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Spatio-temporal patterns of parturition of the black rockfish *Sebastes inermis* in Sendai Bay, northern Japan

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ABSTRACT: The reproductive performance of 941 female specimens of black rockfish *Sebastes inermis* collected from four sites (from north to south, Ayukawa, Shichigahama, Yuriage and Haragama) along Sendai Bay, northern Japan from October 2000 to March 2001, was analyzed. Mature female *S. inermis* ranged from 2 to 9 years in age, from 15 to 29 cm in total length and from 80 to 496 g in total weight. Mean gonadosomatic index ranged from 0.42 to 14.6, showing a similar tendency in all locations, increasing from October, peaking around early December, and decreasing thereafter. The same pattern was observed in ovary weight, ranging from 0.72 to 33.74 g. Seasonal fluctuation in the percentage of occurrence of four development stages of ovaries (ripe, fertilized, eyed and spent) indicated that parturition season extended from late December to early March in Sendai Bay. However, parturition shifted on both a temporal and spatial scale, that is, the extrusion began and finished later, the more northerly was the site. There were significant differences in the age of spawners as extrusion season progressed, with older female *S. inermis* (approx. 5 years old) occurring at the beginning and younger ones (approx. 2 years old) occurring at the end of the season. A similar tendency was also observed in size, weight and ovary weight in most ovarian developmental stages.

KEY WORDS: **age, fish, gonadosomatic index, otolith, reproduction.**

INTRODUCTION

Although reproduction of coastal marine fishes often extends over considerable long periods of the year, usually there are certain times of the year when large numbers of species and large numbers of individuals of a respective species reproduce.[1] In consequence, the timing of spawning of a given species should reflect an adaptive strategy to match spawning with the optimal phase of the annual planktonic production cycle, to maximize the survival of its progeny.[2–4] However, given the high variability in the timing of spawning over a year occurring even in evolutionary closed species, many aspects of reproductive strategies in coastal fishes remain undescribed. This seems to be the case for an evolutionary homogenous group, *Sebastes* species.

Sebastes rockfishes are viviparous, that is, after mating and copulation, fertilization occurs within the ovary, and the embryos develop within egg envelopes for most of the gestation, hatching several days before parturition.[5,6] In addition, most species of *Sebastes* have protracted extrusion seasons[7,8] and, depending on the species, one or several broods are produced. Most southern species of *Sebastes* are multiple brooders, and it has been hypothesized that this reproductive strategy may either reflect the constant availability of abundant food supply or that the food supply is inadequate for the production of a single, large brood but suitable for several smaller broods spread over a period of time.[9] Conversely, nothing has been examined to date concerning the variation of timing of parturition and reproductive strategy for single brooder species of *Sebastes*, some of which have an extended latitudinal distribution (e.g. *Sebastes inermis*).

The black rockfish *S. inermis* is a single brooder and is a commercially important species, distributed from southern Hokkaido to Kyusyu in Japan and in southern Korea.[10] The parturition season of this species occurs in the winter months, providing the main larval supply for settlement of young-of-the-year (YOY) in nearshore areas (e.g. *Zostera and Sargassum* beds). Studies on the reproductive cycle of this species conducted in waters off Kyushu have

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stated that maturation begins in November and larvae are extruded from early January to early February.[11,12] However, Hatanaka and Iizuka found evidence that extrusion began earlier (from late December) in Matsushima Bay, in Miyagi waters.[13] This evidence suggests that *S. inermis* might have a more protracted parturition season, which has not been suitably described. In addition, the distribution of the parturition of *S. inermis* within a spatial scale has not been explored as yet. In the present paper we classify ovaries in different development stages to characterize the reproductive traits of the parturition season of *S. inermis* in four sites along Sendai Bay, northern Japan. Furthermore we examine the relationship between population structure and reproductive patterns.

