Bull. Fac. Fish. Hokkaido Univ.
34(1), 1–10, 1983.

Sublittoral distribution and reproductive periodicity of crustose coralline algae (Rhodophyta, Cryptonemiales) in southern Hokkaido, Japan[1]

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Abstract

This study was aimed at understanding some aspects of the ecology of crustose coralline algae at Kaitorima, Hiyama Province, Hokkaido in northern Japan. In this area economically useful species of *Laminaria* and *Undaria* have largely disappeared and have been replaced primarily by coralline algae. Twelve taxa of saxicolous crustose coralline algae have been enumerated. One of them, *Lithophyllum yessoense* is the dominant species at depths from 0 to 20 m below low water mark reaching a maximum in the relative area coverage of 73% at 10 m. *Lithophyllum yessoense* and *Neogoniolithon* sp. produce most of their conceptacles in the late summer and fall.

Introduction

It has long been known in Japan that useful seaweeds such as *Gelidium* spp., *Laminaria* spp. and *Undaria pinnatifida* (Harv.) Sur. sometimes decrease markedly in quantity for unknown reasons, resulting in lowered production of sea urchins, abalones and other economically valuable molluscs which feed on the seaweeds. In regions where these fleshy algae have disappeared, crustose coralline algae may be unusually conspicuous on most rocky surfaces. This phenomenon occurs primarily on open coasts which are washed by warm currents and has been known as "Isoyake" which means barren of fleshy seaweeds. For a long time special attention has been given to the coralline algae in connection with this problem. Yendo[1)2)3)] surveyed conditions contributing to a decrease in useful seaweeds on the eastern shore of Izu Peninsula, Shizuoka Prefecture, in Chiba Prefecture and in Tokyo Bay. Okamura & Tago[4)] carried out a similar survey at Shimokita Peninsula, Aomori Prefecture in northern part of Honshu. Noting a decrease of useful seaweeds in the Tsugaru Straits area between Honshu and Hokkaido, Ohmi[5)] suggested methods for restoring *Laminaria* beds. For the purpose of

[1] This paper represents a portion of a Thesis that was submitted by T. Noro as partial fulfilment of Master's degree at the Faculty of Fisheries, Hokkaido University.

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controlling the vigorous growth of coralline algae, from 1952 to 1955, Japanese algologists in several local groups carried out comprehensive studies on the growth of useful marine animals and plants in the shallow water in relation to the growth of coralline algae (Yamada[6]). Recently, Kikuchi and his colleagues in the Tohoku Regional Fisheries Research Laboratory fostered the recovery of destroyed *Laminaria* beds by removing sea urchins by hand (Kikuchi *et al.*[7]: Kito *et al.*[8]).

Our purpose in the study presented below was to obtain some basic ecological data, especially distribution and reproductive seasonality, on crustose coralline algae in an "Isoyake" area.

Materials and Methods

The study was carried out at Kaitorima, Taisei-cho, Hokkaido, on the Sea of Japan, from 1974 to 1976 (Fig. 1). The coast here consists mostly of a rocky shore and is influenced by the warm Tsushima current.

Various types of substrates, including bed-rock fragments and pebbles, which were covered by crustose coralline algae, were collected by SCUBA diving in depth zones of 0–3, 5, 10, 15 and 20 m below mean low water mark at least once a month.

Specimens to be fixed by Susa's fluid were chosen from saxicolous plants, which were kept alive in seawater after collection, by breaking partially the collected substrate using hammer and chisel. The remaining 290 substrates were dried to measure the area occupied by each species with centimeter grids and the percentage of the total area occupied by crustose coralline algae in a same depth zone was

