Feeding Activity Rhythms of Juvenile Gobiid Fish, *Chaenogobius gulosus,* at Tidally Different Localities.

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Abstract

Feeding chronology of juvenile gobiid fish, *Chaenogobius gulosus,* was concurrently studied at two tidally different localities, i.e. the shore of Asamushi facing Mutsu Bay, and the shore of Fukaura facing the Sea of Japan. The main food items were classified into three categories, namely, benthic animals, planktonic animals, and terrestrial insects. Benthic animals were much taken at night, but were also taken during the daytime when water level was low. Zooplankters were chiefly taken when water level was high during the daytime. Terrestrial insects were mainly eaten in the evening. Thus the feeding chronology of juvenile *C. gulosus* was composed of diel rhythm and tidal rhythm, corresponding to observed behaviour of the fish.

Keywords: Feeding activity rhythm, intertidal fish, goby, *Chaenogobius gulosus*

Intertidal fishes are exposed not only to diel but also to tidal change of environment. Tidal change of environment is drastic to these fishes, including abiotic factors such as water level, water turbulence, temperature and light intensity, as well as biotic ones like prey availability and predation risk.

Fishes, including gobiids, inhabiting this habitat are known to display an endogenous circatidal rhythm of ca. 12.4 hours when placed in a constant environment (Gibson 1973, Gibson and Hesthagen 1981, Northcott et al. 1990, Sawara and Azuma 1992). Typical tidal rhythm is a rhythm of about 12.4 hours, but it varies from coast to coast, depending on the local topography. So, it is an interesting problem to compare the activity rhythms between different populations, belonging to a same species, inhabiting tidally different localities. Sawara (1992) studied the activity rhythm in the juveniles of a goby, *Chaenogobius gulosus* (formerly *Chasmichthys gulosus*), in a constant environment, and compared the rhythms between two goby populations inhabiting rocky shores which have very different tidal regimes. The goby collected at Asamushi, which faced Mutsu Bay, had a clear circatidal rhythm, whereas those from Fukaura, which faced the Sea of Japan, did not exhibit such clear one.

However, it is not known what kind of activities in the field corresponds to the activities exhibited in laboratory. So, it is an interesting problem to study and compare the activity rhythm of the juvenile *C. gulosus* in the field, between the above two localities.

In the present study, we examined the changes of the index of gut fullness and of the diet composition of juvenile *C. gulosus* over 27 hours, concurrently collected at two tidally different localities, on spring tide and on neap tide. Moreover, we observed the behaviour of the *C. gulosus* at each time of collection, especially on two aspects, namely, whether they were shoaling or solitary, and whether they were floating in water column or being on substrate. Then we discussed the correspondence between the high activity exhibited in constant environment and the activity pattern in the field.

Study Area

Samples were collected at two rocky shores facing Mutsu Bay and the Sea of Japan, in Aomori Prefecture (Fig. 1). These sites were the same localities where the materials were collected in a former study (Sawara 1992). Both sites are well protected from heavy wave actions. The shore of Asamushi (40°54′N, 140°52′E), facing Mutsu Bay, has a comparatively regular, semidiurnal tidal regime, and larger amplitude. In contrast, the shore of Fukaura (40°39′N, 139°56′E), facing the Sea of Japan, has an irregular tidal regime, alternating semidiurnal and diurnal tides, and smaller amplitude. These differences in tidal regime were previously described in detail by Sawara (1992).

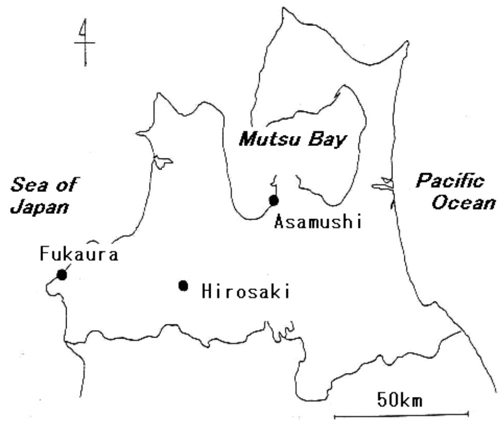


Fig. 1. Sketch map of the collection localities.

