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Taxonomic studies on *Porphyra variegata* (KJELLMAN) HUS and *P. tenuitasa* FUKUHARA (Bangiales, Rhodophyta)[1)]

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One local population of *Porphyra variegata* (Kjellman) HUS and two populations of *P. tenuitasa* FUKUHARA in Hokkaido were investigated phenologically and morphologically. The following differences were found among the populations: the growing period, thallus length and thallus thickness. The Muroran *P. variegata*, which grew in the uppermost subtidal zone exposed to the waves, appeared in early April, persisted until early July, and had thalli 14-21 cm long and 70-130 μm thick. The Muroran *P. tenuitasa* which grew near the low water line sheltered from the waves, appeared in mid-March, lasted until late June and had thalli 6-17 cm long and 40-100 μm thick. The Otaru *P. tenuitasa* which grew in the uppermost subtidal zone weakly exposed to the waves, appeared before April, was present until early June, and had thalli 6-23 cm long and 30-80 μm thick. However, the plants of the three populations were similar in shape, structure of the rhizoidiferous basal part and division formulae of the reproductive structures. The phenological and morphological differences of the three populations are probably caused chiefly by water temperature. It is concluded that *P. tenuitasa* is conspecific with *P. variegata*.

Key Index Words: *Bangiales*; Diploderma; *morphology*; *phenology*; Porphyra; Porphyra tenuitasa; Porphyra uedae; Porphyra variegata; *Rhodophyta*; *taxonomy*.

NAKAMURA (1947) suggested the existence of two ecological forms of *Porphyra variegata* (KJELLMAN) HUS in Muroran, Hokkaido, one of which had a thin thallus and the other had a thick thallus. FUKUHARA (1968) distinguished the two forms at species level and described two new species; the thin form as *P. tenuitasa* FUKUHARA and the thick form as *P. uedae* FUKUHARA. He described another diagnostic character as follows: "the holdfast [=rhizoidiferous basal part, in the present paper] of *P. tenuitasa* and *P. variegata* is monostromatic below and becomes distromatic upward, gradually in the former but abruptly in the latter". Later, *P. uedae* was reduced to synonymy with *P. variegata* by KUROGI (1977).

However, plants which were equally similar to both *P. tenuitasa* and *P. variegata* were frequently collected in Hokkaido. This suggests that comparative studies on the two species are needed to clarify their taxonomic relationship.

In the present study, three populations of the species inhabiting different environments, one population of *Porphyra variegata* and two populations of *P. tenuitasa*, were investigated to analyze the range of variation of their morphological characters.

Materials and Methods

Phenological observations and collections

[1)] Dedicated to Professor Munenao KUROGI on the occasion of his academic retirement.

were made fortnightly at Denshin-hama, Muroran in 1978-1979 and at Syukutsu, Otaru in 1980-1981. In the present paper, the data are combined and shown in 1979 at Muroran and in 1981 at Otaru.

At Denshin-hama in Muroran where *P. variegata* and *P. tenuitasa* were present; the former growing in the uppermost subtidal zone as an epiphyte, mainly on *Phyllospadix iwatensis* MAKINO, and exposed to the force of waves; the latter growing near the low water line and epiphytic mainly on *Palmaria palmata* (L.) O. KUNTZE sheltered from the waves. The two study sites were provisionally named as "Muroran Exposed" and "Muroran Sheltered". The distance between the two study sites was about 20 m, but there was a breakwater made of concrete tetrapods between the two sites and thus the effect of waves was greatly lessened in the latter site.

At Syukutsu in Otaru, *P. tenuitasa* grew in the uppermost subtidal zone and was epiphytic mainly on *Neorhodomela aculeata* (PERESTENKO) MASUDA or on *Laurensia nipponica* YAMADA, in an area of low wave exposure. This study site was called "Otaru".

Morphological observations were made with fresh material which was carried to the laboratory in an ice chest.

