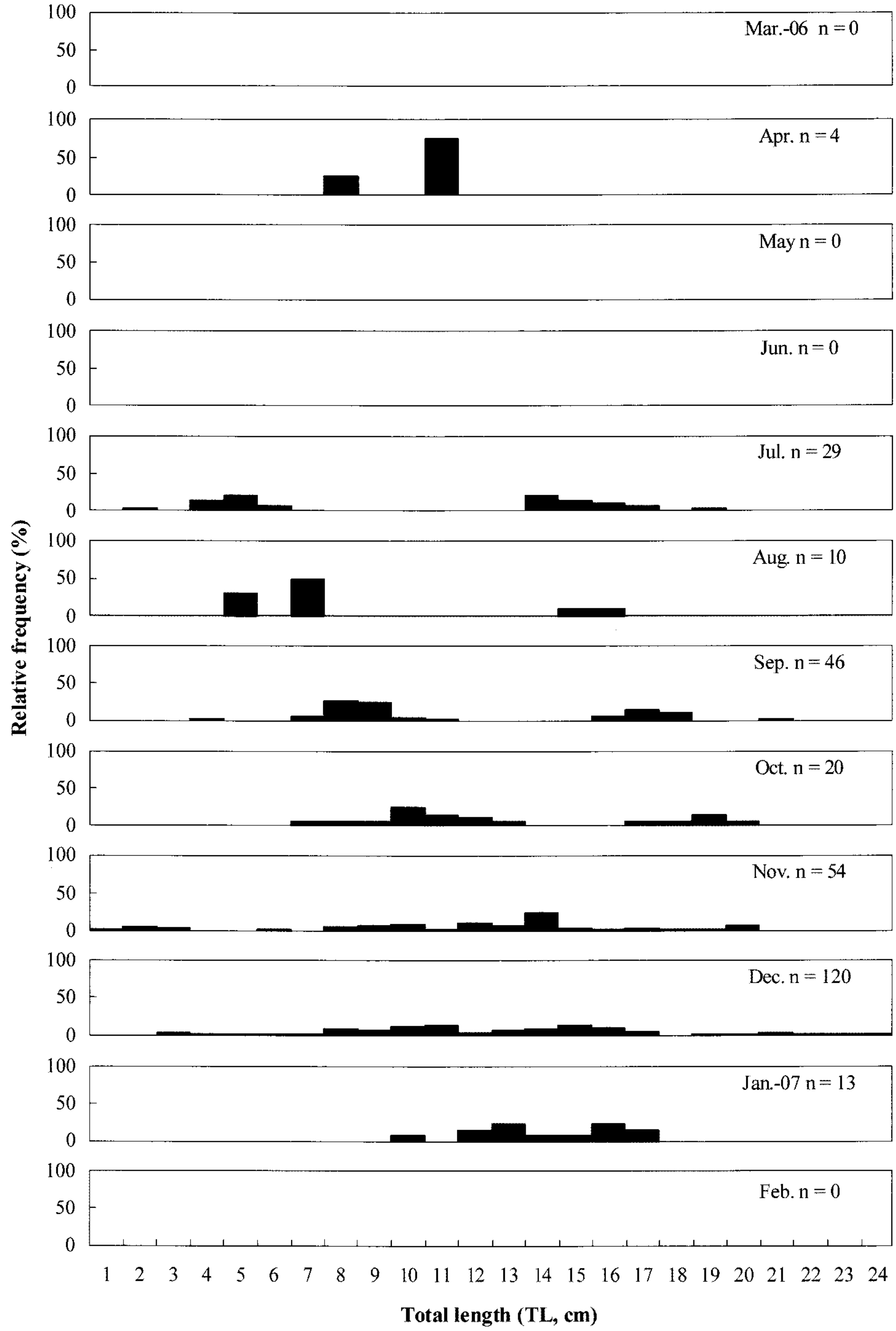

Fig. 3. Monthly variation in size distribution of *A. flavimanus* in Dongdae Bay.

appeared in July 2006 for the first time would be moved after these individuals were spawned in other areas nearby at our study sites. Such conclusions were in agreements with other studies that the spawning periods of *A. flavimanus* was from February to May 2006 with gonad development and sex steroid hormone levels (Park et al., 2005). Most of fish species essentially stop growing after maturation in temperate area, and then increased growth rate rapidly after spawning (Baeck et al., 2004a, b; Cha et al., 2008).

