Maturation patterns of *Sargassum autumnale* Yoshida (Phaeophyceae, Fucales) in Maizuru Bay, Sea of Japan

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Maturation patterns (growth of main branch, presence of receptacle, etc.) of the *Sargassum autumnale* population in Maizuru Bay were investigated. This population formed mature main branches with receptacles twice a year. The first period was from July to November, and the second was from October to March. The main branches elongated during spring and early summer. In July, the length of main branches reached the annual maximum, and most of them began to form receptacles. The main branches shed receptacles and decayed from October to December. In July, new main branches appeared from the stem at the basal part of thalli, and these formed receptacles from October. The main branches, which formed receptacles in autumn, decayed from December to March, while those without receptacles gradually grew during spring and early summer the next year. Eggs and fertilized embryos on the surface of female receptacles were observed for both first and second maturations.

Key words: Maizuru Bay, Maturation, *Sargassum autumnale*

The maturation period of *Sargassum* is important, because seasonal fluctuations in vegetative growth and attrition are closely related to the cycle of sexual reproduction (De Wreede, 1976; McCourt, 1984; Umezaki, 1985). In temperate areas, the abundance of *Sargassum* population increases to the annual maximum during the maturation period, and mature thalli decay or are cut from the basal part at the end of maturation (Marui *et al*., 1981; Umezaki, 1985). These seasonal patterns are interpreted as a strategy to maintain population (Reed *et al*., 1996).

Sargassum species in temperate zones have an annual cycle of regeneration, growth, maturation, and senescence (Ajisaka, 1997). However, a few exceptions have been observed. Some individuals of *Sargassum thunbergii* (Mertens) O. Kuntze on the Pacific Coast of Chiba Prefecture mature both in spring and autumn (Arai *et al*., 1985). *Sargassum horneri* (Turner) C. Agardh, cultured under an optimal growth condition in an early growth stage (until 10 cm in length), matured both in June and December (Yoshida *et al*., 2003). These exceptions provide insights into mechanisms to regenerate *Sargassum* populations.

In and around Maizuru Bay, 16 species of the genus *Sargassum* mature in spring or summer (Umezaki, 1974, 1983, 1984a,b; Douke, 2004), while S*argassum ringgoldianum* Harvey subsp. *coreanum* (J. Agardh) Yoshida (Umezaki, 1986; Douke, 2004) and *S. autumnale* Yoshida (Douke, 2004) mature in autumn. *Sargassum autumnale* is a perennial seaweed growing in the upper sublittoral zone of sheltered coasts from Yamagata Prefecture through Nagasaki Prefecture in the Sea of Japan (Yoshida, 1983; Kajimura, 1989). This is the most dominant species in the *Sargassum* bed in the middle part of Maizuru Bay.

The purpose of this study was to clarify the maturation patterns of the *S. autumnale* population in Maizuru Bay. The growth of main branches and formation of receptacles were examined on a monthly basis. Unique characteristics of the maturation of this species are reported in this study.

Materials and methods

Sargassum autumnale populations in Nejirimatsuzaki and Nagahama in the middle part of Maizuru Bay (Fig. 1) were observed every month. At Nejirimatsuzaki, thalli of *S. autumnale* in four quadrats (25 cm × 25 cm) were collected every month from November 2003 to November 2004.

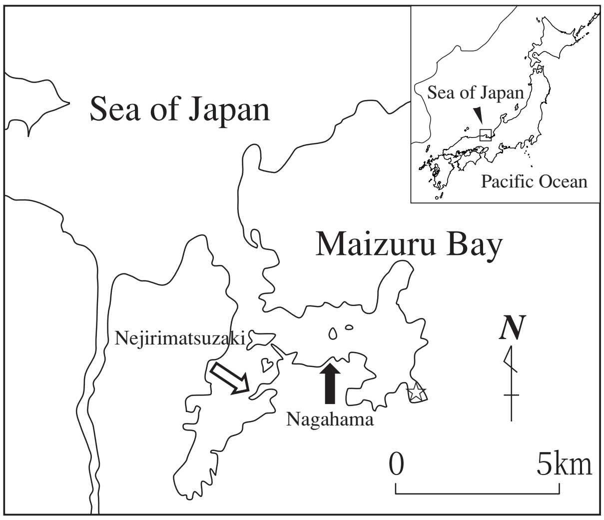

Fig. 1 A map showing Maizuru Bay. Open and closed arrows indicate Nejirimatsuzaki and Nagahama, respectively. The star indicates the Maizuru Bay Tide Station.

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The water temperature at the surface and a depth of 1 m in Nejirimatsuzaki was measured at every visit. Data on the tidal level at the Maizuru Bay Tide Station (Fig. 1) recorded by the Maizuru Marine Observatory* were obtained for the year.