Water temperatures in Muroran and in Otaru are shown in Fig. 1. Yearly range of monthly mean water temperature in Otaru was from 3.2°C to 21.0°C and in Muroran it was from 2.8°C to 18.1°C. The water temperature at "Muroran Sheltered" was 2.7-4.0°C higher than that of "Muroran Exposed" in late spring and summer in low water at the times of collections. Specimens on which observations were made have been pressed and are deposited in the herbarium of the Department of Botany, Faculty of Science, Hokkaido University (SAP 043000-043078).

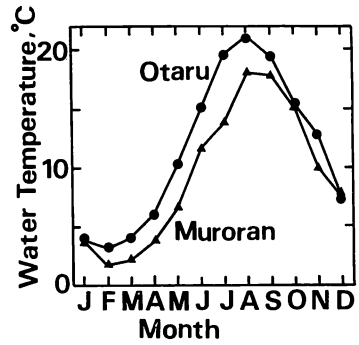

Fig. 1. Monthly mean seawater temperature measured at Charatsunai-hama, Muroran and at Oshoro Bay, Otaru, in 1976-1980.

Results

Phenology

Plants of *P. variegata* and *P. tenuitasa* are monoecious (FUKUHARA 1968, KUROGI 1977).

The following six stages were established to describe the maturation of plant (Fig. 2).

(0) The thallus has no reproductive structures. (1) Half of the thallus becomes slightly faded due to the initiation of antheridia. (2) The antheridial part of the thallus becomes colorless and clearly distinguised from the other half. (3) Spermatia are released from the antheridial part. (4) The antheridial part is eroded leaving the cystocarpic part and the thallus becomes falcate. (5) Carpospores are released from the cystocarpic part.

All the plants examined went through these stages of maturation in this order and did not skip over any stage. No plants released spermatia and carpospores at the same time.

Figs. 3A, 3B show the seasonal changes in the mean length of 20 of the largest plants collected in each population and the seasonal variation in the maturation stages of all the plants to give an outline of growth and maturation.

"Muroran Exposed": Young sterile plants up to 1.2 cm in length appeared on *Phyllospadix iwatensis* in March. Growth was rapid during late April to late May and plants reached a maximum of 16.2 cm in mean length (range 14-21 cm, SD 2.3) in June. Some plants were in the maturation stages 1-2 in late April and released spermatia in mid-May. Plants in various maturation stages (stages 1-5) were found in late May and some plants began to release carpospores. During June the mean length of the plants