The daily production of *A. flavimanus* was 0.00817 g/m^2/day, 11.76 g/m^2 in biomass at 13.7 in an eelgrass bed although average value was 0.006 g/m^2/day, whereas 0.00338 g/m^2/day, 14.16 g/m^2 in biomass at 16.1 in the unvegetated tidal flat. Compared with other studies in production of gobiid fish species (Table 3), *Gobius cobitis* and *Gobius paganellus* was 0.00784 and 0.00916 g/m^2/day at rocky shore, *Lesueurigobius friesii* was 0.00251 g/m^2/day at muddy shore, and *Pomatoschistus minutus* and *Pomatoschistus microps* were 0.00996 and 0.001 g/m^2/day at estuary

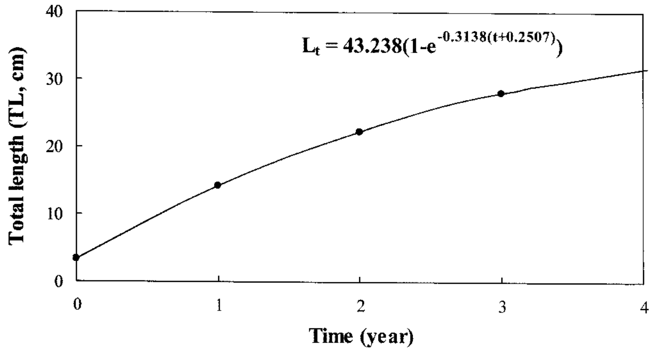

Fig. 4. Theoretical von Bertalanffy length growth curve of *A. flavimanus* in Dongdae Bay.

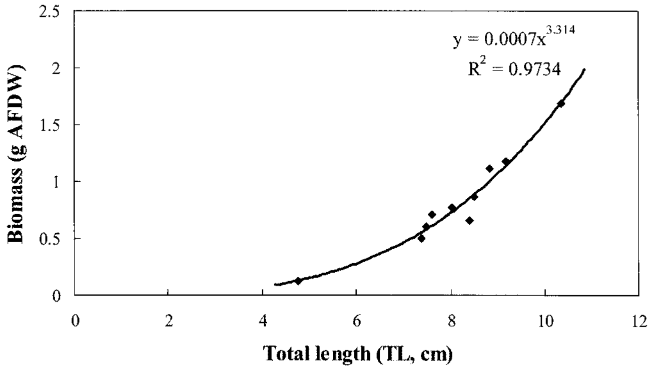

Fig. 5. Correlation between ash-free dry weight and total length of *A. flavimanus* in Dongdae Bay.

Table 2. Estimated densities, biomass (g), daily production ($g/m^2/day$), annual production ($g/m^2/yr$) and P/B ratio of *A. flamivanus* at eelgrass bed and unvegetated tidal flat in Dongdae Bay

Habitats	Density (m^2)	Biomass (g/m^2)	Daily production ($g/m^2/day$)	Annual production ($g/m^2/yr$)	P/B
Eelgrass bed	0.299	7.754	0.006	2.149	0.277
Unvegetated tidal flat	0.190	1.747	0.001	0.351	0.201

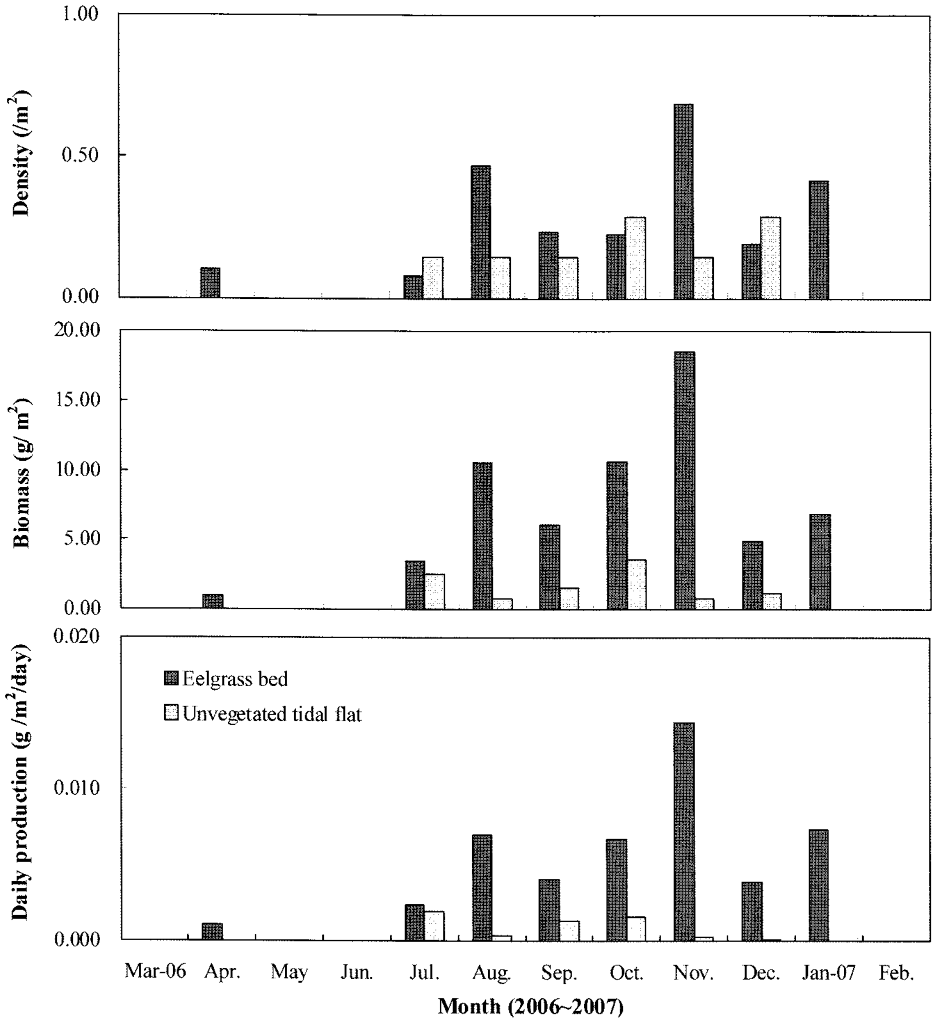

Fig. 6. Density, biomass and daily production of *A. flavimanus* at eelgrass bed and unvegetated tidal flat in Dongdae Bay.

