Differences in the Activity Rhythms of Juvenile Gobiid Fish, *Chasmichthys gulosus*, from Different Tidal Localities

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Abstract Activity patterns of intertidal gobiid fish, *Chasmichthys gulosus*, collected from different tidal localities, were recorded in a constant environment. Gobies collected from a rocky shore with a large tidal range and a regular tidal regime displayed a ca. 12 hour rhythm in their activity pattern. Gobies from a rocky shore with a small tidal range and an irregular tidal regime, however, did not clearly display any such rhythm. The ecological implications of such activity rhythms are discussed from the viewpoints of feeding and avoidance of predators.

Many fish species inhabiting intertidal zones are known to show circatidal activity rhythms under a constant environment (Gibson, 1970, 1971, 1973; Ishibashi, 1973). As the tidal regime varies according to the geographic characteristics of a locality, the circatidal rhythm of fishes can also be expected to vary. This project was to determine whether or not conspecific fishes, which inhabited different tidal localities, showed different rhythmic activities when placed in an identical constant environment. Gibson and Hesthagen (1981) compared activity patterns of a gobiid fish, *Pomatoschistus minutus* (Pallas), in populations inhabiting coasts with different tidal regimes. Individuals from a large tidal range (the Scottish coast) showed a clear circatidal activity rhythm, whereas those from a small tidal range (a Norwegian fjord) showed considerable individual and seasonal variations in activity, with some of them exhibiting an unexpected circatidal rhythm. However, neither the experimental apparatus used in the two localities, nor the duration of the experimental periods, were strictly identical. Therefore a strict comparison could not be made. It was therefore felt that experiments on a fish species inhabiting different tidal areas during the same period, using the same experimental methods, were required. Although there are few locations in the world where two markedly different tidal coasts are within easy access, some areas of Japan fall within this category, due to the accessibility to both the Pacific Ocean and the Sea of Japan, which have very different tidal regimes. The present experiment was run in Hirosaki, Aomori Prefecture, which is one of such locations in Japan.

Materials and Methods

Chasmichthys gulosus (Guichenot) is a gobiid fish widely distributed along the Japanese coast. The species is a permanent resident of rocky tidal zones and is abundant throughout the year. Early in life, these fish swim in the water column, but later become demersal.

The fish used for this study were juveniles, intermediate between the swimming and benthic stages. They were collected at two localities which greatly differed in their tidal regimes. The rocky shore of Asamushi (40°54′N, 140°52′E) is situated along the inner part of Mutsu Bay, where the tidal mode, two high tides per day, is relatively regular (Fig. 1a). The tidal range is 60–70 cm during spring tides. In contrast, the other locality, the rocky shore of Fukaura (40°39′N, 139°56′E), faces the Sea of Japan where the tidal mode is irregular (Fig. 1b). Only one high tide occurs per day during one half of the month, with two high tides during the other half. The tidal range is much smaller in the Sea of Japan, being only about 35 cm at Fukaura, even on spring tides. Both collection sites are topographically well-protected from heavy wave action. The seawater temperatures, measured at the collection sites on each visit, were in the range of 20.7–25.4°C for Asamushi and 22.0–26.2°C for Fukaura, respectively. Juvenile examples of *Chasmichthys gulosus* are found in abundance during summer along both shores.

The fish were caught from the lower intertidal

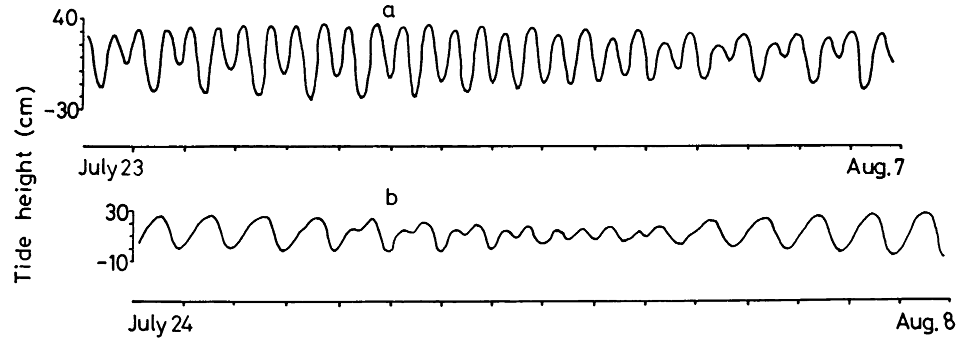

Fig. 1. Tidal regimes of the collection sites during the experimental period. Drawn from data published by the Japan Weather Association, Aomori Branch. a, Asamushi; b, Fukaura.