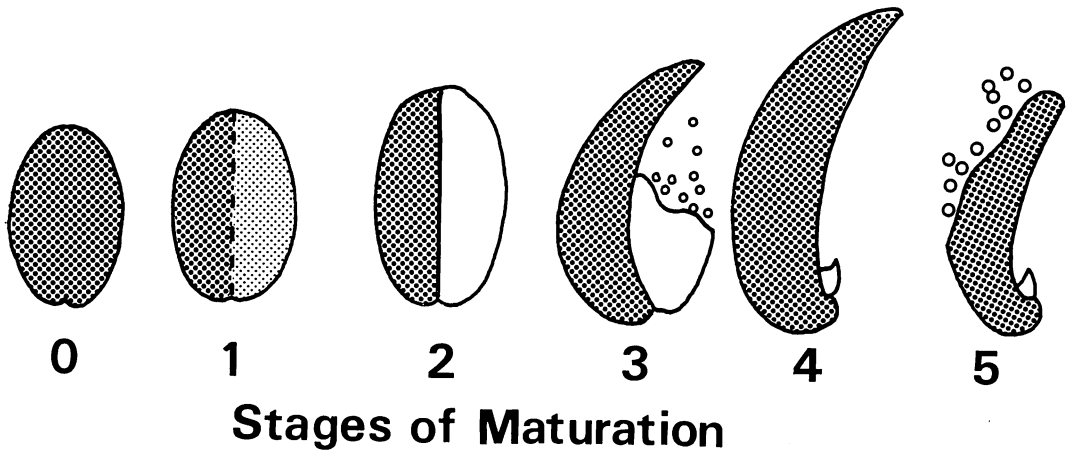

Fig. 2. Diagramatic representation of different stages of maturation in *Porphyra variegata* and *P. tenuitasa*. The left half of thallus is the cystocarpic part and the right half is the antheridial part. (0) The thallus has no reproductive structures. (1) Half of the thallus becomes slightly faded due to the initiation of antheridia. (2) The antheridial part of the thallus becomes colorless and clearly distinguished from the other half. (3) Spermatia are released from the antheridial part. (4) The antheridial part is eroded leaving the cystocarpic part and the thallus becomes falcate. (5) Carpospores are released from the cystocarpic part.

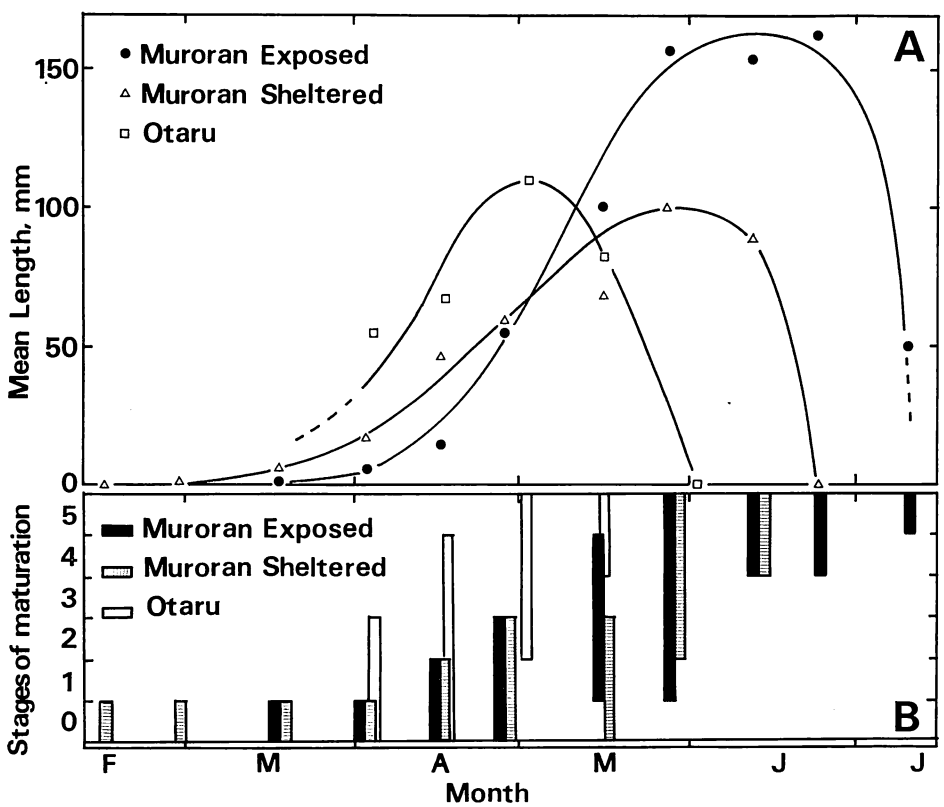

Fig. 3. Seasonal changes in mean length (A) and seasonal variation in the stage of maturation (B) of plants for the three populations, "Muroran Exposed", "Muroran Sheltered" and "Otaru" (cf. Fig. 2).

in stages 4-5 changed little. In early July all the plants released carpospores and soon decayed.

"Muroran Sheltered": Microscopic germlings (maximum length is 30 μm) appeared on *Palmaria palmata* in mid-February. Plants grew rapidly and reached a maximum of 10.0 cm in mean length (range 6-17 cm, SD 2.8) in late May. Maturation progressed at nearly the same rate as that of "Muroran Exposed" until late April when the maturation stages were 0-2. Spermatia and carpospores were released from the end of May. The plants disappeared in late June one month earlier than those of "Muroran Exposed" population.