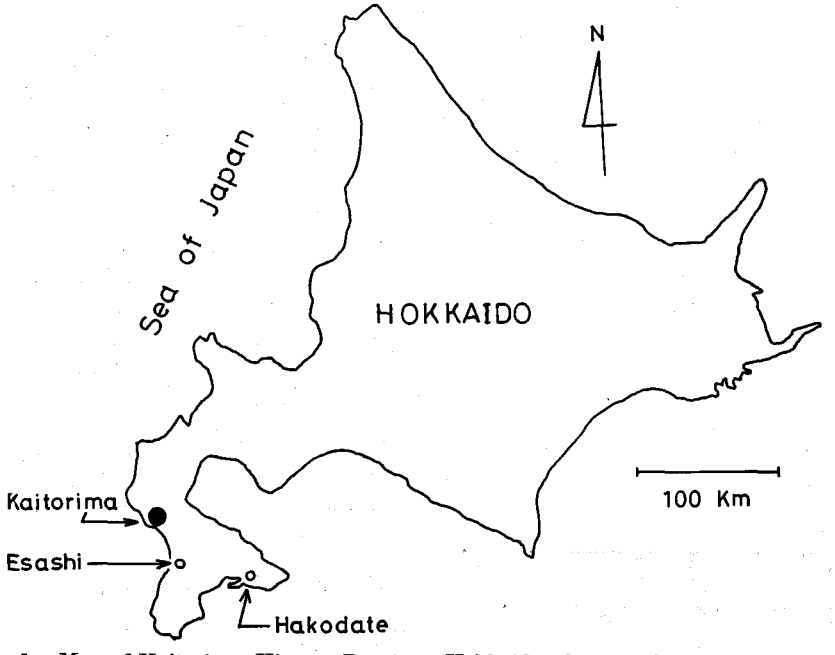

Fig. 1. Map of Kaitorima, Hiyama Province, Hokkaido, showing the site of collection.

caliculated. Sections were cut 7–8 μm thick by the paraffine method and stained with phosphotungstic acid haematoxylin.

The experimental procedures employed in field and laboratory are mostly the same as described by Adey[9] and Adey *et al.*[10].

Reproductive index is determined by using the following equation.

$$\text{Reproductive index (\%)} = \frac{\text{Number of microscope slides with mature conceptacles}}{\text{Total number of microscope slides examined}} \times 100$$

Results and Discussion

Four species of crustose coralline algae are prominent at Kaitorima and eight other taxa are also present (Table 1). *Lithophyllum yessoense* Fosl. is most abundant at depths from 5 to 20 m below low water mark, and reaches a maximum relative area coverage of 73% at 10 m. The maximum area covered for *Lithophyllum okamurai* Fosl., *Neogoniolithon* sp. and *Lithothamnium japonicum* Fosl. was at 0–3 m, 3–5 m and 15 m, respectively (Fig. 2.).

According to fishermen, *Laminaria* and *Undaria* grew luxuriously at Kaitorima about ten years ago, but have gradually diminished in quantity. Hence, this is an "Isoyake region" (Fig. 3). "Isoyake" may be caused by: (1) extraordinary decreases in salinity resulting from floods originating from the overcutting of mountain forests (Yendo[1]; Okamura & Tago[4]): (2) changes of water quality as a result of the shift of current direction (Okamura & Tago[4]; Kawajiri *et al.*[11]): (3) change of substrate caused by the intrusion of volcanic ashes (Ohmi[5]); and (4) intensive grazing by herbivorous invertebrates, particularly sea urchins (Leighton *et al.*[12]; Breen & Mann[13]; Kito *et al.*[8]). At Kaitorima sea urchins in *Strongylocentrotus nudus* (A. Agassiz) are so crowded that their grazing traces are easily found on the thalli of the crustose coralline algae (Fig. 4). Possibly any juvenile fronds of *Laminaria* and *Undaria* that become established are eaten by the animals.

Lithophyllum yessoense distributes widely in many other area of Hokkaido even where the "Isoyake" condition is not present (Adey *et al.*[10]). However, the reasons why *L. yessoense* has developed so vigorously in this area are uncertain.

Table 1. *List of crustose coralline algae and their percentage relative area coverage at depths from 0 to 20 m below low water mark at Kaitorima, Hiyama Province, Hokkaido.*

Species	Relative area coverage (%)
Lithophyllum yessoense	69
Lithothamnium japonicum	8
Neogoniolithon sp.	6
Lithophyllum okamurai	5
Lithothamnium sp.	3
Hydrolithon sp.	3
Tenarea sp.	+
Ezo epiyessoense	+
Other 4 taxa	6