MATERIALS AND METHODS

Sampling and laboratory analysis

Adult female *S. inermis* were caught using angling and gill nets through cooperative research with fishermen in four locations along the coast of Sendai Bay from October 2000 to March 2001 (Fig. 1; Haragama, Yuriage, Shichigahama, and Ayukawa). Samples were obtained bimonthly whenever possible, at the beginning and the end of each month. Most of the fish were kept frozen below –25°C until they were weighed and measured a few days after catching. All ovaries were weighed and the gonadsomatic index [GSI; (gonad weight × 100)/body weight[1]] was calculated. To characterize the reproductive season, ovaries were classified into four morphological stages: ripe ovaries (mature ovaries without evidence of fertilization; Fig. 2a); fertilized ovaries (ovaries with fertilized oocytes, and ovaries with early embryonic development but without retina pigmentation (Fig. 2b)); eyed ovaries (ovaries with early to advanced retina pigmentation, and pigmentation of the peritoneal wall

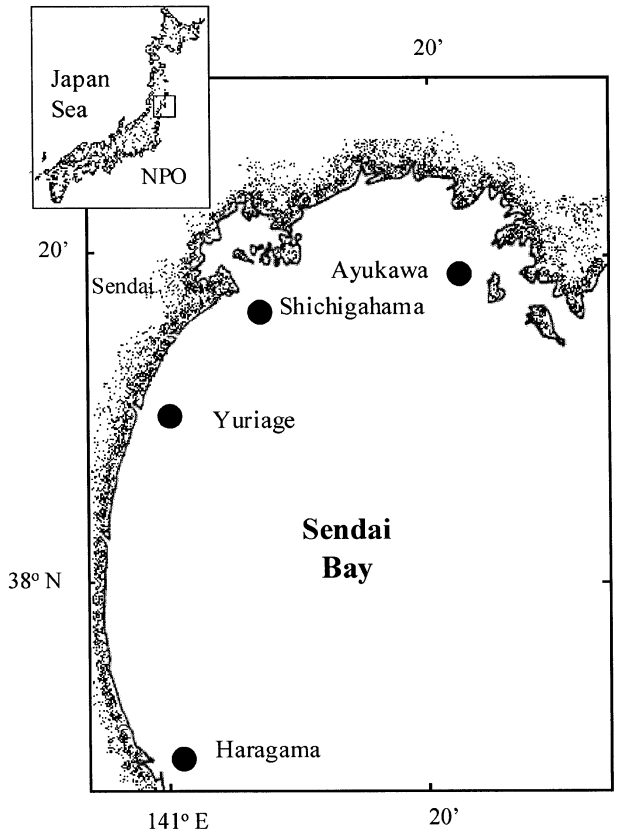

Fig. 1 Map of Sendai Bay, Miyagi, northern Japan, showing the location at which adult female *Sebastes inermis* were collected by angling and gill nets. NPO, North Pacific Ocean.

Table 1 Female *Sebastes inermis* collected from four sites along Sendai Bay during the reproductive season from October 2000 to March 2001

	Haragama *n* = 212	Yuriage *n* = 218	Shichigahama *n* = 129	Ayukawa *n* = 382
Age (years)				
Mean	4.17	4.20	4.38	3.96
SD	0.93	0.88	0.88	0.58
Range	2–9	2–8	2–8	2–6
TL (cm)				
Mean	21.7	20.7	20.9	20.3
SD	1.9	1.6	1.6	1.5
Range	16.8–29.0	15.6–27.8	17.0–26.6	15.0–26.0
Weight (g)				
Mean	198.51	170.92	176.15	156.65
SD	61.94	47.46	48.86	41.35
Range	85.6–496.3	70.3–450.9	92.2–400	80.6–376