"Otaru": It was not possible to detect when the plants appeared. In early April the plants already reached 5.5 cm in mean length (range 1-10 cm, SD 2.6) and a few of them started to form antheridia. They grew rapidly and reached a maximum of 11.3 cm in mean length (range 6-23 cm, SD 3.8) in early May. The length was nearly the same as that of "Muroran Sheltered" plants but smaller than "Muroran Exposed" ones. Spermatia were released from the end of April. All the plants disappeared at the beginning of June one month earlier than "Muroran Sheltered".

Morphology

Thallus shape: Generally, *P. variegata* and *P. tenuitasa* have ovate to elliptical thalli. To compare the thallus shapes of the three populations, the length and width of immature plants (maturation stages 0, 1, 2) were measured. The measured plants of "Muroran Exposed" and "Muroan Sheltered" were collected on April 28, 1979 and the plants of "Otaru" on April 17, 1981. The distributions of length and width of each population are shown in Fig. 4 with logarithmic graduation. The mean ratio of length/width is 1.98 in "Muroran Exposed", 1.82 in "Muroran Sheltered" and 1.92 in "Otaru". The thallus of the three populations were similar in shape to each other.

Thallus color: The thallus color was compared in living and in dry conditions. Generally, thalli in "Muroran Exposed" were dark purplish red and those in "Otaru" were pink. Thalli in "Muroran Sheltered" population were intermediate in color. However, the color is different according to individual plants of each population.

Thallus thickness: The thickness was measured in imperfectly or perfectly matured plants in the maturation stages 2-5 (Fig. 2) of "Muroran Exposed" population collected on June 24, 1979, of "Muroran Sheltered" on May 28, 1979 and of "Otaru" on May 2, 1981, when each population reached a maximum in mean length. Measurements were made in the center of the thalli.

The distribution of thickness of measured

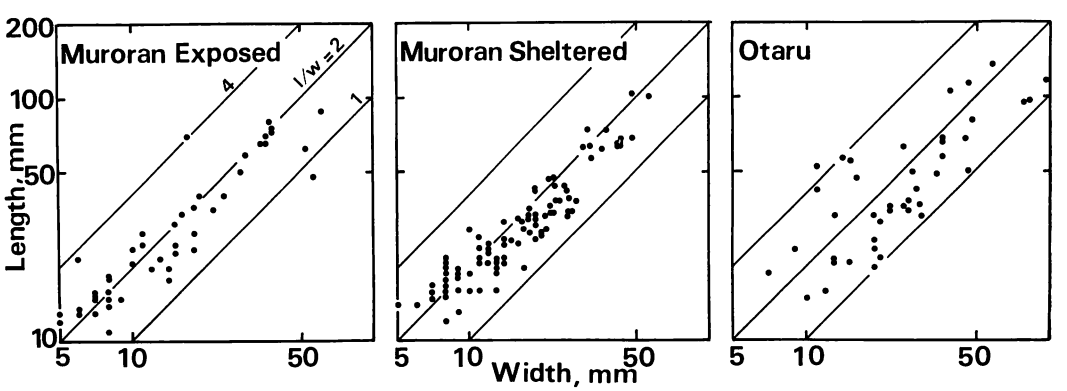

Fig. 4. Relationship between length and width of plants for the three populations. Samples were collected on 28 April 1979 from "Muroran Exposed" population and "Muroran Sheltered" population, and on 17 April 1981 from "Otaru" population.

plants is shown in Fig. 5. Among the three populations, "Muroran Exposed" plants were thicker (ca. 70-130 μm) than the other two and "Otaru" plants thinner (ca. 30-80 μm) than the other two. "Muroran Sheltered" plants were intermediate in thickness (ca. 40-100 μm). Overlaps in the thickness between "Muroran Exposed" and "Muroran Sheltered" and between "Muroran Sheltered" and "Otaru" are apparent.

