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Relation	

Diel feeding rhythms, daily ration, and seasonal changes thereof in marbled flounder *Pseudopleuronectes yokohamae*

Running title: Daily ration of marbled flounder

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The authors have no conflict of interest to declare.

Summary

This paper aims to assess the diel feeding pattern and seasonal variation in the daily ration of immature and mature marbled flounder (*Pseudopleuronectes yokohamae*). A day-night collection by bottom trawls was conducted in Sendai Bay in July 2014. Marbled flounder (131–493 mm total length; N of collected individuals = 1830, N of analyzed individuals = 497) fed mainly on polychaetes during the day. At night, stomach content weight decreased with time, but the weight and proportion of bivalve siphons were consistently higher at night than during the day, suggesting nocturnal feeding by the flounder on bivalve siphons. Daily ration was greater in females (<300 mm: 2.6–3.2% body weight; ≥300 mm: 1.5–2.5%) than in males (<300 mm: 1.7–2.6%; ≥300 mm: 1.3–1.9%). Seasonal surveys were also carried out, and the greater ration in females than males were consistent throughout the year, suggesting that greater growth in females than males attributes to the greater food intake of females. The ration was highest in June, especially for large individuals, although water temperature in June was lower than that in September. These results indicate that the amount of food intake is related to the annual life cycle of the marbled flounder.

1 Introduction

Assessment of food consumption by predators is an important ecological issue for understanding energy flow and ecosystem structures. Daily food demand can be estimated in laboratory experiments, but daily food consumption in the field generally needs day-night field collections of the predator at small intervals (Elliott & Persson, 1978). Furthermore, seasonal dynamics of food consumption should be investigated to reveal annual life cycle of the predator.

Pleuronectid flatfishes are visual diurnal predators that use chemical and mechanical senses (de Groot, 1969, 1971). Diel feeding rhythms of pleuronectid flatfishes have been studied in juveniles (Thijssen, Lever, & Lever, 1974; Chen, Purser, & Blyth, 1999; Hurst, Ryer, Ramsey, & Haines, 2007), immature, and adults (Worobec, 1984; Yang & Livingston, 1988). However, only limited studies have been performed regarding daily food intake and daily ration. The food consumption by flatfish is essential in understanding the role of predators in benthic ecosystems as they are often an important component.

The present study aimed to reveal diel feeding patterns and daily rations of immature and mature marbled flounder (*Pseudopleuronectes yokohamae*). This species is a common and important flatfish distributed in the coastal waters of Japan (Minami, 1981; Tomiyama, 2013). In Sendai Bay, northern Japan, the great earthquake and associated tsunami and resulting accident in the nuclear power plants in March 2011 considerably affected the coastal fisheries. Owing to the sudden decrease in fishing pressure, the stocks of commercially important fishes, such as Japanese flounder (*Paralichthys olivaceus*) and Pacific cod (*Gadus macrocephalus*), have greatly increased (Narimatsu, Shibata, Hattori, Yano, & Nagao, 2017; Shibata et al., 2017). Under such circumstances, studies on food web dynamics in these areas are of importance. We first conducted a survey cruise for day and night collections of marbled flounder to assess diel feeding patterns. We then conducted seasonal surveys to assess annual changes in the daily ration of marbled flounder. Body size and sex were taken into consideration when assessing variations in daily ration.

2 Materials and methods

2.1 Study site and field surveys

Field collections of marbled flounder were conducted in Sendai Bay, northeastern Japan (Figure 1). Marbled flounder is a common flatfish in this area.

A day-night survey was carried out at a site (38° 12′ N; 141° 13′ E; 37 m deep; Figure 1) in July 2014. Otter trawls with 5.4-m wide mouth-openings, length of 44 m, and 50-mm mesh net covered with 8-mm mesh at cod-end were towed by RV Wakatakamaru (692 tons) at ca. 3.0 knots for 30 min. This trawl sampling was repeated at 3–4 h intervals in day (06:00–19:00) and night (21:00–04:00) surveys. The day survey was conducted on two days, and nocturnal survey was conducted on one night (total number of tows = 11, Table 1). At each tow, 74–339 individuals of marbled flounder were collected. Of these samples, 65–120 individuals/tow were randomly selected and measured (total length [TL], mm) onboard immediately after collection. Subsamples of 15–36 individuals/tow were used for stomach content analysis with sex determination from the gonads: stomachs of the flounder were removed onboard and preserved in 10% formalin for later observation to minimize a decrease in stomach contents weight by autolysis after collection. Other additional subsamples (30–41 individuals/tow) were frozen onboard for later measurements. Bottom water temperature was measured at each tow by AAQ175 (JFE Advantech Co., Ltd., Nishinomiya, Japan).

To determine seasonal changes in the food intake of marbled flounder, daytime surveys were conducted at six stations at depths of 35–80 m in Sendai Bay (Figure 1) from February to November 2014. This survey was carried out approximately once every three months. The otter trawls were towed at ca. 3.0 knots for 30 min at each station during 05:30–12:00 (total number of tows = 21). Marbled flounder were collected and brought to the laboratory under chilled conditions. Then, fish were frozen for later measurements. Bottom water temperature was measured at each tow by AAQ175.