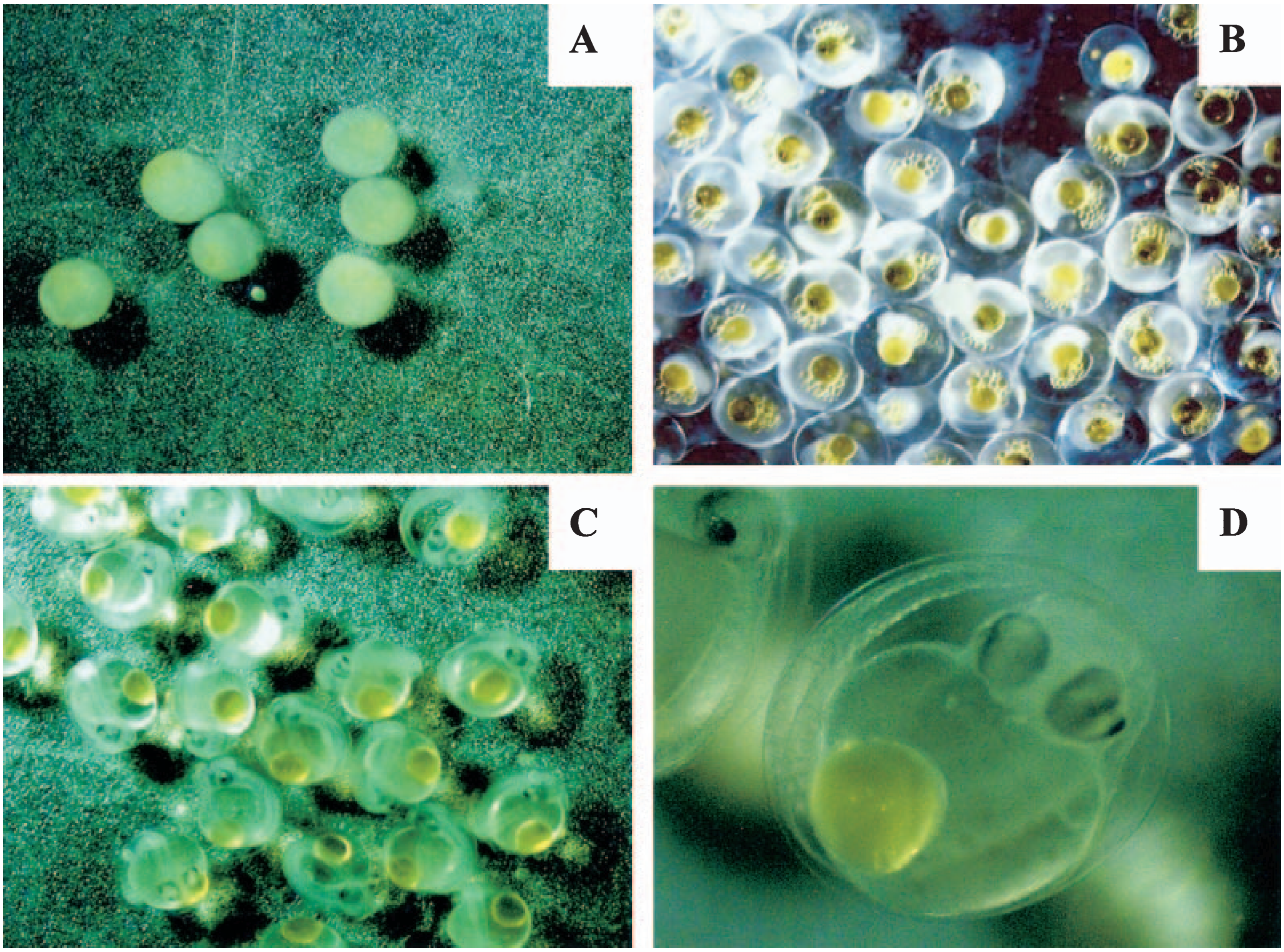

Fig. 2 (a) Ripe, (b) fertilized, and (c,d) eyed ovaries of female *Sebastes inermis* collected during the reproductive season from October 2000 to March 2001 along Sendai Bay, northern Japan. All photographes were taken from fresh samples.

(Fig. 2c,d)); and spent ovaries (partially and totally spawned ovaries).

Accurate macroscopic classification of ovaries was made by placing a small section of ovary tissue in a Petri dish containing physiological saline solution,[14] for observation and photography under a dissecting microscopy connected to an image analysis system (Quantimet 600, Leica, Wetzlar, Germany).