Structure of rhizoidiferous basal part: FUKUHARA (1968) described the rhizoidiferous basal part of *P. variegata* and *P. tenuitasa* as being monostromatic below and distromatic upward, and that in the former species the basal part became abruptly distromatic upward, but in the latter species gradually distromatic upward. The rhizoidiferous basal part of the three populations was examined. Such a distinct difference between *P. variegata* ("Muroran Exposed") and *P. tenuitasa* ("Muroran Sheltered" and "Otaru") was not found (Fig. 6). However, the distance between two cell layeres with thicker basal part was greater than that with the thinner basal part.

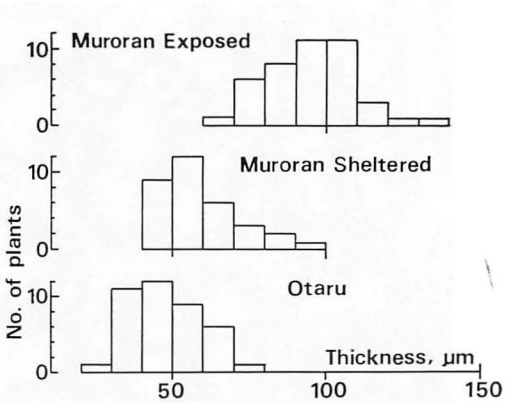

Fig. 5. Frequency distribution of thallus thickness for the three populations, "Muroran Exposed", "Muroran Sheltered" and "Otaru", class interval 10 μm.

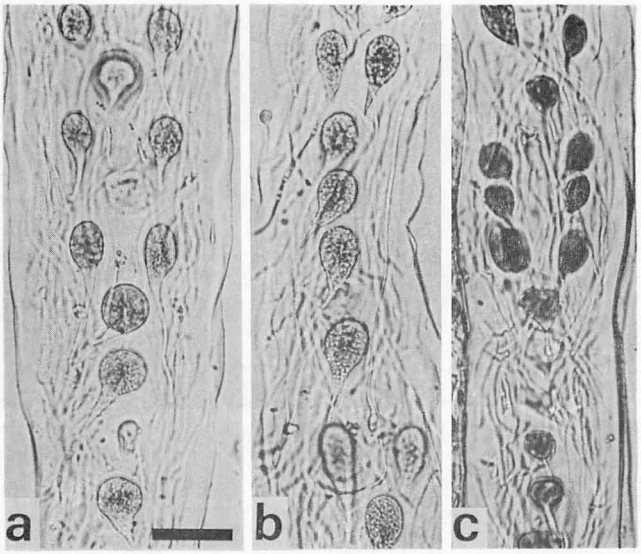

Fig. 6. Longitudinal sections of rhizoidiferous basal parts for the three populations. a, "Muroran Exposed" population; b, "Muroran Sheltered" population; c, "Otaru" population. Scale in a is 50 μm and also applies to b-c.

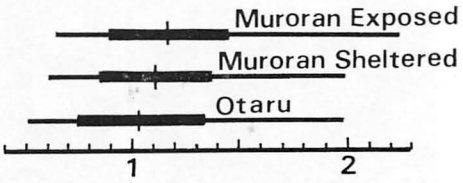

Fig. 7. Variation of height/width ratio of vegetative cells in cross section of plants for the three populations. Horizontal line indicates total variation; thick line, SD; cross bar, mean.