2.2 Measurements

In the day-night survey, individuals frozen onboard were measured in the laboratory. After being defrosted, TL and the body wet weight (BW, g) of each fish were measured, their sex was identified from the gonadal observation, and their stomachs were removed and preserved in 10% formalin. BW of flounder of which stomachs were preserved onboard was estimated based on the relationship between BW and TL estimated from flounder frozen onboard: $BW = 7.055 \times 10^{-6} \times TL^{3.102}$ (n = 173, $r^2 = 0.99$). Stomachs of a total of 497 individuals were used. Stomach contents were blotted with paper towels to remove excess water. Effects of preservation in 10% formalin were regarded as negligible. Preliminarily, the weight of stomachs was measured for 10 individuals before and 1 mo after the formalin preservation, and it did not change significantly (paired t-test, $t = 0.88$, $p = .40$). The stomach content wet weight (SCW) was determined to the nearest 0.01 g. Stomach contents were sorted into the following categories and weighed: polychaetes, bivalve siphons, bivalves, opisthobranchs, actiniarians, crustaceans, and others.

For the seasonal survey samples, fish were defrosted and their TL and BW were measured similarly. Sex was identified from the gonads. Total SCW was determined similarly.

2.3 Analyses

Prey composition was assessed on the basis of the percentage weight of each prey category. To test whether diet composition varied between day and night, between sexes, and between the size classes of marbled flounder, a multivariate analysis of variance (MANOVA) was carried out. The percentage weight of each prey category was determined for each individual flounder. The data were arcsine square root transformed. Series of net tows (tows #1–3 [night], 4–7 [day], or 8–11 [day]), sex (male or female), and TL were used as explanatory variables.

Diel feeding rhythms were assessed based on changes in empty stomach rates, stomach content weight, and prey composition. To analyze empty stomach rates, we constructed a generalized linear mixed model (GLMM) with binomial family and logit-link function. The response variable was presence/absence of stomach contents; initial explanatory variables were day/night time, sex (male/female), methods (measured onboard/frozen onboard), and TL of fish; the random variable was the tow number.

The stomach content weight index (SCI) was used to standardize the stomach contents data: $SCI = SCW \times BW^{-1} \times 100$. To analyze variation in the SCI, we constructed a GLMM with Gaussian family and log-link function, following Hattori, Okuda, Narimatsu, Ueda, & Ito (2009) with some modifications: the response variable was [SCW + 0.00001], initial explanatory variables and random variable were same as those in the GLMM for empty stomach rates, and log (BW) was used as an offset term. Because the SCW involves zero data, we added a negligible value of 0.00001 to the SCW to allow logarithm transformation. The final model was selected based on the Akaike information criterion (AIC). Similarly, we constructed a linear mixed model (LMM) for the weight of bivalve siphons in the stomachs of marbled flounder, using the same initial explanatory variables except methods and the random variable.

To estimate the daily ration (*DR*: percentage to the body weight) , gastric evacuation rate (*GER*) should be determined. It was calculated from the water temperature (*WT*, °C), following Durbin, Durbin, Langton, & Bowman (1983):

$$GER = 0.0406 \times e^{0.111 \times WT} \quad (1)$$

To test the validity of estimated GER, changes in the SCI from the dusk (tows # 7 and 11) to dawn during the night (tows # 1–3) in the day-night survey were analyzed. Preliminarily, weight of the bivalve siphons were subtracted from stomach contents weight because the flounder seemed to consume bivalve siphons during the night (see results). The SCI that does not include the weight of bivalve siphons was defined as SCI'. The linear model for the SCI' was constructed; the [SCI' + 0.1] was natural-logarithm transformed because SCI' involves zero data. The constant of 0.1 was used because the regression coefficient was the highest between using 1, 0.5, 0.1, 0.05, and 0.01. Initial explanatory variables were time from 18:00 (h), sex, and body size class (≥300 and <300 mm TL). The final model was selected based on the AIC. The coefficient of the time from 18:00 was regarded as the GER.

In the day-night survey, we determined the *DR* of marbled flounder of two size groups (≥300 mm TL and <300 mm TL) across sexes using the Elliott & Persson model (Elliott & Persson, 1978), as follows:

$$DR = \sum C_t \quad (2)$$

$$C_t = (S_t - S_0 \times e^{-GER \times t}) \times GER \times t \times (1 - e^{-GER \times t})^{-1} \quad (3)$$

where C_t is the ration from time 0 to time t (h), S_t and S_0 are the mean SCI at times t and 0, respectively. Empty stomachs were included for calculating both S_t and S_0. The SCI data from both specimens measured with their stomachs preserved in formalin onboard and specimens frozen onboard and measured in the laboratory were pooled for analysis, because the "methods" were excluded from the GLMM explaining the SCW (see results). The C_t was estimated for the time between each successive two tows, e.g. average SCIs of samples from tows # 2 and 1 were used as S_t and S_0, respectively. The daily ration was determined by summing C_t regardless of whether C_t was positive or negative. Since the day survey was conducted twice (Table 1), the daily ration was determined from two combinations of diurnal and nocturnal datasets, i.e. tows # 1–3 + 4–7 and tows # 1–3 + 8–11 (Table S1, supporting information).