Materials and Methods

Chaenogobius gulosus (Guichenot) is a gobiid fish and a resident in all types of intertidal zone including sandy shore and sometimes brackish estuaries, though mostly found at rocky shores. Although adults are benthic and solitary, juveniles are often seen floating in water column, usually forming shoals. The materials used in this study were juveniles at the transient stage from floating to benthic life.

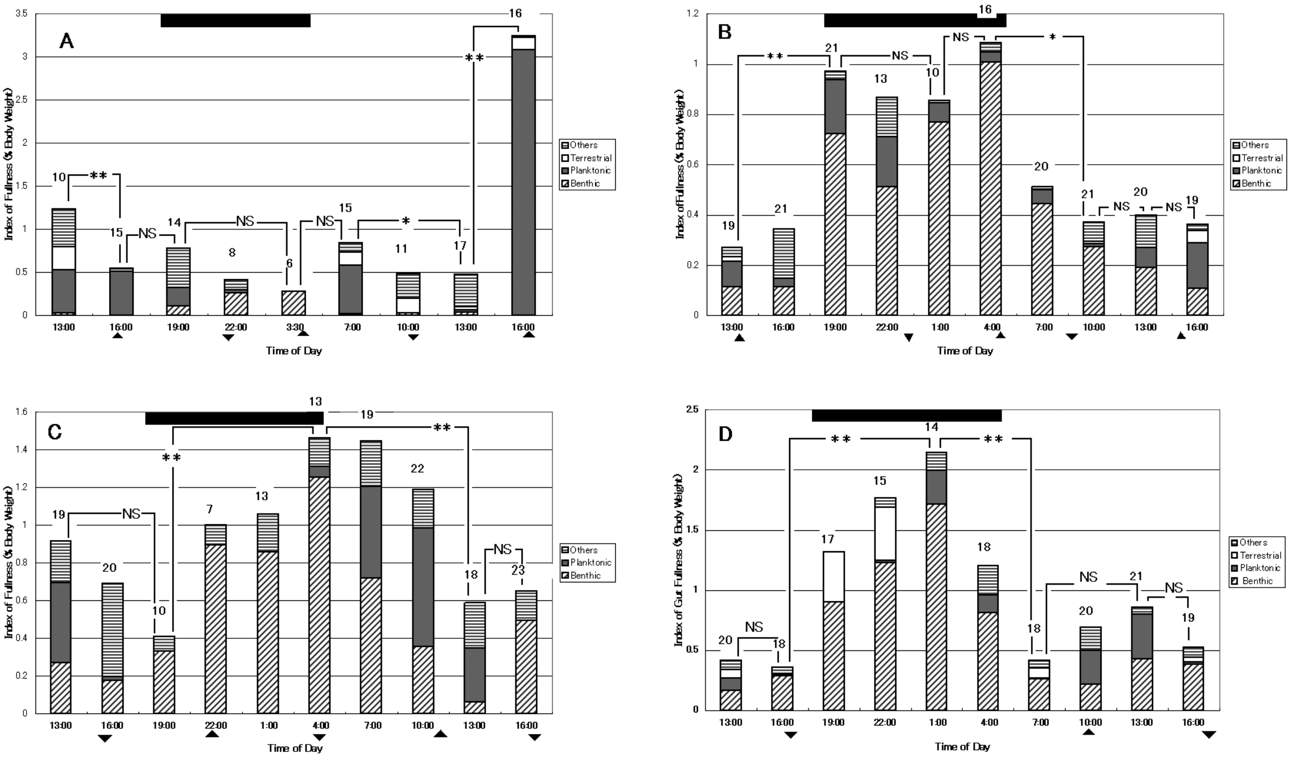
Collection of the fish was concurrently made in 1996 at rocky shores of Asamushi and Fukaura, over 27 hours on 30-31 July (spring tide) and on 7-8 August (neap tide), and once more for Asamushi fish on 14-15 August (spring tide), though over 24 hours this time. These collection sites were the same sites where the materials were collected in a previous study (Sawara 1992). The fish were collected at three hours interval, except for nighttime on 31 July at Asamushi when collection was difficult, by three to five persons at a time, using hand-nets. Collection was made within 40 minutes at most, usually less than 10 minutes. Collected fish were immediately killed by overdose of an anesthetic, MS222, to prevent regurgitation of gut contents, and transferred to 10% formalin. Head lamps were used for nighttime collection. Water temperature, weather condition, and the behaviour of the juvenile *C. gulosus* (shoaling or solitary, floating or benthic) were recorded at each time of collection. An automatic water level recorder (Rigosha RMT) was used at Fukaura, whereas the data for water level at Asamushi were available from the records by Asamushi Water Level Recording Station.