Age determination

The age structure of the spawners was determined for each location. In all fish collected, sagittae were removed and cleaned in a solution of 5% sodium hypoclorite, and preserved in glass vials under dry conditions. Annuli were counted by surface reading after placing the sagittae in a capsule containing distilled water and then observing them using an image analysis system supported by a stereomicroscope. The opaque zone was taken as being the annulus because it has been found to be formed once a year for this species.[13,15]

RESULTS

Age and size structure

A total of 941 adult female *S. inermis* were collected from October 2000 to March 2001 in the four locations (Table 1). Female *S. inermis* ranged from 2 years to 9 years in age, from 15 cm to 29 cm in total length and from 80 g to 496 g in total weight. Neither age nor body sizes structure of the population differed significantly among locations (ANOVA $P > 0.05$). Scatterplots of mean age on collecting time were distributed at approximately 4 years old (Fig. 3a). The same pattern was also observed for total length among locations (Fig. 3b).

Extrusion season

Mean GSI ranged from 0.42 to 14.6, having a similar tendency in all locations. The GSI increased from October and peaked around early December. By late January GSI had decreased to approximately 2.5, except for Ayukawa in which the GSI remained higher (Fig. 3c). The same pattern was observed in ovary weight (Fig. 3d), for which mean values ranged from 0.72 g to 33.74 g. The tendency toward later extrusion in Ayukawa was more evident in the seasonal fluctuation in the percentage occurrence of the development stages of ovaries and spent ovary rate (Figs 4,5). Ripe ovaries occurred until early December in Haragama, and until early January in Ayukawa, which confirmed that the extrusion of *S. inermis* began and finished later in Ayukawa than in southern sites. A peculiar feature was the occurrence of a few ripe female *S. inermis* from the end of January to late February in almost all sites. Based on the frequency of occurrences of spent ovaries, it seems that extrusion was extended from late December to late January in Haragama, from late December to early February in Yuriage, and from early January to late February in Ayukawa. Unfortunately in Shichigahama there were no data in January to estimate the relative duration of the extrusion season (Fig. 4c).

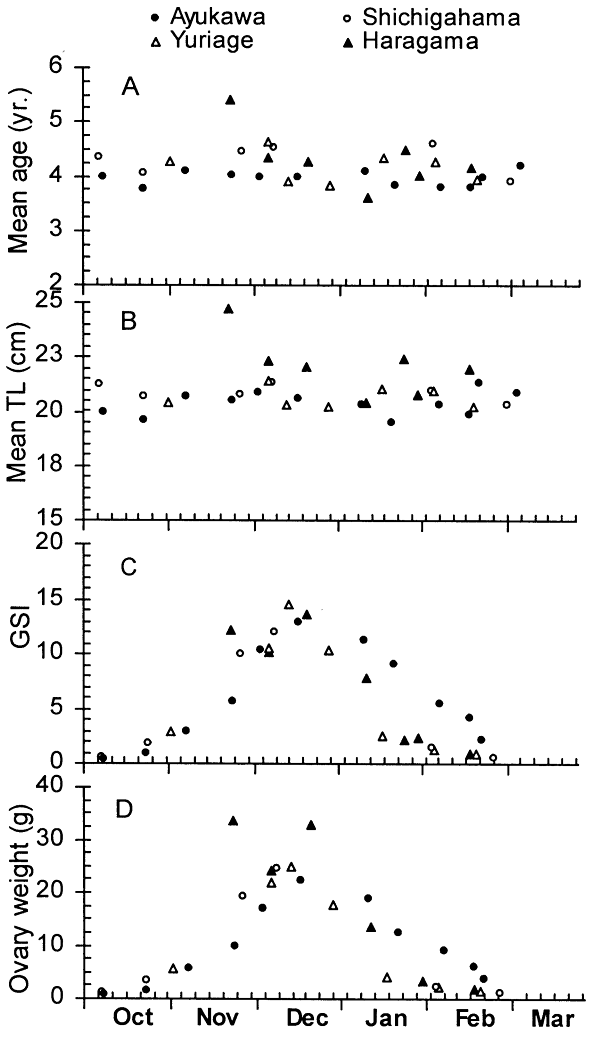

Fig. 3 Scatterplots illustrating the distribution of mean values of (a) age, (b) fish total length (TL), (c) gonadosomatic index (GSI) and (d) ovary weight of females *Sebastes inermis* in Sendai Bay, northern Japan. Each plot represents an average on a collecting date in a given site.