We also assessed seasonal changes in *DR* for the two size groups (≥300 mm TL and <300 mm TL) across sexes of marbled flounder, using the equation following Eggers (1979):

$$DR = 24 \times \bar{S} \times GER \quad (4)$$

where $\bar{S}$ is the average SCI over 1 day and GER is the value estimated from the equation (1). The $\bar{S}$ cannot be determined directly because our seasonal samplings were carried out only in the morning (from 06:00 to 11:00). Therefore, $\bar{S}$ was estimated from the average SCI during the morning. A relationship between $\bar{S}$ and the average SCI during the morning (tows # 4–5 and 8–9) was obtained from two size groups across sexes of marbled flounder in the day-night survey: $\bar{S}$ = 1.057 × (SCI during the morning) (n = 8, r = 0.69). We also confirmed that the *DR* by Eggers was similar to the *DR* estimated by Elliot & Persson model from the day-night survey ([*DR* by Elliott & Persson] = 1.037 × [*DR* by Eggers], n = 8, r = 0.68). All calculation for SCI included individuals with empty stomachs.

3 Results

3.1 Feeding habits of marbled flounder

The size of marbled flounder ranged from 131 to 485 mm TL, with a single peak around 250–300 mm TL (Figure 2). Empty stomach rates were the greatest at the tow conducted at around 03:00 (Table 1).

Marbled flounder fed mainly on polychaetes, bivalves and their siphons, opisthobranchs, and actiniarians (Figure 3). Dietary composition differed significantly between series of net tows and body size, but not between males and females (MANOVA; series of net tows, $F_{2,361}$ = 16.87, p < .001; TL, $F_{1,361}$ = 6.08, p < .001; sex, $F_{1,361}$ = 1.82, p = .082). The proportion of bivalve siphons was consistently higher during the night than that during the day and this tendency was clear in flounder of small size classes (≥300 mm: 0.2–4.9% and 5.9–48.1%; <300 mm: 0.8–12.1% and 34.6–57.6% during the day and night, respectively). The weight of bivalve siphons per individual marbled flounder was also greater during the night than in the day (Figure 4). In the LMM for the bivalve siphon weight, "day/night" and TL were adopted as the explanatory variables ("day/night": $p < .001$; TL: $p = .08$), and sex was eliminated from the selected model. The proportion of bivalves was also greater at night than in the day (≥300 mm: 1.3–12.3% and 3.0–24.8%; <300 mm: 3.2–10.4% and 1.3–14.2% during the day and night, respectively). The proportion of opisthobranchs was greater in large individuals ≥300 mm (2.4–59.3%) than in small individuals (0.3–17.9%).

3.2 Diel feeding rhythm and daily ration

In the GLMM for empty stomach rates, only "day/night" was adopted as an explanatory variable. The empty stomach rates were significantly higher during the night than during the day (GLMM, $p < .001$). In the GLMM for SCW, sex and TL were adopted as explanatory variables (Table 2). The day/night and methods were excluded from the model (Table S2, supporting information). From the selected model, the SCI of females and smaller fish was greater than males and larger fish.

Stomach content weight decreased during the night (Figure 5). Average SCI changed from 0.69 to 0.08, 0.71 to 0.16, and 0.90 to 0.14 in large female, large male, and small male flounder at night, respectively, although it was relatively high at night (>0.5) in small females. During the day, it increased as the time passed with a single peak before sunset.

Daily ration, as calculated from two datasets, was 1.54 and 2.47% BW in females ≥300 mm, 1.27 and 1.89% BW in males ≥300 mm, 2.63 and 3.17% BW in females <300 mm, and 1.73 and 2.56% BW in males <300 mm.

Average bottom water temperature was 10.5 °C (Table 1). The GER at 10.5 °C, estimated from the equation (1), was 0.130. On the other hand, the estimated GER from the changes in SCI' was 0.169 (Figure 6). Preliminarily, the time from 18:00 was only adopted in the selected linear model for SCI', and sex and the size class was removed from the model. The estimated daily ration would increase by 30% when the GER of 0.169 was used, compared with the above data.

3.3 Seasonal variations in daily ration

Although individuals with empty stomachs were frequently observed from samples, greater rations in smaller (<300 mm TL) than in larger individuals were generally common, except for samples collected in February (Table 3). Large individuals, both male and female, consumed larger amounts of food (>1% BW of daily ration) during the lower temperature conditions of February–June than during the higher temperatures of September–November (>16°C, Table 3). However, small females consumed considerable amounts of food (>2% BW) from June to November, and small males consumed greater amounts in June–September, even when the temperature in June was low (<9°C). Empty stomachs were observed more frequently in males than in females. Females generally consumed more prey than males throughout the year.

4 Discussion

The diel feeding patterns of immature and mature marbled flounder revealed in the present study were similar to those reported for immature fish in previous studies (Takahashi, Tominaga, Maeda, & Ueno, 1982; Tokai & Ito, 1991): their feeding intensity was highest after sunrise and before sunset. Additionally, the present study constitutes the first report that the food intake of marbled flounder is greater in females than in males throughout the year. Since their spawning season is around December–January (Hatanaka & Iwahashi, 1953; Takahashi, Saito, Maeda, & Kimura, 1983; Tanda, Nakamura, & Okamoto, 2008), the sexual differences in food intake, as observed in the day-night survey in July, would be hardly related to their reproductive investment. The dietary composition did not differ significantly between males and females, but food intake of females was greater than males, suggesting that female fish consume more food than males without changing their prey.