Later the samples were weighed and measured for their body lengths to the nearest 0.5mm, and dissected under a binocular microscope. The gut was divided into two parts, namely, the anterior portion and the posterior portion, at the first bending, and the contents were separately weighed, and the food items in the anterior were classified and the volume of each item was recorded by points method, allocating 100 points in total to each food item according to its volume by eye. The index of gut fullness was calculated as gut content weight / body weight×100.

Results

The tidal amplitudes on the days studied were as follows: ca. 70cm and 60cm on spring tides at Asamushi(30-31 July and 14-15 August, respectively), ca. 30cm on spring tide at Fukaura(30-31 July), and ca. 32cm on neap tide at Asamushi (7-8 August) and ca. 19cm on neap tide at Fukaura (7-8 August).

The ranges of the water temperature variation during the study periods were: 1.3 (Asamushi) and 1.0 (Fukaura) degrees centigrade on 30-31 July, 4.9 (Asamushi) and 2.2 (Fukaura) degrees on 7-8 August, and 3.3 degrees at Asamushi on 14-15 August, respectively. The highest temperature measured was 26.9 at 16:00 at Fukaura on 8 August, whereas the lowest was 20.2 at 1:00 and 4:00 at Asamushi, on 8 August.



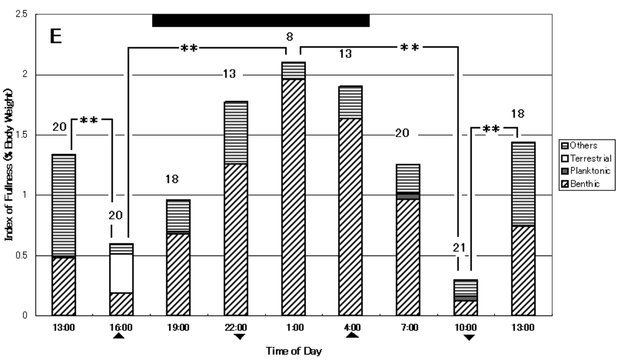


Fig. 2. Changes of the average index of fullness of anterior gut and diet composition. Food components were classified into three categories, benthic animals, planktonic animals, and terrestrial insects, with unidentifiable materials. Black bar represents nighttime. Arrows indicate high tide (▲) and low tide (▼), respectively. Each figure indicates the number of samples dissected. The index of fullness of anterior gut was compared between successive high and low peaks. NS: Not significant, ＊: P<0.05, ＊＊: P<0.01 (Mann-Whitney U-test). A: Asamushi spring tide (July 30-31). B: Fukaura spring tide (July 30-31). C: Asamushi neap tide (August 7-8). D: Fukaura neap tide (August 7-8). E: Asamushi spring tide (August 14-15).