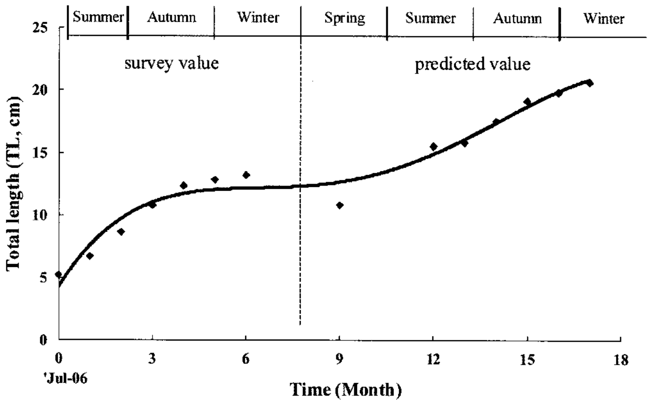

Fig. 7. Growth patterns in total length (TL, cm) of *A. flamivanus* in cohort analysis. The dots represented mean value of each cohort.

(Miller, 1961; Gibson, 1970; Gibson and Ezzi, 1978; Dolbeth et al., 2008). These results indicated that daily production of *A. flavimanus* was similar to those of other gobiid fish species regardless of different habitats. Monthly variation in daily production of *A. flavimanus* appears to be considerable marked at our study sites. These peaks in production corresponded closely with density, biomass and growth rate.

On the other hand, significance differences were between an eelgrass bed and unvegetated tidal flat for annual production of *A. flavimanus*. The *A. flavimanus* at the primary eelgrass bed (2.149 g AFDW/m^2/yr) was four times as productive as at unvegetated tidal flat (0.642 g AFDW/m^2/yr), whereas no discussed compared with production of each fish species because most of studies in production have been confined with dimensions of fish communities. Almost all studies with production of fish communities have been reported that higher productive at seagrass beds than those of at unvegetated sites worldwide (Hellier, 1962; Adams, 1976; Lubbers et al., 1990; Edgar and Shaw, 1995). For example, small fish assemblages at seagrass sites were over twice as productive as at unvegetated sites (3.856 g AFDW/m^2/yr in seagrass cf. 1.58 g AFDW/m^2/yr in unvegetated habitats) in the Southern Australia (Edgar and Shaw, 1995), 3.8 g AFDW/m^2/yr in production of four dominant in North Carolina, 3.1 g AFDW/m^2/yr in six common fish species in the Laguna Madre of Texas, 0.2 to 5 g AFDW/m^2/yr in the Swedish coast, and 2.8 g AFDW/m^2/yr in Chesapeake Bay. This estimation should, however, be treated with caution as it assumed that production of *A. flavimanus* was comparable higher with the published estimates for temperate and subtropical fish communities elsewhere despite of difference in study area and number of fish species. Several other studies have demonstrated that great numbers of fishes including *A. flavimanus* have been more utilized eelgrass beds as feeding and nursery function than those of other areas (Klumpp et al., 1989; Huh and Kwak, 1997; Connolly et al., 1999; Hemminga and Duarte, 2000; Nagelkerken et al. 2002). Eelgrass beds thus have the potential to hold large numbers and higher production of fish species with a variety of prey organisms for fish species. Our study presented that an eelgrass bed supported substantially higher production parameter (e.g. density, biomass) of *A. flavimanus* than unvegetated tidal flat in Dongdae Bay.

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Table 3. Comparisons between our study and other studies in production of gobiid fish species

Species	Temp. (°C)	Biomass (g/m^2)	Daily production (g/m^2/day)	Habitats	References
Acanthogobius flavimanus	**13.7**	**11.76**	**0.00817**	**Eelgrass bed**	**Our study**
Acanthogobius flavimanus	**16.1**	**14.16**	**0.00338**	**Unvegetated tidal flat**	**Our study**
Gobius cobitis	14.5	1.67	0.00784	Rocky shore	Gibson (1970)
Gobius paganellus	18	0.493	0.00916	Rocky shore	Miller (1961)
Lesueurigobius friesii	12	0.203	0.00251	Muddy substrate	Gibson and Ezzi (1978)
Pomatoschistus minutus	about 20	4.545	0.00996	Estuary	Dolbeth et al. (2008)
Pomatoschistus microps	about 20	0.157	0.00100	Estuary	Dolbeth et al. (2008)

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