The dietary composition differed between day and night, with the most considerable difference being the greater proportion of bivalve siphons at night. One possible explanation is that bivalves extend their siphons up to the sediment surface to feed at night, to avoid siphon predation by visual day feeders (Levinton, 1971). Pleuronectid flatfish are visual day feeders but they can use sensory organs to detect prey, as well as visual searches (de Groot, 1969, 1971). In fact, juvenile stone flounder (*Platichthys bicoloratus*) usually forage for food during the day, but can capture prey, such as bivalve siphons, in the dark (Tomiyama, Katayama, Yamamoto, & Shoji, 2016). Marbled flounder could possibly detect bivalve siphons that actively feed in the dark. Another possible explanation is the difference in gastric evacuation rates between prey items, as observed in the field (Rindorf, 2004). However, it is unlikely that bivalve siphons are difficult to digest by marbled flounder. A greater siphon weight per individual flounder stomach was observed at night than during the day (Figure 4), which supports nocturnal feeding by marbled flounder on bivalve siphons. Additionally, newly bitten siphons were observed in the stomachs of flounder collected at tow #3 (around 03:30), strongly indicating nocturnal feeding on bivalve siphons.

The greater daily ration of females than males was consistent throughout the year (Table 3), which could be related to the faster growth and greater maximum size of females than males (Solomon, Sano, Shimizu, & Nose, 1987; Tanda, Gorie, Nakamura, & Okamoto, 2008). The greater food intake of females than males was also observed for *Limanda limanda* in the laboratory (Pandian, 1970; Lozán, 1992). The ration of males was extremely low in November. Gonad weight of male and female fish peaks in November and December, respectively (Hatanaka & Iwahashi, 1953; Kume, Horiguchi, Goto, Shiraishi, Shibata, Morita, & Shimizu, 2006; Tanda, Nakamura, & Okamoto, 2008), indicating that male fish could reduce their feeding activity and prepare for reproduction earlier than females. High food consumption under preferable temperature conditions has been observed in pleuronectid flatfishes (Pandian, 1970; Worobec, 1984; Kusakabe, Hata, Shoji, Hori, & Tomiyama, 2017), and food consumption of marbled flounder of 200 mm increases as temperature increases from 2 to 24°C under laboratory conditions (Takahashi, Tominaga, & Maeda, 1987).

The daily ration was greatly affected by the GER. This study consistently used the GER estimated from the literature (Durbin et al., 1983) to apply it to the seasonal data, because the GER is temperature-dependent and the GER estimated from our day-night survey in July is not applicable to estimate the daily ration of fish in other seasons with different temperatures. However, the literature-derived value was lower than that estimated from the day-night survey on the assumption that flounder consume no food except bivalve siphons during the night. As the GER would also be affected by the food type or size (Durbin et al., 1983; He & Wurtsbaugh, 1993), the estimation of GER should be developed to increase the accuracy of the daily ration.

Daily ration estimated in the present study was <3% BW, which was lower than that in the laboratory experiment, 4–10% BW at 10–25°C (Takahashi et al., 1987). The lower values in the present study may be related to the high stock level. In another locality, density-dependent effects in the growth of marbled flounder have been observed (Lee et al., 2009). The stock of marbled flounder has increased considerably in the study area because of the temporal termination and subsequent reduction of fishing efforts of coastal fisheries after the environmental disaster in 2011. Therefore, their food intake and growth could be similarly reduced, although the main prey for marbled flounder were polychaetes and opisthobranchs and were similar to the past studies (Omori, 1974; Takahashi et al., 1982). It is necessary to determine whether the ration estimated in this study changes with various stock levels. Furthermore, the impact of predation by increased demersal fishes on benthic ecosystems should also be studied.

This study revealed the food intake of marbled flounder in relation to season, body size, and sex. This information is expected to contribute to future studies revealing the flow of energy and radioactive materials in ecosystems of the study area.

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TABLE 1 Cruise details for the day-night surveys in 2014

Tow #	Date	Time of net tows	BWT (°C)	N of collected fish	N of fish analyzed			
					Female ≥300 mm TL	Female <300 mm TL	Male ≥300 mm TL	Male <300 mm TL
1	July 6	21:13–21:45	10.7	183	5 (0)	23 (3)	9 (1)	17 (1)
2	July 7	0:38–1:09	10.3	339	6 (1)	2 (0)	1 (0)	6 (2)
3	July 7	3:15–3:45	10.5	243	14 (9)	17 (5)	9 (4)	30 (18)
4	July 8	6:59–7:29	10.2	154	10 (3)	17 (0)	9 (0)	27 (2)
5	July 8	10:08–10:39	10.5	129	9 (1)	2 (0)	4 (1)	18 (1)
6	July 8	14:34–15:04	10.7	74	14 (0)	22 (3)	2 (1)	36 (4)
7	July 8	18:06–18:36	10.5	144	14 (1)	17 (4)	8 (0)	28 (4)
8	July 9	7:03–7:35	10.5	123	4 (1)	7 (0)	3 (1)	17 (0)
9	July 9	10:07–10:47	10.2	177	5 (0)	5 (0)	6 (0)	14 (0)
10	July 9	14:25–14:54	10.5	130	3 (0)	6 (0)	7 (0)	14 (0)
11	July 9	18:23–18:52	10.6	134	2 (0)	6 (0)	9 (0)	13 (0)

Numerals in parentheses show the number of individuals with empty stomachs. Sunrise and sunset were at 04:20 and 19:03, respectively, on July 8. N = the number of individuals of marbled flounder (*Pseudopleuronectes yokohamae*); BWT = bottom water temperature; TL = total length.