<Changes of index of gut fullness>

The number of the samples dissected was 787 in total (N=112 for Asamushi July 30-31, N=164 for Asamushi August 7-8, N=151 for Asamushi August 14-15, N=180 for Fukaura July 30-31, N=180 for Fukaura August 7-8). The average body length slightly increased during the study period, from 27.83 ± 2.65mm (mean±SD) on 30-31 July to 28.59 ±3.80mm on 7-8 August for Fukaura fish, and from 23.67 ± 2.75mm (mean±SD) on 30-31 July to 29.88 ±3.80mm on 14-15 August for Asamushi fish. The overall average body length was 28.21±3.29mm (mean±SD, N=360) for Fukaura fish and 27.09±4.40mm (mean ±SD, N=427) for Asamushi fish, respectively.

The index of anterior gut fullness was higher during the nighttime than daytime for 4 sampling periods except for Asamushi 30-31 July when planktonic copepods were much taken in the daytime (Fig. 2A-E). Gastric evacuation rate was not directly measured, but the quick disappearance of anterior gut contents in the morning on 31 July at Fukaura, 8 August at Fukaura and 15 August at Asamushi suggests the rate of evacuation for juvenile *C. gulosus* in the field. Considering the change of the index of fullness, juvenile *C. gulosus* seems to forage both in the daytime and at night, but more food was taken during nighttime in most cases.

<Food composition>

The main food items, known from the gut content analysis for all samples collected irrespective of the time of day (N=787), were small invertebrates, such as crustaceans (gammaridean amphipods, isopods, copepods, ostracods, caprellids etc.), polychaetes, foraminiferans, and terrestrial insects (hymenopteran adults, aphids etc.). Plant materials were negligible. Gammaridean amphipods were by far the most important food item, comprising 37.3 percent of gut content weight for overall samples combined (N=787). Foraminiferans (genus *Ammonia*) (8.9 percent) and planktonic copepods (calanoids and cyclopoids) (8.6 percent) were the second and third important items. The fish collected on 30-31 July at Asamushi had a strikingly different diet composition from the other samples. Gammaridean amphipods comprised only 2.8 percent in weight, while the percentage of planktonic copepods amounted to 58.3 percent. In contrast, gammaridean amphipods amounted to 34.8-47.4 percent for the other four samplings.

We classified these food items into three categories, namely, benthic animals(gammaridean amphipods, isopods, ostracods, harpacticoid copepods, benthic foraminiferans [genus *Ammonia*], polychaetes, caprellids), planktonic animals (calanoid and cyclopoid copepods, zoea larvae, fish larvae, mysids), and terrestrial insects such as hymenopteran adults and aphids.

The three food categories were consumed in different time of day and time of tide. Benthic animals were primarily taken at night, but they seemed to be also taken in the daytime particularly when the water level was low. On the other hand, zooplankters were chiefly taken in the daytime, especially when water level was high. This was particularly notable on 30-31 July (spring tide) and on 8 August (neap tide) at Asamushi when planktonic copepods were abundantly consumed. However, fish larvae and zoea larvae were eaten irrespective of the tidal state, being consumed even when water level was relatively low as 14 August (spring tide) at Asamushi and 30 July (spring tide) at Fukaura. Terrestrial insects did not seem to have clear period of consumption, but were much eaten in the evening on 14 August at Asamushi and on 7 August at Fukaura.

Juvenile *C. gulosus* were usually found to be in one of two conditions, i.e., either forming shoals in midwater or dispersed on substrate. However, some juveniles were found forming shoals on substrate, particularly in the early morning, and some, probably strayed individuals, were occasionally found solitarily in midwater in the daytime.

At night, the juveniles were always found dispersed on substrate irrespective of tidal state. In the daytime, on the other hand, they were not always forming shoals in midwater, and some individuals were found solitarily on substrate, when water level was low, like those at night. Therefore, the behaviour of juvenile *C. gulosus* was related to two environmental rhythmicities, namely, diel rhythm and tidal rhythm. There was no difference in the behaviour neither between the two localities nor between tidal regimes (spring tide or neap tide).