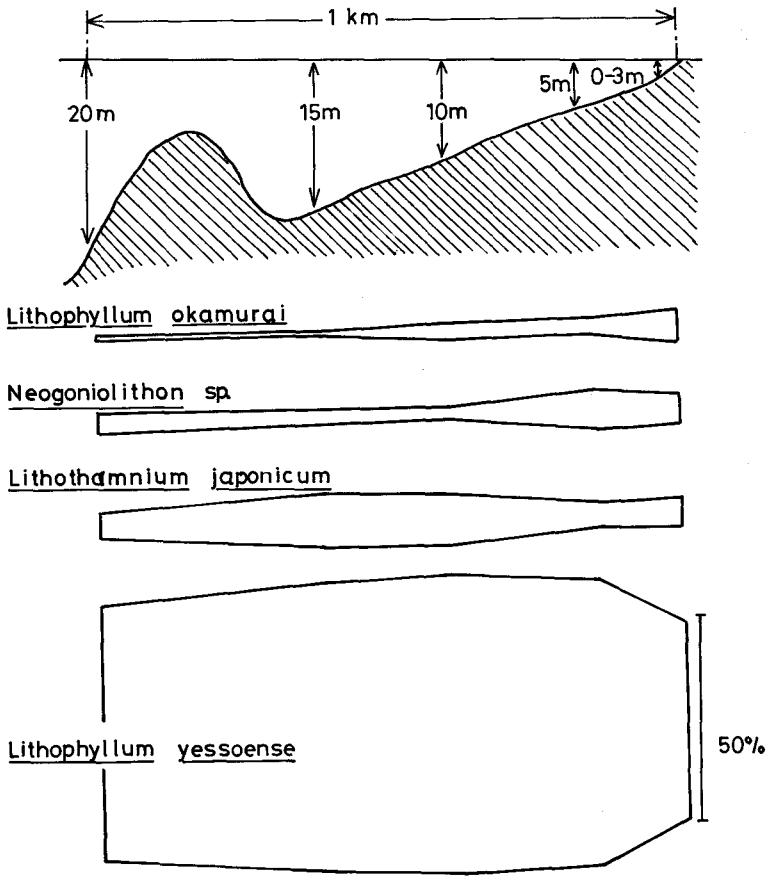

Fig. 2. Percentage relative area coverage of crustose corlline algae extending across the Kaitorima and about 1 km off the shore. Uppermost illustration is a bottom profile.

Probably this species has the ability to grow where conditions are unfavorable for non-calcareous seaweeds.

Most crustose coralline algae studied at Kaitorima show distinct reproductive cycles with conceptacles developing during summer and fall. In *L. yessoense*, on the other hand, mature asexual conceptacles are formed throughout the year with a peak in winter. Sexual conceptacles of all kinds are not common, and were observed from spring to fall. As the period of sexual reproduction is shorter than that of asexual reproduction, the wide distribution of this species seems to be attributable to the prolonged liberation of tetraspores (Fig. 5). Asexual conceptacles of *Neogoniolithon* sp. are found in summer to fall and female and cystocarpic conceptacles occur from June to September (Fig. 6). Most other crustose coralline algae in this region seem to have a reproductive pattern similar to that of *Neogoniolithon* sp. Chihara[14)15)] examined 42 species of coralline algae which