TABLE 2 Results of the generalized linear mixed model for stomach content weight index (SCI) of marbled flounder (*Pseudopleuronectes yokohamae*) in the day-night surveys in 2014

Analysis of deviance				Summary			
Error source	df	Chisq	*p*	Parameter	Estimate	SE	*p*
				Intercept	–4.20	0.25	< .001
Sex	1	12.30	< .001	Sex (male)	–0.23	0.07	< .001
TL	1	26.17	< .001	TL	–0.0027	0.0005	< .001

Analysis of deviance was operated by the Type II Wald chi-square tests. Response variable was stomach contents weight (SCW) + 0.00001. Initial explanatory variables were day/night, sex, preservation method, and total length (TL). Tow number was included as a random variable. Day/night and the preservation method were excluded after model selection based on the Akaike information criterion. Effect of males was assessed on the basis of females.

TABLE 3 Seasonal surveys to determine the daily ration of marbled flounder (*Pseudopleuronectes yokohamae*) in 2014

Season	N of fish analyzed	SCI (%BW)	Daily ration (%BW)
≥300 mm TL, female			
Feb	27 (5)	0.67 ± 0.66	1.71
June	51 (8)	0.75 ± 0.69	2.03
Sep	23 (13)	0.15 ± 0.21	0.98
Nov	30 (8)	0.19 ± 0.19	1.22
≥300 mm TL, male			
Feb	7 (3)	0.40 ± 0.58	1.03
June	15 (2)	0.66 ± 0.75	1.79
Sep	7 (5)	0.06 ± 0.11	0.41
Nov	15 (14)	0.01 ± 0.05	0.09
<300 mm TL, female			
Feb	23 (8)	0.36 ± 0.43	0.91
June	25 (6)	0.83 ± 1.04	2.26
Sep	23 (4)	0.43 ± 0.43	2.90
Nov	9 (0)	0.42 ± 0.24	2.73
<300 mm TL, male			
Feb	24 (13)	0.14 ± 0.18	0.35
June	34 (6)	0.72 ± 0.52	1.97
Sep	30 (7)	0.29 ± 0.26	1.94
Nov	17 (11)	0.11 ± 0.19	0.70

Numerals in parentheses show the number of individuals with empty stomachs. Stomach content weight index (SCI) is presented as mean ± standard deviation, calculated including individuals with empty stomachs. Both SCI and daily ration are shown by percentage to body weight (%BW). Survey dates were February 2 and 22 for “Feb”, June 15 and 21 for “June”, August 30 and September 13 for “Sep”, and November 11 for “Nov”. Average bottom water temperatures was 8.2, 8.8, 16.9, and 16.5°C for Feb, June, Sep, and Nov, respectively.

Figure captions

FIGURE 1. Map of the study area in Sendai Bay, Japan. An open triangle indicates the station for the day-night survey in July 2014. Solid circles indicate stations for seasonal surveys in 2014.

FIGURE 2. Length-frequency distribution of marbled flounder (*Pseudopleuronectes yokohamae*) collected in the day-night survey in July 2014. Open and shaded bars denote female and male fish, respectively.

FIGURE 3. Diet composition (proportion in wet weight) of marbled flounder (*Pseudopleuronectes yokohamae*) (a) ≥300 mm TL and (b) <300 mm TL in the day-night survey. Solid and open horizontal bars indicate night and day, respectively. Numerals above bars indicate sample sizes without empty stomachs. Abbreviations are as follows: Po, polychaetes; Si, bivalve siphons; Bi, bivalves; Op, opisthobranchs; Ac, actiniarians; Cr, crustaceans; Ot, others.

FIGURE 4. Weight of bivalve siphons in the stomachs of (a) female and (b) male marbled flounder (*Pseudopleuronectes yokohamae*). Large and small indicate flounder ≥300 and <300 mm TL, respectively. Numerals indicate sample sizes including individuals with empty stomachs.

FIGURE 5. Stomach content weight index (SCI) of (a) female and (b) male marbled flounder (*Pseudopleuronectes yokohamae*) in the day-night survey. Solid triangles with dotted lines and open circles with solid lines indicate flounder ≥300 mm TL and <300 mm TL, respectively. Solid and open horizontal bars indicate night and day, respectively. Vertical

bars denote standard deviation. The data include fish with empty stomachs. Sample sizes are shown in Table 1.

FIGURE 6. Changes in the stomach contents weight index determined without bivalve siphons (SCI') in marbled flounder (*Pseudopleuronectes yokohamae*) collected from 18:00 to 04:00. Solid and open horizontal bars indicate night and day, respectively. The data were natural logarithm transformed with adding 0.1. The regression was fitted to the data: log (SCI' + 0.1) = –0.169 × Time – 0.0356 (r^2 = 0.38).