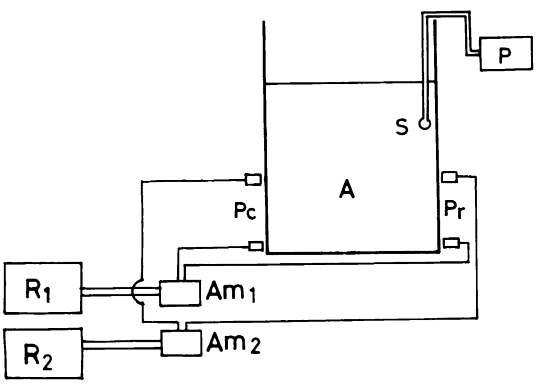

Fig. 2. Diagram of the apparatus used for the experiment. A, glass tank (30 cm × 17 cm, 23 cm height); S, air-stone; P, air-pump; Pc, photocells; Pr, infrared light beam projectors; Am, amplifiers; R, recorders.

zone using hand nets, on alternate days over a 14 day period, collecting at Asamushi on one day, and at Fukaura the next. They were placed in an experimental glass tank within 2.5 hours after collection. The experiment was conducted in 1987: 23 July through 7 August for the Asamushi fish, 24 July through 8 August for the Fukaura fish. In addition to the routine collections for the laboratory experiment, other samples were collected for gut content analysis. The latter were collected at Asamushi on 25 July, at about 13:00 (rising tide), and at Fukaura the following day (26 July) at about 13:50 (high tide). After fixation and preservation in 10% formalin solution, the fish were dissected and their stomach contents examined under a binocular microscope. The body lengths of the fish used in the experiments were 27.2±1.4 and 26.6±1.3 mm (mean±SD) for the Asamushi fish and the Fukaura fish, respectively.

The experimental apparatus used (Fig. 2) was essentially the same as that used by Sawara and Ogawa (1984). The bottom of a glass tank was covered with a thin layer of sand. Three infrared light beams (940 nm wavelength), one at the bottom level, the other two 7 cm above the bottom, were set to pass through the tank. The photocells were connected to the recorders via amplifiers. When a fish interrupted a beam, a spike was recorded on the chart. Accordingly, activity was represented as the number of spikes per 30 minute period on the recording chart. Two sets of experimental apparatus, one for the Asamushi fish and the other for the Fukaura fish, were surrounded by white curtains with slits for direct observation. They were partitioned by a sheet of white paper in order to prevent the fish from seeing the behavior of the other fish group. A fluorescent light (40 w) was set above the glass tanks. There was no other light source.

The experiment was run under constant conditions; i.e. at constant water temperature (25°C) and in constant light intensity (about 300 lx, just above the center of the water surface). The water level was maintained at about 17 cm. No food was given to the fish during the experimental period. Preliminary observations at the collection sites showed that juvenile *Chasmichthys gulosus* swim in the water column, forming shoals at least during high tide. Accordingly, three individuals were treated as one group and exchanged for freshly collected ones every other day without disturbing those in the other glass tank, the reason for this being that the rhythm of this fish seemed to be short-lived, lasting three days at most.