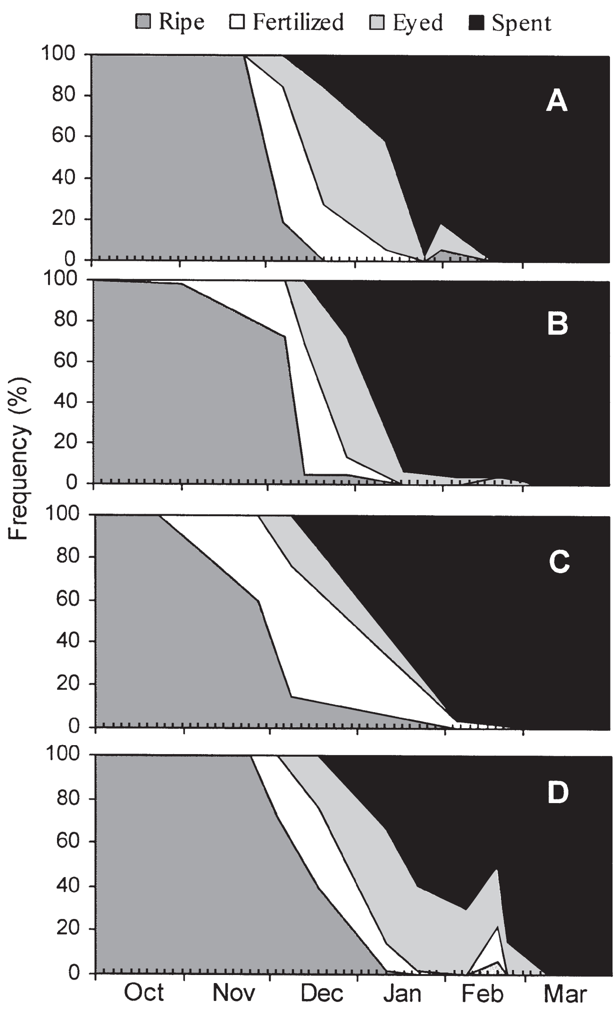

Fig. 4 Percentage of occurrence of four development stages of ovaries in female *Sebastes inermis* collected from October 2000 to March 2001 in four locations in Sendai Bay: (a) Haragama), (b) Yuriage, (c) Shichigahama, and (d) Ayukawa.

Table 2 Female *Sebastes inermis* grouped by collecting date, site, and five developmental stages of ovaries

Haragtama					Yuriage					Shichigahama					Ayukawa				
Date	Ripe	Fertilized	Eyed	Spent	Date	Ripe	Fertilized	Eyed	Spent	Date	Ripe	Fertilized	Eyed	Spent	Date	Ripe	Fertilized	Eyed	Spent
23 Nov	5	0	0	0	1 Nov	49	0	0	0	7 Oct	25	0	0	0	7 Nov	19	0	0	0
7 Dec	5	18	4	0	4 Dec	23	9	0	0	23 Oct	17	0	0	0	24 Nov	38	0	0	0
21 Dec	0	11	24	3	14 Dec	0	13	9	0	27 Nov	16	12	0	0	4 Dec	12	9	0	0
12 Jan	4	4	18	12	29 Dec	6	4	14	6	9 Dec	5	13	9	0	18 Dec	12	12	10	0
26 Jan	0	0	4	28	18 Jan	0	0	4	29	5 Feb	0	2	3	26	11 Jan	0	10	26	12
31 Jan	3	0	5	31	6 Feb	0	0	3	29	5 Mar	0	0	0	13	22 Jan	0	0	20	19
19 Feb	0	0	0	35	21 Feb	0	0	0	28	7 Oct	17	0	0	0	8 Feb	0	0	7	16
										23 Oct	25	0	0	0	19 Feb	3	8	11	25
															23 Feb	0	0	4	18
															9-Mar	0	0	0	25

0, female *S. inermis* did not occur at the specified ovary stage.