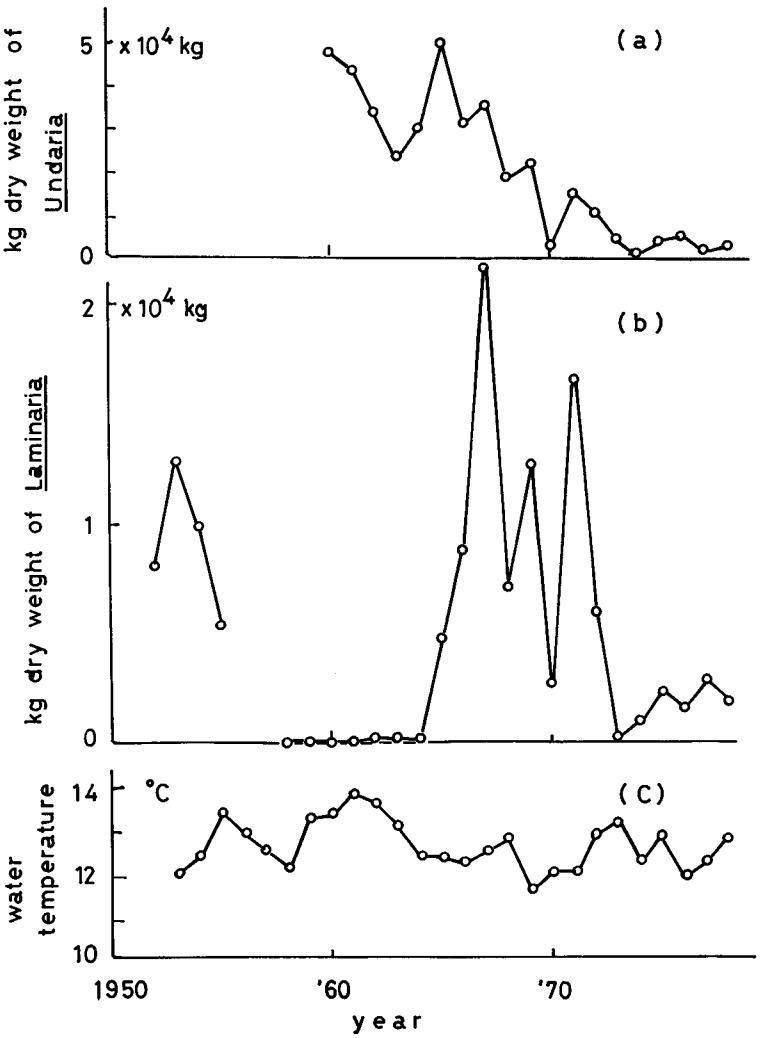

Fig. 3. Annual yield of *Undaria pinnatifida* (a) and *Laminaria japonica* (b) at Kaitorima, Hiyama Province, Hokkaido, and yearly mean sea surface temperature (c) in Esashi near Kaitorima. These data were provided by the Kaitorima Fishermen's Cooperative and the Hakodate Marine Meteorological Observatory.

grow mostly around Shimoda near Tokyo and proposed two groups, the *Amphiroa-Lithophyllum* group and *Corallina-Lithothamnium* group, on the basis of yearly reproductive cycles, spore dimensions and spore germination characteristics. He stated also that vigorous spore liberation occurred only in summer in the former group but that maturity existed exclusive of summer or throughout the year in the latter one. Contrary to expectations, *L. yessoense* belongs to the *Corallina-Lithothamnium* group rather than the *Amphiroa-Lithophyllum* group. This implies

Fig. 4. Desert sea bottom at a depth of 5 m at Kaitorima, Hiyama Province, Hokkaido, showing sea urchin *Strongylocentrotus nudus* on rocks covered mostly with *Lithophyllum yessoense*.

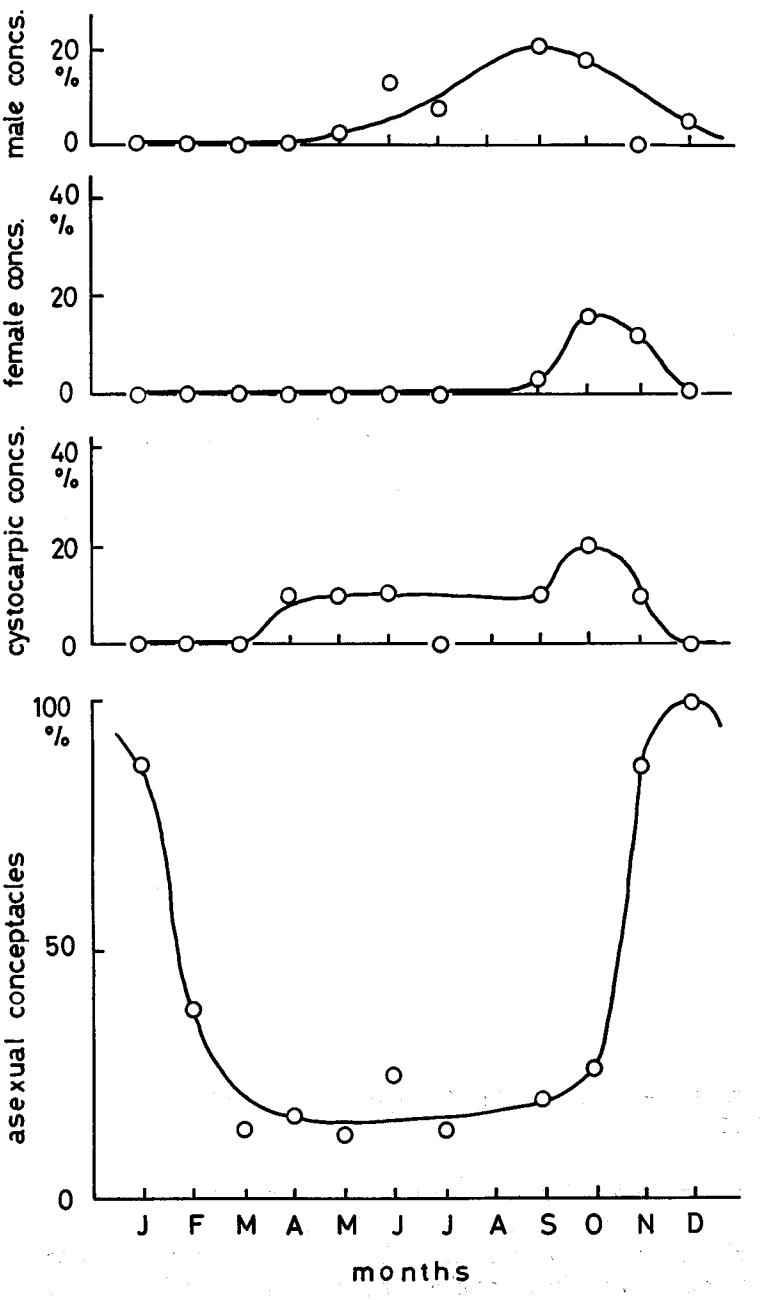

Fig. 5. Yearly reproductive cycles of *Lithophyllum yessoense* at Kaitorima, Hiyama Province, Hokkaido.