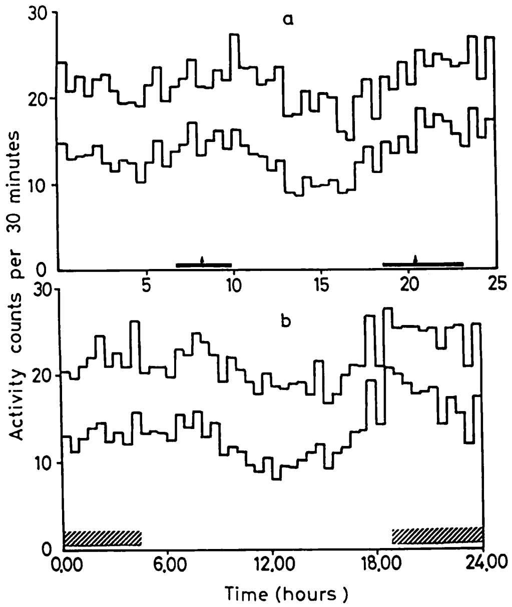

Fig. 3. Form estimates from 15 days' data from the fish collected at Asamushi. Upper columns represent the total beam counts; the lower ones show the upper beam counts only. a, 25 hour form estimate. The onset of the experiment was chosen to be zero time. Black bars and arrows represent the range and mean of the predicted time of high tide during the experimental period, respectively. b, 24 hour form estimate. Hatched bars represent the period equivalent to night-time.

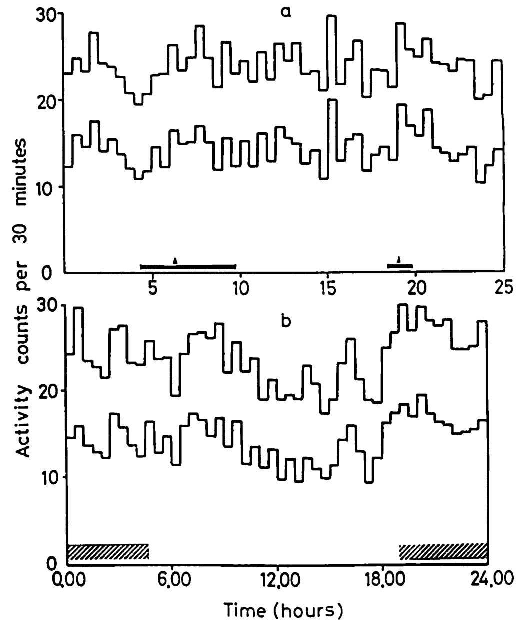

Fig. 4. Form estimates from 15 days' data from the fish collected at Fukaura. Upper columns represent the total beam counts; the lower ones show the upper beam counts only. a, 25 hour form estimate. Black bars and arrows represent the range and mean of the predicted time of high tide. b, 24 hour form estimate. Hatched bars show the period equivalent to night-time.

Results

All the fish used remained healthy during the experimental period. Observations through the curtain slits revealed that the fish showed only weak aggressive tendencies, simply chasing other individuals which happened to be nearby. However, such behavior seemed to have little influence on the activity counts overall. No territorial behavior was observed. The fish exhibited, in some cases, temporal increase in activity while they settled down to a new environment. The "form estimates" (Enright, 1965) prepared from the data from the 15-day experiments are shown in Figs. 3 and 4. Data recorded during the first hour following introduction of the fish to the aquarium, was discarded owing to irregular activity. The fish from Asamushi showed higher counts recorded by the upper infrared beams around the predicted times of high tide (Fig. 3a). This pattern

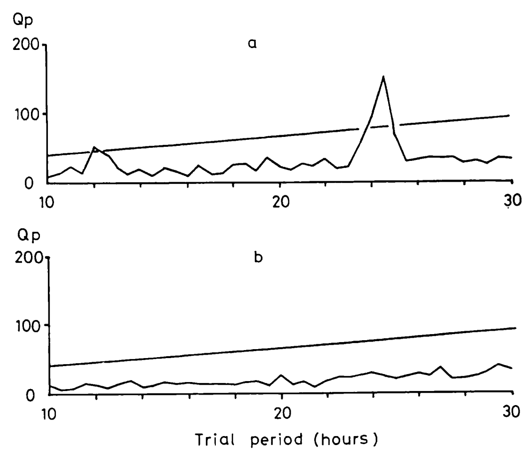

Fig. 5. Chi-square periodograms prepared from the upper beam counts obtained over 15 days. a, Asamushi fish; b, Fukaura fish. Slanted lines indicate 95% confidence limit.