The number of main branches was counted for all collected thalli. The total length of the five longest individuals was measured, and their average was regarded as the mean total length of the *S. autumnale* population. For more than six months, two types of main branches, i.e., old and new main branches, appeared. Thus, the length from the holdfast to the apex of the longest old and new main branch was also measured for each thallus. Female or male receptacles were determined by visually examining the shape of receptacles (Yoshida, 1983; Kajimura, 1989).

At Nagahama, additional investigations were carried out as follows. The presence of eggs and embryos on the surface of female receptacles was examined from July 2005 to March 2006, during which receptacles were observed. Since receptacles did not appear on every branch during late autumn and winter, the presence of receptacles was examined for all main branches of two individuals collected at Nagahama on December 4, 2005. Every main branch was cut from the stem, and their lengths were measured. Old and deteriorated main branches were discarded and new main branches were classified into the two following types: main branches with or without receptacles.

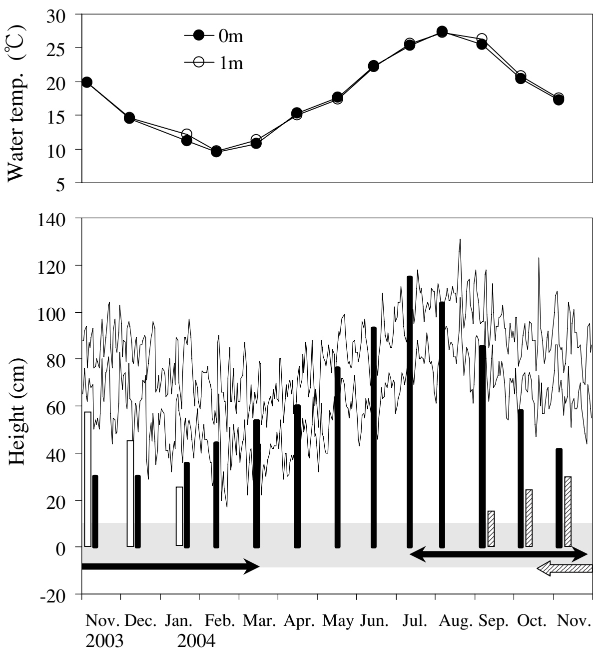

Fig. 2 Monthly changes in water temperature (upper figure), and the length of *Sargassum autumnale* at Nejirimatsuzaki, and the tidal level in Maizuru Bay (lower figure), from November 2003 to November 2004. The two fluctuating lines indicate the daily minimum and maximum tidal levels. White, black, and hatched bars indicate the length of old main branches in 2003, new main branches in 2003, and new main branches in 2004, respectively. The length of the plant and tidal level are expressed with reference to the zone at which *S. autumnale* densely grew (dotted zone). Arrows indicate the periods for which receptacles are formed on old (black arrows) or new (hatched arrow) main branches.

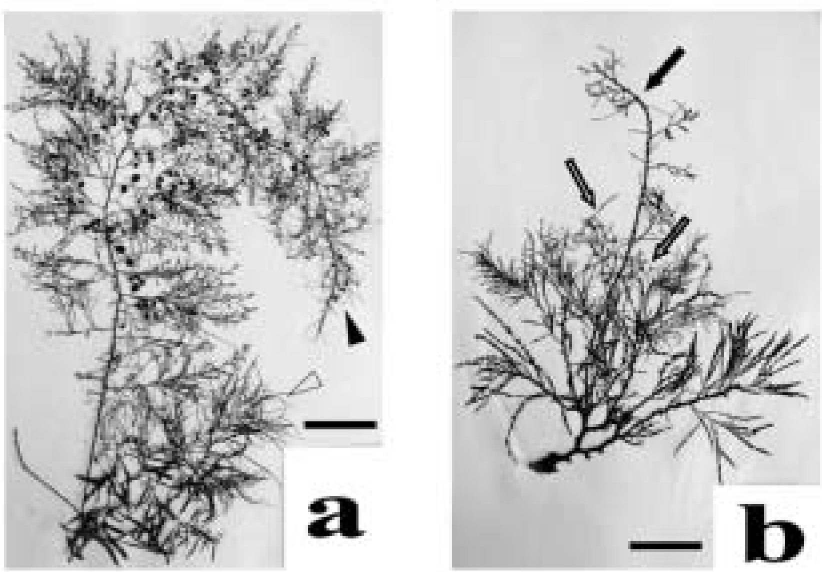

Fig. 3 *Sargassum autumnale* specimen collected in Nejirimatsuzaki on September 6, 2004 (a); Main branch with receptacles (closed arrowhead) and newly growing main branch (open arrowhead). A specimen from Nagahama on November 23, 2004 (b); Decayed, old main branch (closed arrow) and receptacles on new main branches (open arrows). Scale bar in (a) and (b) indicates 5 cm.