Fig. 1

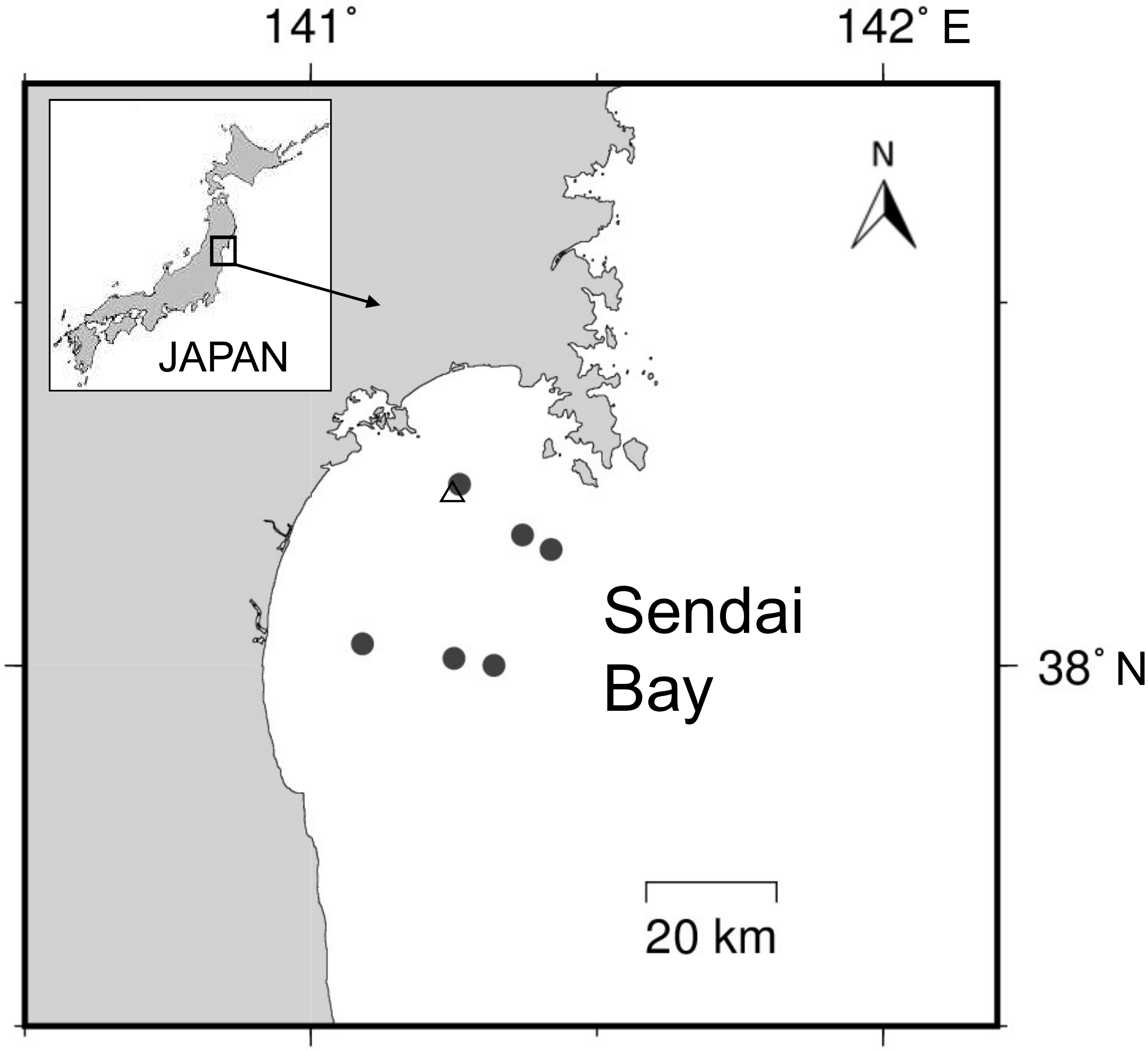
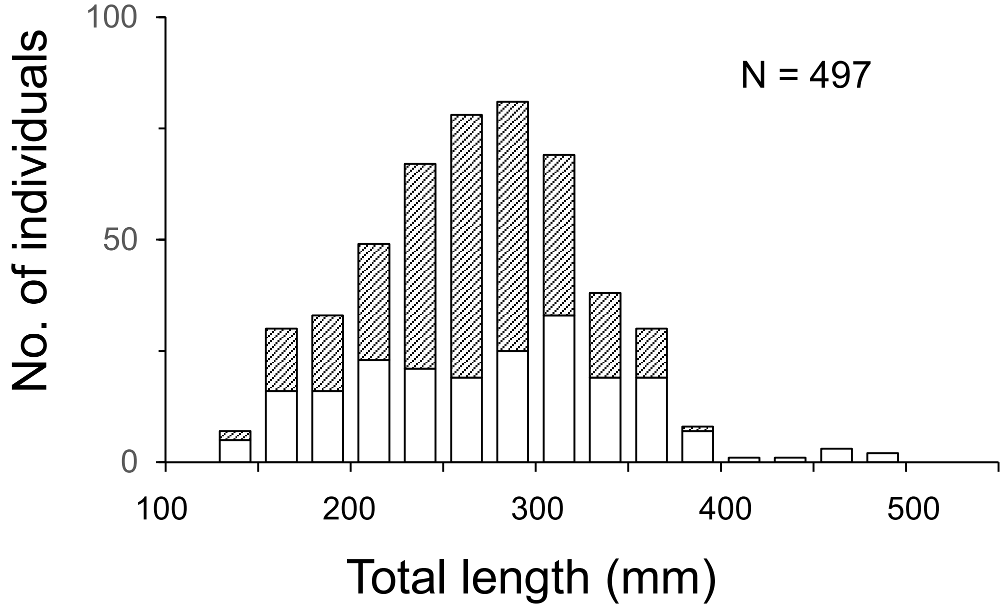


Fig. 2



N = 497
No. of individuals
0
50
100
100
200
300
400
500
Total length (mm)