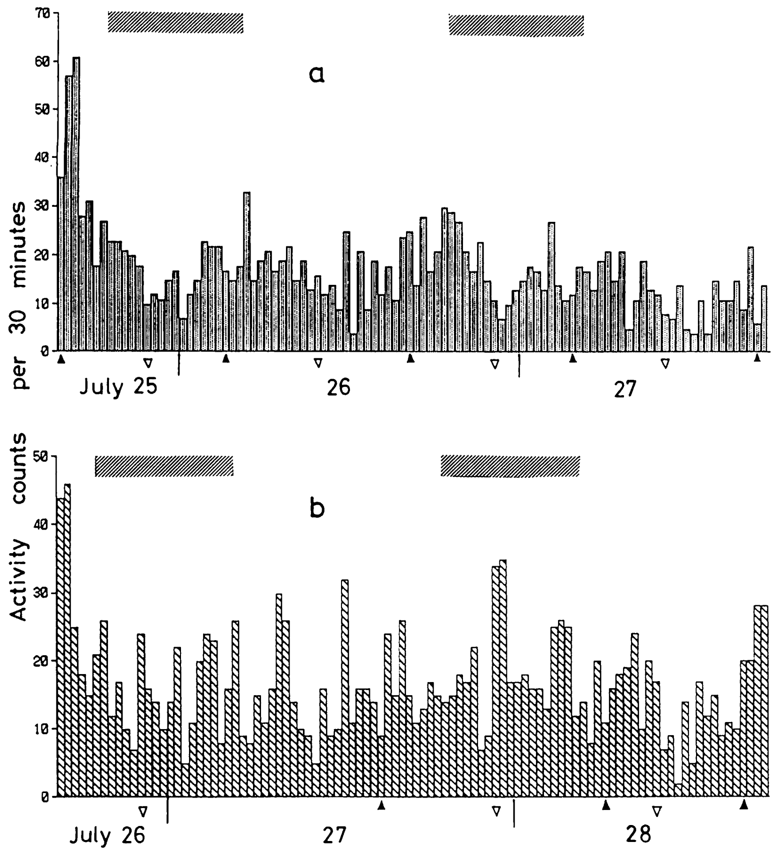

Fig. 6. Upper beam data for the period equivalent to spring tide. a, Asamushi fish, July 25–27; b, Fukaura fish, July 26–28. Closed and open triangles indicate the predicted times of high tide and low tide, respectively. Hatched bars show the period equivalent to night-time.

was not as clear for the bottom beam. The fish from Fukaura did not show such a pattern for either the upper or lower beams (Fig. 4a). On the other hand, fish from both collection sites displayed a similar pattern of activity relative to the solar day (24 hour form estimates: Figs. 3b, 4b), showing a relatively high level of activity at the times equivalent to night and morning followed by a gradual decrease and increase during the times equivalent to midday and around sunset, respectively.

Chi-square periodograms (Sokolove and Bushell, 1978) prepared from the 15-day upper beam data showed a marked contrast between fish from different localities. The fish from Asamushi displayed a significant level ($p<0.05$) of activity over an approximate 12 hour cycle (Fig. 5a), while those from Fukaura did not show any such activity (Fig. 5b). A significant 24.5 hour rhythm was observed only in Asamushi fish, in spite of the apparently 24 hour activity pattern in the form estimates from both populations. The bottom beam data from both localities did not indicate any clear rhythmicity.

To examine the differences in activity patterns in more detail, the first two day's data from the upper beams obtained from each group were treated separately. Figs. 6 and 7 show the upper beam data of *C. gulosus* from both collection sites during the periods equivalent to spring tide (Fig. 6) and neap tide (Fig. 7). Asamushi fish showed a tide-related activity pattern over both tidal periods, having peaks slightly after the predicted times of high tide. On the other hand, Fukaura fish did not display any such pattern. Correlograms (Ito and Murai, 1977) also showed a clear difference between these two groups (Figs. 8, 9). Although small peaks were recognized at 12.5 hrs and 25 hrs in Fig. 9b (Fukaura fish), these peaks