Discussion

The main food of juvenile *C. gulosus* was small invertebrates, such as gammaridean amphipods, isopods, ostracods, copepods, polychaetes, caprellids, foraminiferans and terrestrial insects. Gammaridean amphipods were the most important food item. These food habits of juvenile *C. gulosus* roughly coincide with those of sub-adults reported by Sasaki and Hattori (1969) at Pacific coasts in Chiba Prefecture, Japan.

The feeding chronology known from the change of gut contents showed that both diel and tidal components contributed to the feeding pattern of juvenile *C. gulosus*. Although juvenile *C. gulosus* took foods throughout a day, it usually foraged more intensively at night than in the daytime. At night, they took benthic foods irrespective of the tidal state. In contrast, in the daytime, the juveniles took benthic foods more around low tide, while consumed planktonic foods more around high tide, thus corresponding to tidal rhythm. The consumption of planktonic copepods at high tide was notable at Asamushi than at Fukaura. It is unlikely that the change of water temperature had any significant effect in forming such feeding patterns, because *C. gulosus* took more food in the nighttime when the water temperature was generally low, suggesting that relatively low water temperature at night did not suppress feeding activity.

These changes in gut contents well corresponded with their behaviour observed in the field. At night, the juveniles were always found dispersed on the substrate irrespective of tidal state. It is uncertain whether this is simply resulted from their inability to keep shoaling and orientation in midwater at night or not. Whatever the reason, benthic small invertebrates are of easier access to the fish then. The diel activity pattern of the small invertebrates eaten are not known in detail, but the amphipods, isopods and ostracods studied so far have rather nocturnal than diurnal activities in most cases (Robertson and Howard 1978, Alldredge and King 1980, 1985, Sudo et al. 1987), although the situation is sometimes complicated (e.g. diurnalism in immatures vs. nocturnalism in adults of an isopod; De Ruyck et al. 1991). Therefore, night activities of the small invertebrates may also have contributed to the nighttime feeding by juvenile *C. gulosus* because of their higher detectability, although the nature of the sense used to take food at night is unknown. Exploitation of small benthic invertebrates when they migrate into water column during nighttime is also reported for other fishes (Robertson and Howard 1978, Robertson and Klumpp 1983, Sudo et al. 1987).

In the daytime, on the other hand, the juveniles more tended to form shoals in midwater around high tide, and planktonic small animals were more likely to be available for them. Planktonic foods usually comprised relatively small portion of the overall foods taken, and consumption of planktonic foods at high tide in the daytime did not regularly occur. However, planktonic copepods can make a large portion of the gut content in some case, like on 31 July at Asamushi. Planktonic copepods (cyclopoids and calanoids) are known to form dense aggregations and make good food patches for shore fishes when they are transferred onshore (Noda et al. 1992, 1998). The larger tidal amplitude at Asamushi may have contributed to transfer the aggregations of planktonic copepods onshore on high tide. Benthic animals, on the other hand, were of easier access when water level was low and most juveniles were on substrate, although some individuals remained in midwater. The terrestrial insects were seemingly more eaten in the evening, but the rhythmicity was not so clear, probably because non-diel factors such as weather and wind condition were more important.