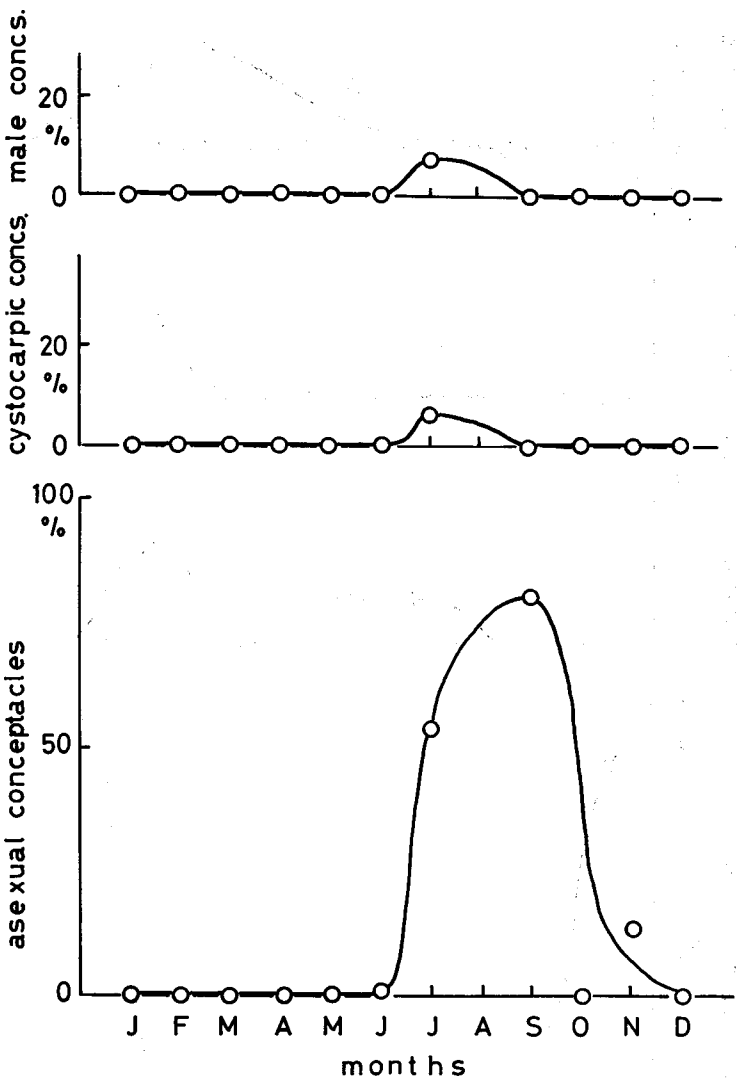

Fig. 6. Yearly reproductive cycles of *Neogoniolithon* sp. at Kaitorima, Hiyama Province, Hokkaido.

that the yearly reproductive cycles are not characteristic of a species or genus but depend on habitat or other environmental factors.

Lithophyllum yessoense, the most abundant crustose coralline species in this "Isoyake" area, has a higher productivity than *Neogoniolithon* sp., *L. japonicum* and *L. okamurai*, even at high temperatures and light intensity (Noro[16]). It is speculated that *L. yessoense* invaded the substratum made available after the fleshy algae disappeared when oceanographic conditions changed, for example, when the sea temperature rosed (Fig. 3). Recently, Masaki *et al.*[17] and Fujita

and Masaki[18] reported that outer epithallium cells of *L. yessoense* sloughed off, resulting in discarding germlings of *Laminaria japonica* grown on its thallus surface in culture. In addition, the sea urchins and other herbivores eat the young fleshy seaweeds as they become established on the crustose coralline algae and their grazing activity as well as the antifouling mechanism in the coralline algae, at least in *L. yessoense*, are thought to accelerate the barren aspects of the area.

Acknowledgements

The authors would like to express their appreciation to Dr. H. William Johansen of Clark University and Dr. Walter H. Adey of Smithsonian Institution for critically reading the manuscript. They also wish to thank to members of South Hiyama Fisheries Instructor Office and Kaitorima Fishermen's Cooperative for providing them facilities to collect the specimens.

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