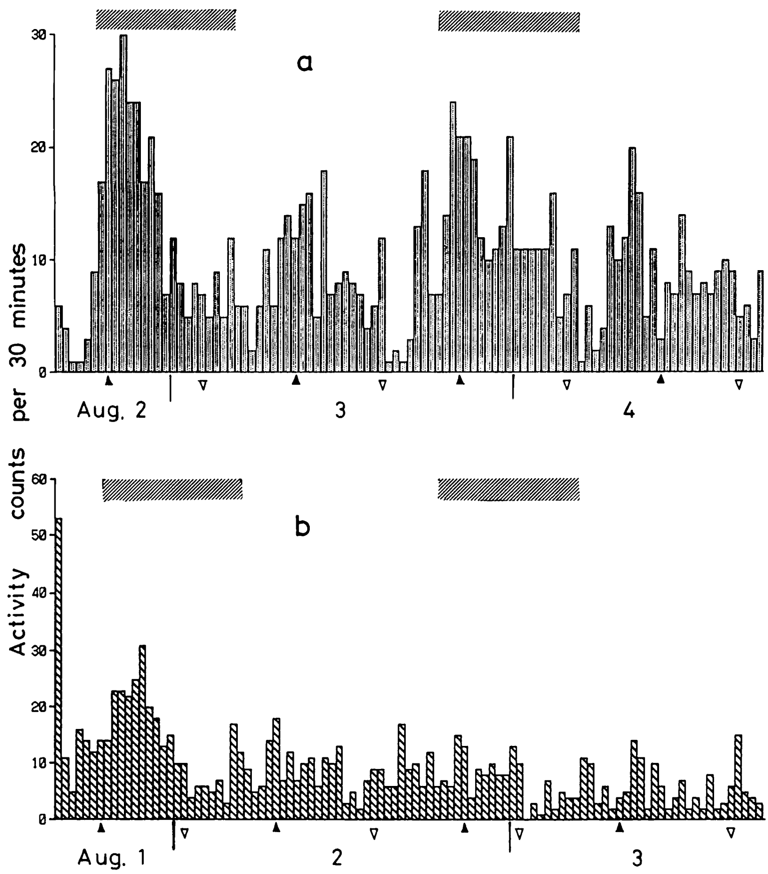

Fig. 7. Upper beam data for the period equivalent to neap tide. a, Asamushi fish, August 2–4; b, Fukaura fish, August 1–3. Symbols as in Fig. 6.

were not so high as those in Fig. 9a (Asamushi fish).

Because of the irregular pattern of the tides at Fukaura, the absence of a ca. 12 hour rhythm does not necessarily exclude the possibility of the presence of tide-related activity. Therefore the changes in mean activity around the predicted time of high tide were examined, irrespective of the tidal heights. During the experimental period, there were 29 (Asamushi) and 21 (Fukaura) high tides, respectively. Fig. 10 shows a comparison of the activity patterns recorded by the upper beams between the two sites. Although the variances of upper beam counts were large, the mean counts of Asamushi fish displayed a tide-related pattern, showing high counts around and after the predicted time of high tide. However, the Fukaura fish did not show any such tendency.

To analyse the data of the Fukaura fish in more detail, the upper beam counts of fish groups caught at various tidal phases were examined. Correlograms were prepared from the four day data from two fish groups, one caught at neap tide (July 30–August 3, corresponding to a twice daily tidal period) and the other caught during the phase of increasing tidal range (August 3–7, a once daily tidal period). Neither group showed a marked ca. 12 hours peak (Fig. 11a, b). In contrast, however, those from fish groups caught at spring tide (July 24–28, a once daily tidal period) displayed a ca. 12 hour rhythm tendency (Fig. 11c). Whether or not this ca. 12 hour rhythm is related to tidal phase is unclear. Form estimates from the above four days data (Fig. 12) suggest that the high activities were related more to sunset and sunrise than to some tidal phase. This pattern was similar to the common pattern observed in the activity of both groups (Figs. 3b, 4b).