*Maizuru Marine Observatory. http://www.maizuru-jma.go.jp/

Table 1 Number of matured or unmatured main branches in each length range

Range of length	0-4 cm	5-9 cm	10-14 cm	15-19 cm	20-24 cm
Main branch without receptacle	18	9	2	0	0
Main branch with receptacle	0	0	2	2	2
Pecentage of matured main branches	0%	0%	50%	100%	100%

Main branches were colledted from two thalli on December 4, 2005.

Results

Seasonal changes in water temperature at depths of 0 and 1 m in Nejirimatsuzaki are shown in Fig. 2. Water temperature at both depths changed similarly. The maximum and minimum water temperature was 27.3 ℃ in August and 9.6 ℃ in February, respectively.

Seasonal changes in the length of main branches of *S. autumnale* at Nejirimatsuzaki and the period in which receptacles appeared are shown in Fig. 2. Thalli of *S. autumnale* grew densely at a depth of 5 to 25 cm below the lowest tidal level. Seasonal changes in the total length of thalli were closely correlated with changes in the tidal level (Fig. 2). The number of main branches per individual collected in this area was 11.2 on average.

Seasonal changes in the length of main branches are shown in Fig. 2. In November and December 2003, old and long main branches deteriorated and shed receptacles, while new and short main branches gradually elongated, and some formed female or male receptacles. In January 2004, old main branches were completely deteriorated, being shorter than new main branches. In this month, the mean total length of *S. autumnale* was the shortest (36 cm) of the year. The new main branches that formed receptacles gradually decayed from December until March, and no receptacles were found in April. Main branches, which did not form receptacles in late autumn to winter, elongated as the tidal level elevated during spring and early summer. The mean total length of thalli reached the annual maximum (115 cm) in July. From this month, most of the main branches began to form female or male receptacles (Figs. 2, 3a). The main branches gradually deteriorated from July 2004 and shed their receptacles from October (Fig. 3b).

When the longer main branches began to form receptacles in July 2004, new and short main branches appeared from the stem (Figs. 2, 3a). The new main branches continued to grow under the canopy, composed of mature old and long main branches (Figs. 2, 3a). In October 2004, some of the new main branches began to form receptacles (Figs. 2, 3a). Though, their length reached 25 cm (Fig. 2), new main branches longer than 10 cm formed receptacles. For the thalli collected on December 4, 2005, all main branches longer than 15 cm formed receptacles, while those less than 10 cm did not (Table 1). The minimum length of main branches with receptacles was between 10 and 14 cm (Table 1).

Eggs and embryos on the surface of female receptacles were observed twice. The first time was from late-September to early-October 2005 in old and longer main branches, and the second time was in early-December 2005 in newly grown and shorter main branches.

Discussion

Sargassum autumnale in Maizuru Bay formed receptacles for three quarters of the year. During their long maturation period, main branches with receptacles deteriorated and new main branches began to form receptacles, alternately. The initially matured main branches formed receptacles from July to November, and the second ones from October to March. The water temperature ranged from 17.2 to 27.3 ℃ and 9.6 to 20.4 ℃ for the first and second maturations, respectively (Fig. 2). Liberation of eggs was also observed for both maturations. This maturation pattern was preliminary observed in 2003 (Yatsuya, personal observation), indicating that this is not an unusual event.

The existence of two maturation periods in temperate *Sargassum* was also reported for an *S. thunbergii* population on the Pacific Coast of Chiba Prefecture (Arai *et al*., 1985). About 30% individuals of the population matured both in spring and autumn. Arai *et al*. (1985) speculated that *S. thunbergii* prepared many main branches for growth and maturation, and they could mature at a relatively small size. Ten or more main branches of *S. thunbergii* were always observed, and thalli less than 20 cm were able to mature (Arai *et al*., 1985). In Maizuru Bay, *S. autumnale* had 11.2 main branches on average, and the minimum length of matured main branches was between 10 and 14 cm (Table 1). Main branches of *S. autumnale* in Maizuru Bay could form receptacles within three months (July to October), a shorter period than for other *Sargassum* species growing in and around Maizuru Bay (Umezaki, 1974, 1983, 1984a,b). These characteristics of *S. autumnale* in

Maizuru Bay could lead them to mature twice a year.

Juvenile thalli of *S. autumnale* at Nagahama appeared most frequently in November (Yatsuya, in press), indicating that the first maturation with egg release during late-September to early-October is more important for the next generation than the second maturation. However, if environmental conditions were unsuitable for the first maturation, the second one would compensate for this.

It has been reported that the maturation of seaweed might be related to nutrient conditions. Sorus formation of the kelp *Laminaria japonica* Areschoug was induced in nutrient-rich medium (Mizuta *et al*., 1998, 1999). The number of spores produced by giant kelp *Macrocystis pyrifera* (L.) C. Agardh increased during nutrient-rich periods (Reed *et al*., 1996). Relations between the nutrient concentration of seawater and maturation patterns of *S. autumnale* should be studied in other areas, especially in nutrient poor open coasts.

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