The feeding rhythm of juvenile *C. gulosus* can be regarded principally as diel one partially superimposed by tidal one. During the nighttime, the juveniles take benthic foods irrespective of tidal state. In the daytime, on the other hand, they take planktonic foods more while water level is high, and benthic foods more around low tide, thus corresponding to tidal rhythm. The coexistence of diel and tidal components in the feeding pattern is known in other intertidal fishes, although some fish is reported to have only tidal component with no diel modulation (Archambault and Feller 1991). The feeding pattern is varied from species to species and/or from habitat to habitat. *Fundulus heteroclitus,* a salt marsh dweller, basically is a diurnal forager, taking more food in the daytime, but is more active while high tide (Weisberg et al. 1981), although the change in food composition was not reported. The feeding chronology of a mudflat inhabitant, the mudskipper *Periophthalmus sobrinus,* is also influenced by both tidal and diel rhythms, being less active after dark and most active around the daytime low tide (on spring tide) or high tide (on neap tide) (Colombini et al. 1996). Juvenile silver perch, *Bairdiella chrysura* feed nocturnally within the intertidal zone during high tide (Kleypas and Dean 1983). In the case of juvenile *C. gulosus,* it is characteristic that the rhythmic change of food items taken is closely related to microhabitat shift between in midwater and on substrate.

In a previous study in laboratory (Sawara 1992), juvenile *C. gulosus* freshly caught at Asamushi exhibited a clear circatidal activity rhythm. The activity peak was around the time of predicted high tide. This high activity was not recorded in bottom beam set at the bottom of the experimental glass tank, but recorded in the upper beams. This means that the juveniles tend to be in midwater around the time of predicted high tide, just being the case in the field known from the present study. Fukaura fish, however, did not show such a clear tide-related activity in laboratory. Both fish showed rather solar day rhythm, having activity peaks also in upper beams around predicted time of dusk. Therefore, the activity pattern of juvenile *C. gulosus* in laboratory had both tidal and diel components. It is unlikely, however, that the high activity around dusk has any coincidence with the present field study. The activity pattern exhibited in laboratory seems to have only partly correspondence with the feeding patterns known from the present study. These activity patterns exhibited in constant environment may be more related to shoal-forming behaviour rather than to feeding behaviour of juvenile *C. gulosus.* However, it is pointed out that the high activity has not always a corresponding activity in the field (Gibson 1992), so we should be cautious to draw any conclusion about the nature of the activity of juvenile *C. gulosus* under constant condition until its ecology and behaviour have been intensively studied in the field.

What is the reason for the juvenile *C. gulosus* to form shoals in midwater in the daytime high tide? It is unlikely that the juveniles float in midwater primarily to take planktonic foods, because these foods appear to be unpredictable and quantitatively less important than benthic foods. Shoaling behaviour must be avoidance from predation, because shoaling by small-sized fish is interpreted to be a response to increased predation risk (Pitcher 1986). We observed some piscivorous fish, such as *Pseudoblennius cottoides* (Richardson), to attack juvenile *C. gulosus* at the study sites when water level was high, but these observations still remain episodic, and the change of predation risk is not clear yet. The nature of the predation pressure to juvenile *C. gulosus* is open to study in the future.

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潮汐の異なる海岸におけるドロメ幼魚の採餌活動周期

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潮汐の異なる 2 つの海岸（浅虫，深浦）において，ドロメ *Chaenogobius gulosus* の採餌活動周期を，3 時間おき連続採集法によって調べた。大潮および小潮の日に，両方の海岸で同時に採集を行い，過麻酔して殺しホルマリン固定したあとで，解剖して消化管内容物を調べたところ，様々なエサ品目が見られ，それらを 3 つのカテゴリー（底生動物，動物プランクトン，陸生昆虫）に分けることができた。底生動物は潮汐を問わず夜間にはよく食われており，また日中でも水位が低くなる時間帯によく食われていた。一方動物プランクトンは日中の，水位が高い時間帯に主に食われており，浅虫の海岸では大潮の満潮の際に特によく食われていることがあった。陸生昆虫はどちらかといえば夕方に食われていた。以上のように，ドロメ幼魚の採餌活動には，日周期の要素と潮汐周期の要素とがみられた。これは現場における行動観察の結果，すなわち夜間には単独で底質上におり，日中には水位の高いときは成群して浮泳し，水位が低下すると群れを解いて底質上に下りることとよく対応していた。

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