The results of the stomach content analysis

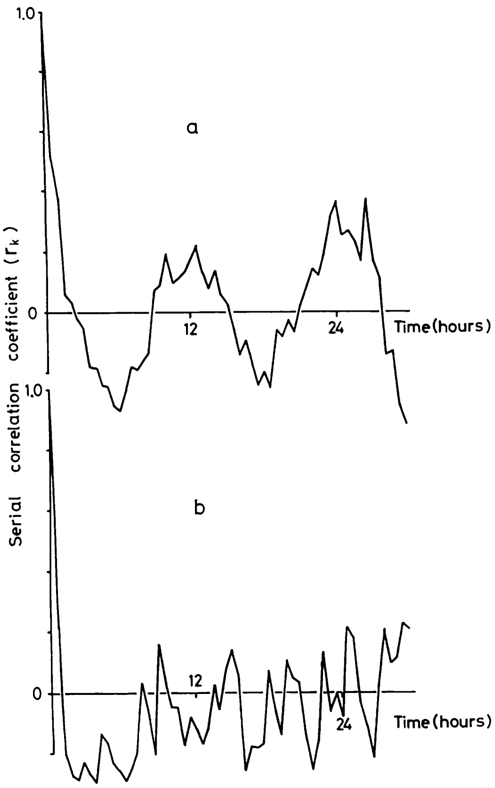

Fig. 8. Correlograms prepared from the data shown in Fig. 6. a, Asamushi fish; b, Fukaura fish.

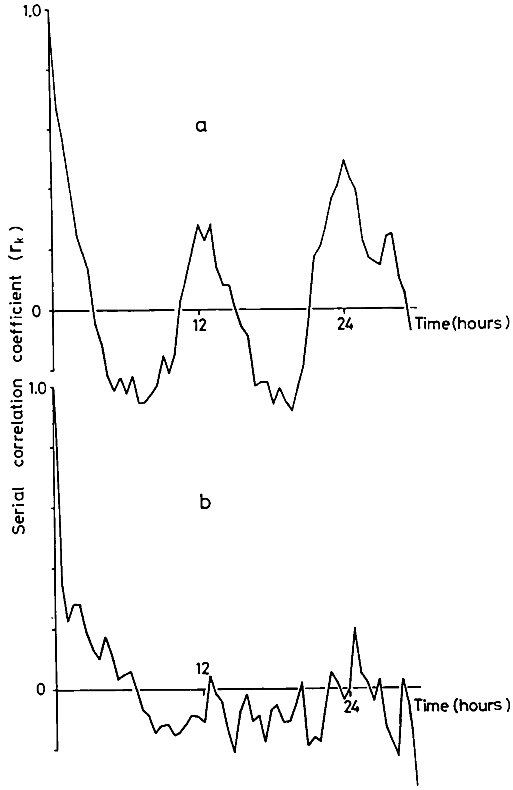

Fig. 9. Correlograms prepared from the data shown in Fig. 7. a, Asamushi fish; b, Fukaura fish.

showed the juveniles to be omnivorous, feeding on many items, including algae. In both samples, the main food items comprised benthic animals as amphipods (gammarids and caprellids), ostracods and harpacticoid copepods. These food habits were roughly similar to those of subadult gobies reported previously from another locality (Sasaki and Hattori, 1969).

Discussion

Juveniles of *Chasmichthys gulosus* from shores with different tidal regimes showed marked differences in their activity. Fish inhabiting a rocky shore with a rhythmic tidal pattern and large tidal range displayed a rhythmic activity of about 12 hours, as recorded by the upper infrared beams, while fish inhabiting a rocky shore with an irregular tidal pattern and small tidal range displayed no such rhythm. Although the individuals caught on the latter shore on spring tide showed a ca. 12 hour rhythm, it was uncertain whether or not such rhythmicity was related to a tidal phase.

Gibson and Hesthagen (1981) compared the activities of a gobiid fish, *Pomatoschistus minutus*, found along the Scottish coast (large tidal range and regular tidal regime) and a Norwegian fjord (small tidal range and irregular tidal regime). Although the Scottish goby showed a clear circatidal rhythm, the results for the Norwegian population were not so clear. Those individuals caught in early spring did not show a circatidal rhythm, unlike those collected later in the year, which displayed a weak circatidal rhythm. There was also great variation between individual fish.