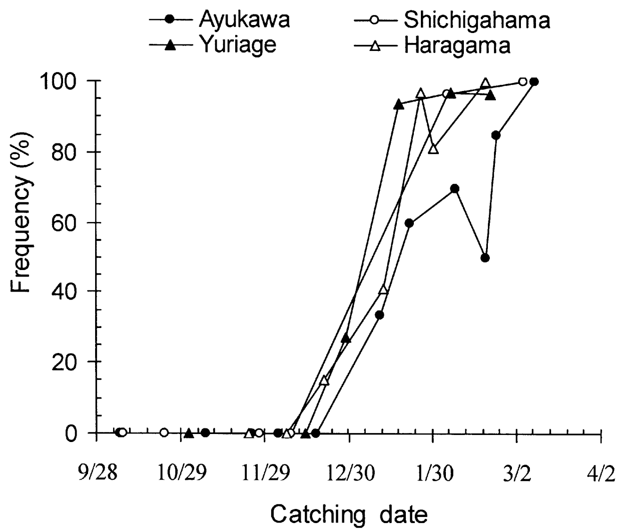

Fig. 5 Spent ovary rate of female *Sebastes inermis* caught in four sites in Sendai Bay from October 2000 to March 2001.

Fluctuation in size, age and ovary weight by ovarian development stage

Results of this analysis are shown as mean values of age, total length, plotted on collecting times for three development stages of ovaries (Fig. 6): ripe ovaries, fertilized ovaries and eyed ovaries. The number of individuals analyzed at each site and date are given in Table 2. There were significant differences (ANOVA $P < 0.05$) in the age of spawners as extrusion season progressed, with older female *S. inermis* (approx. 5 years old) occurring at the beginning and younger ones (approx. 2 years old) occurring at the end of the season. This tendency was also observed in size, weight and ovary weight in most of the ovarian developmental stages and occurred regardless of the catch site.

DISCUSSION

Population structure and extrusion season

The range of ages in mature female *S. inermis* analyzed in the present study was not >7 years, with the younger female *S. inermis* being aged around 2 years and the older ones around 9 years. Similar or lower age ranges have been recently reported for this species elsewhere in Japan.[15–18] The narrow age range observed in the present study might be a result of the size selectivity of gill nets, and/or also might reflect the juvenilization of the population due to fishing over-exploitation. Nevertheless, the narrow age range observed here was enough to