Fig. 3

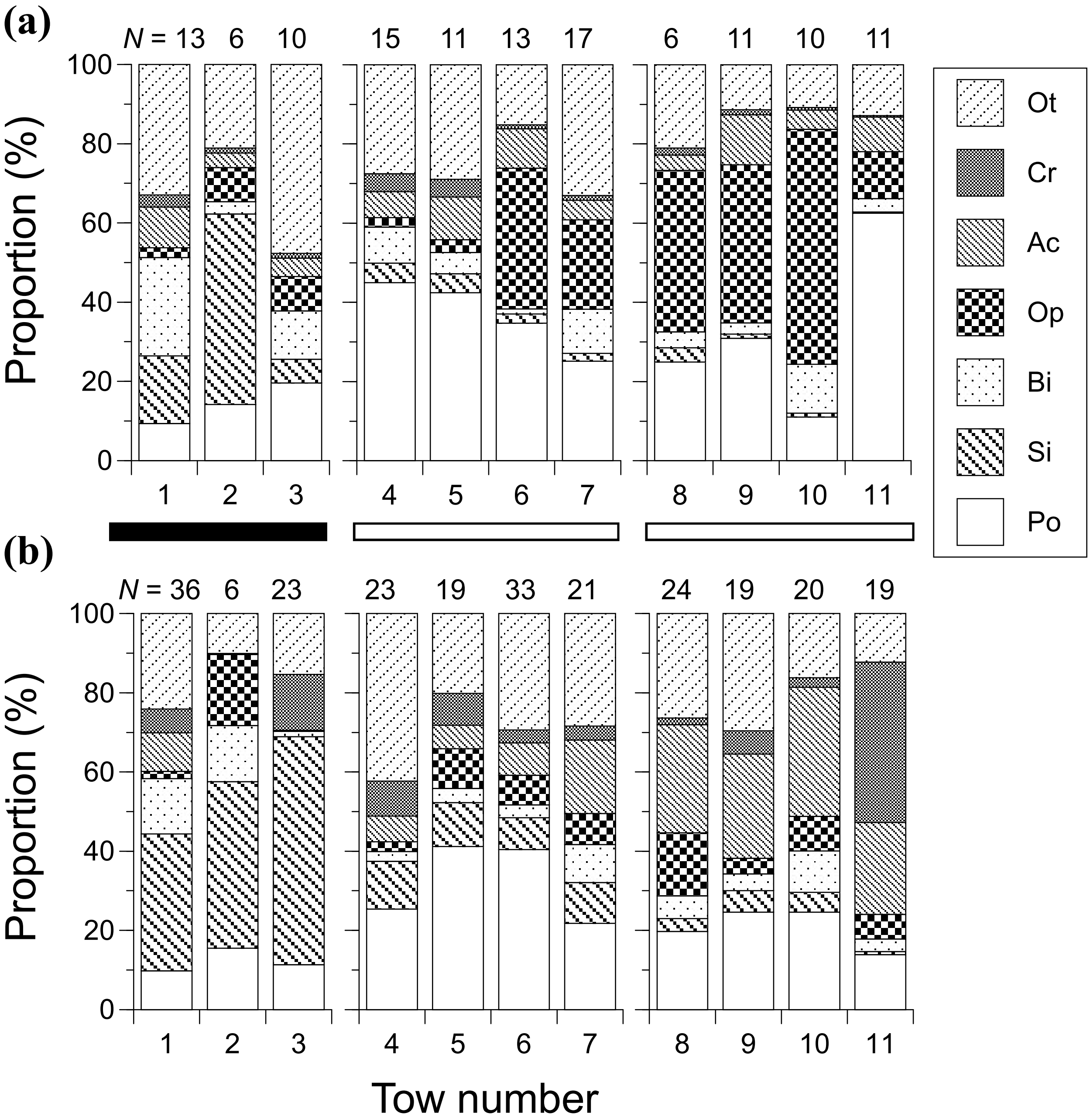

(a)
N = 13 6 10
15 11 13 17
6 11 10 11
Proportion (%)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11
Ot
Cr
Ac
Op
Bi
Si
Po
(b)
N = 36 6 23
23 19 33 21
24 19 20 19
Proportion (%)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11
Tow number