Another factor for consideration was the nature of the high level of activity observed in the constant environment. Although circatidal activity rhythms are documented for many fish species inhabiting intertidal zones, the timing of this high activity

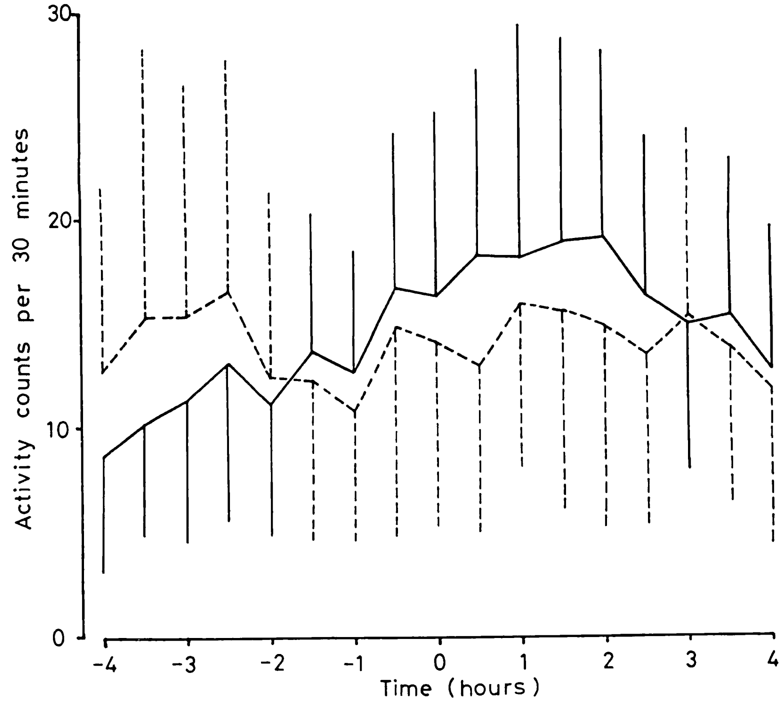

Fig. 10. Comparison of changes in upper beam counts before and after the predicted time of high tide between Asamushi fish (solid line) and Fukaura fish (broken line). Vertical lines (only one side is shown) indicate standard deviations.

differs amongst species. Fishes inhabiting rocky shores, such as blennies (Gibson, 1970, 1971), generally show their activity peaks around the predicted time of high tide. Such rhythmicity was interpreted as a behavioral adaptation that synchronizes activity with the high water phase, when the fish can move and feed (Gibson, 1982). In the case of juvenile *C. gulosus* from Asamushi, the activity peak was observed slightly after the predicted time of high tide. However, the ecological significance of this high activity seems to be somewhat different. During occasional observations at the collection sites, juvenile fish were noticed to form shoals and swim in midwater during high water period, although they dispersed and settled on the substratum when water turbulence was high. On the other hand, most of them were found dispersed on the substratum during low tide, although some individuals, found in deeper water, still formed shoals similar to those found during high tide, suggesting that these individuals had migrated offshore. The high activity counts recorded in the upper beam slightly after the predicted time of high tide generally coincided with such shoal-formation in the natural habitat. As mentioned above, however, shoals were not always formed during high tide. Such occasional discrepancies between natural activity patterns and activity under constant conditions have already been pointed out by Green (1971). The reason why the juvenile fish form shoals and swim in midwater during high tide is unknown. Judging from the benthivorous habit of the goby, swimming in midwater is not associated with feeding activity.

Many other fish species, including predatory species, inhabit the same area as *C. gulosus*. Among them, a cottid fish *Pseudoblennius cottoides* (Richardson) appears to be a particularly important predator of juvenile gobies, considering its abundance and apparently visually-mediated, piscivorous behavior observed both in its natural habitat and in the laboratory. In fact, Hatanaka and Iizuka (1962) reported that the main food item of *P. cottoides* in the *Zostera* area of Matsushima Bay was fishes, especially young gobiids. Shoal-formation by juvenile gobies in midwater may be antipredatory behavior, for it is widely accepted that the forming of shoals is a behavioral tactic employed against predators (Pitcher,