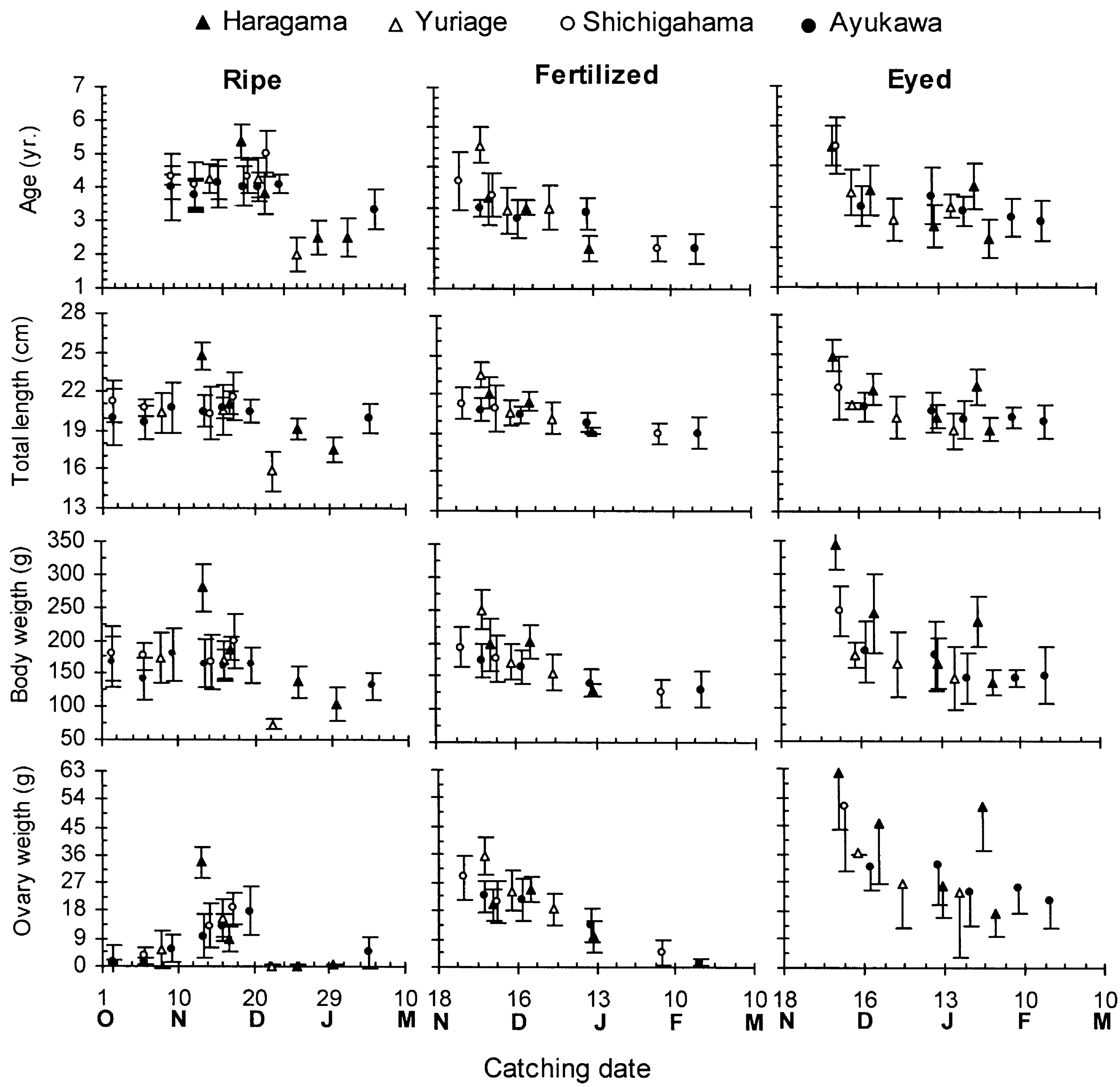

Fig. 6 Mean values of age, total length, total body weight and ovary weight by ovary stages of female *Sebastes inermis* caught in four sites in Sendai Bay from October 2000 to March 2001. Each plot represents a mean value of a single collection date in a given site illustrated in the Table 2. Capital letter and vertical bars denote month and standard deviation, respectively.

allow analysis of the seasonal variation of age, body size, body weight and ovary weight of spawners by ovarian developmental stage as the extrusion season progressed. This analysis made it possible to avoid the overcast that could occur when these variables were averaged in females with ovaries of different development stages. The approach showed clearly that older and bigger female *S. inermis* tended to start their extrusion earlier than younger and/or smaller female *S. inermis*. This decrease in age and body size progressed gradually from the beginning to the end of the extrusion season in all locations, with plots for Ayukawa having a significantly lower age, size, weight, and ovary weight owing to later extrusion. Early spawning has been reported in larger sized and older female specimens for a number of marine fish[19–21] and for a species of rockfish as well.[8] In addition, there is no doubt that older and larger female fish produce larger eggs than younger fish,[22] and the larger eggs result in larger larvae at hatching with higher survival potential. Likewise, larger and older female fish also produce a large amount of eggs.[6,22,23] In consequence, the marked decrease in ovary weight at the end of the extrusion season in younger and smaller female *S. inermis* suggests that they have a lower reproductive potential. These findings are relevant for fishery management because an unrestricted fishing season could seriously affect the reproductive potential of this rockfish.