Fig. 4

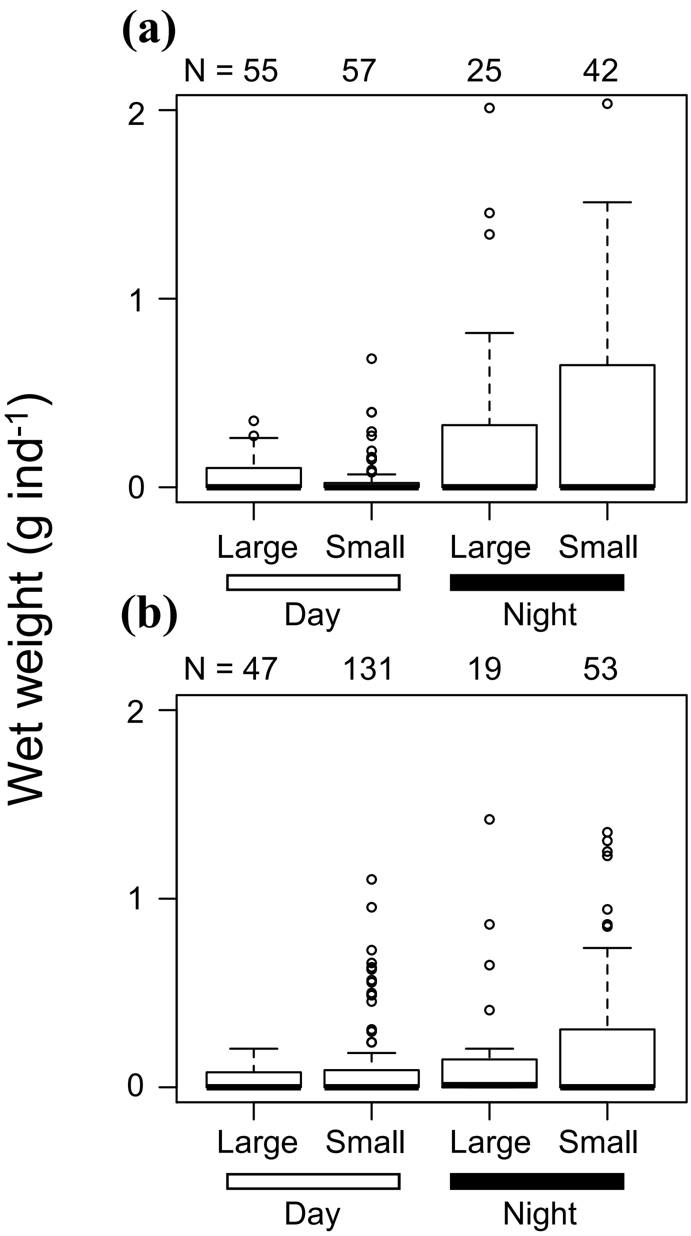
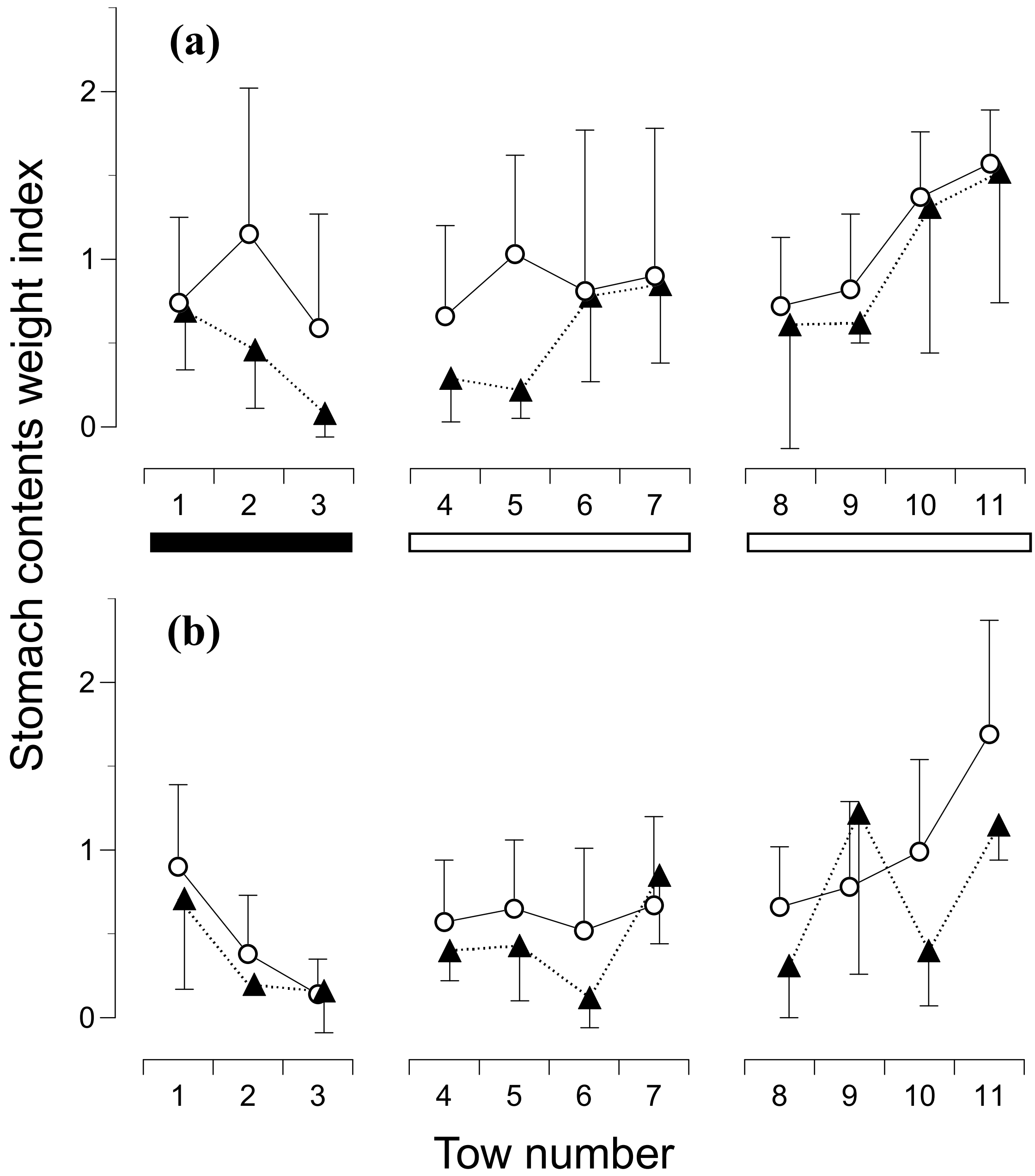

(a)
N = 55
57
25
42
2
1
0
Large
Small
Large
Small
Day
Night
(b)
N = 47
131
19
53
2
1
0
Large
Small
Large
Small
Day
Night
Wet weight (g ind-1)

Fig. 5



(a)
(b)
Stomach contents weight index
Tow number
0
1
2
1
2
3
4
5
6
7
8
9
10
11

Fig. 6