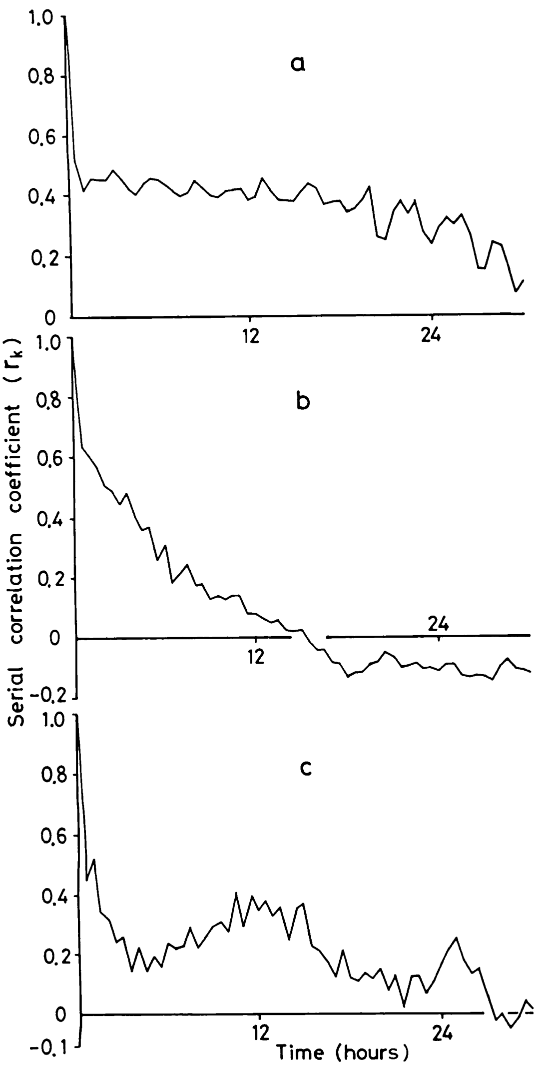

Fig. 11. Correlograms prepared from upper beam counts over 4 days for Fukaura fish. a, fish caught on neap tide; b, fish collected during the phase of increasing tidal range; c, fish caught on spring tide.

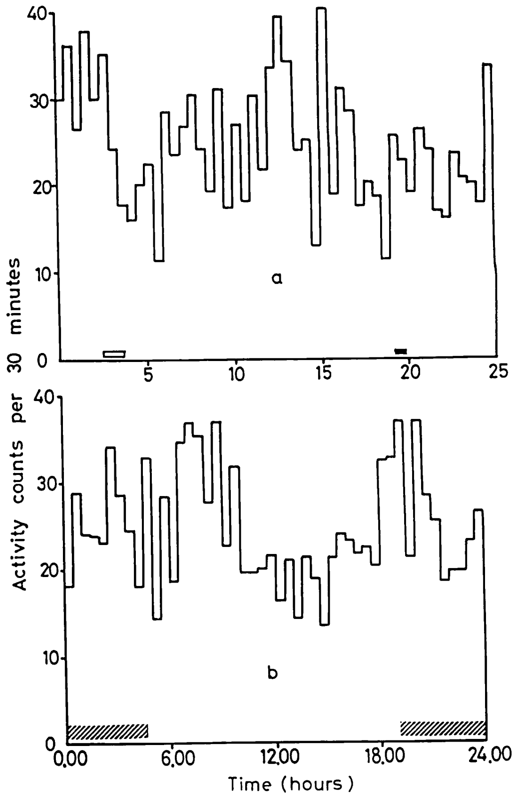

Fig. 12. Form estimates made from 4 days' data (July 24–28) from the upper beam counts of Fukaura fish. a, 25 hour form estimate. White and black bars represent the expected times of low tide and high tide, respectively. b, 24 hour form estimate. Hatched bars show expected night-time.

1986). However, the rhythmic activity of the predatory cottid has not yet been studied. More research, both in the field and in the laboratory, is needed to elucidate the ecological significance of the rhythmic activity of juvenile *C. gulosus.*

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潮汐の異なる海岸にすむドロメ幼魚の活動周期性の違い

佐原雄二

潮汐変化が比較的周期的で潮位差も大きい浅虫（陸奥湾）と，潮汐変化が周期的でなく潮位差も小さい深浦（日本海）の二つの海岸から採集したドロメ幼魚を同一の一定条件下でほぼ同期間活動性を記録し，その異同を調べた．浅虫のドロメは概潮汐周期を示したが，深浦のドロメには明白な概潮汐周期は認められなかった．ドロメ幼魚の活動周期について，その生態的な意味をエサ摂取と捕食者回避の視点から考察した．

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