A clear feature was the presence of ripe female *S. inermis* at the end of the extrusion season in most locations, particularly in Ayukawa at the end of February. The gestation period usually lasts approximately 2 months for rockfish.[6] Hence, the existence of ripe female *S. inermis* at the end of the parturition season would permit potential events of extrusion even beyond April for *S. inermis*. However, it is unclear if these young female *S. inermis* complete the process. The remarkable low ovary weights of these young female *S. inermis* (approx. 2 years and 15 cm total length) suggest that oocytes may be reabsorbed, remaining functionally immature, such as has been found in other *Sebastes* species.[7,8]

Spatio-temporal distribution of extrusion season

Results found in the present study also demonstrate that effectively *S. inermis* has a more protracted extrusion season (approx. 3 months) than that described for the water of Kyushu (approx. 1 month,[11,12]), the southern limit of its latitudinal distribution. Inter-species variation in the timing of extrusion in *Sebastes* species may occur with latitude,[24,25] presumably because parturition may be linked to highest ocean productivity, which may have a distinct geographic pattern. Unfortunately nothing is known concerning intra-species latitudinal differences in the timing of extrusion in *Sebastes*. The longer parturition season for *S. inermis* underlined here may be a result of either interannual variations or encompass preliminary evidence for latitudinal variability in the timing of parturition in *S. inermis*, a rockfish with an extended latitudinal distribution. Further research comparing the timing of parturition of *S. inermis* along Japan coast on an interannual basis will be needed to test these inferences. However, the most apparent characteristic found in the present study was that the extrusion season of *S. inermis* shifted both in temporal and spatial scales in Sendai Bay, beginning and finishing earlier in southern locations than in northern ones. The shift was not related to the age-structure of spawners and seemed to be gradual. Such a variation at a small spatial scale of kilometers has not been reported for any other rockfish species to date. *Sebastes inermis* is a single brooder; hence in order to explain these variations found at a small spatial scale, we must suggest that female *S. inermis* are shifting their extrusion season in response to some environmental cues as an adaptive strategy. It is well-known that temperature plays a key role in the reproductive performance of marine fishes in temperate waters.[1] Temperature can affect the egg size, and egg size can affect the duration of the embryonic period (i.e. larger eggs develop more slowly than smaller ones at the same temperature[6]). We could not obtain exact estimates of water temperature at the time of capture, but in winter in Sendai Bay the water temperature decreases from December to March, owing to the southward influence of the cold water Oyashio current.[26] This fact was confirmed when published raw data (Miyagi Prefectural Fisheries Research and Exploitation Center) of water temperature closer to Yuriage and Ayukawa were compared (Fig. 7). Hence, delay in extrusion events from south to north could be the result of an increase in the gestation time of the embryos, perhaps triggered by the lower temperatures in the northern site, although the higher temperature found in January in Ayukawa argues against this explanation. In consequence, other factors cannot be discarded, for example (i) female *S. inermis* are shifting their extrusion season as a reproductive strategy linked perhaps to the survival of its progeny; (ii) a noisy effect produced to

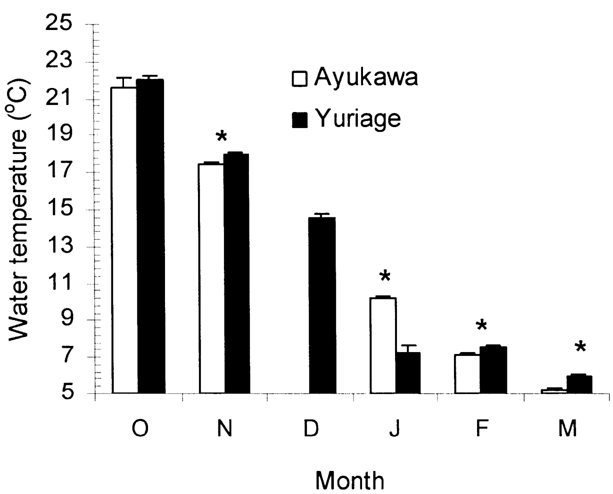

Fig. 7 Mean water temperature from surface to 20 m depth in two coastal stations closer to Yuriage (38°14′N; 141°32′E) and Ayukawa (38°08′N; 141°00′E) sites in Sendai Bay. Source for raw data: Miyagi Prefectural Fisheries Research and Exploitation Center. *Significant difference (ANOVA, $P < 0.05$); vertical bar, SD.

blend several morphotypes of *S. inermis*, a species not still fully defined taxonomically;[27–30] and/or (iii) merely coincidental. Further analysis testing the relationship between reproductive performance and early life history events on the basis of morphotype variability would be useful to test these inferences.

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