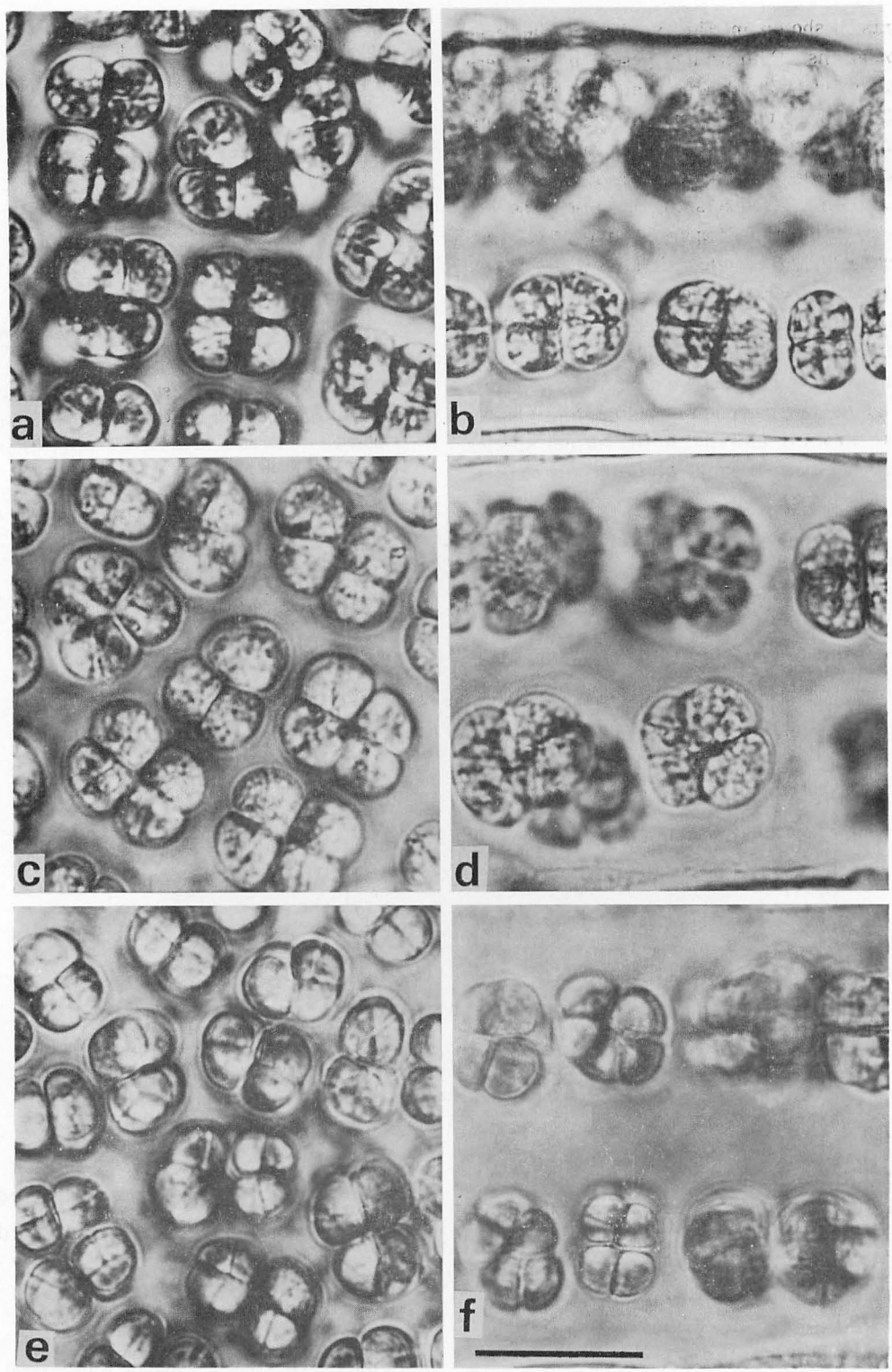

Fig. 8. Antheridia of plants for the three populations. a–b, "Muroran Exposed" population; c–d, "Muroran Sheltered" population; e–f, "Otaru" population; a, c, e, surface view; b, d, f, cross section. Scale in f is 25 μm and also applies to a–e.

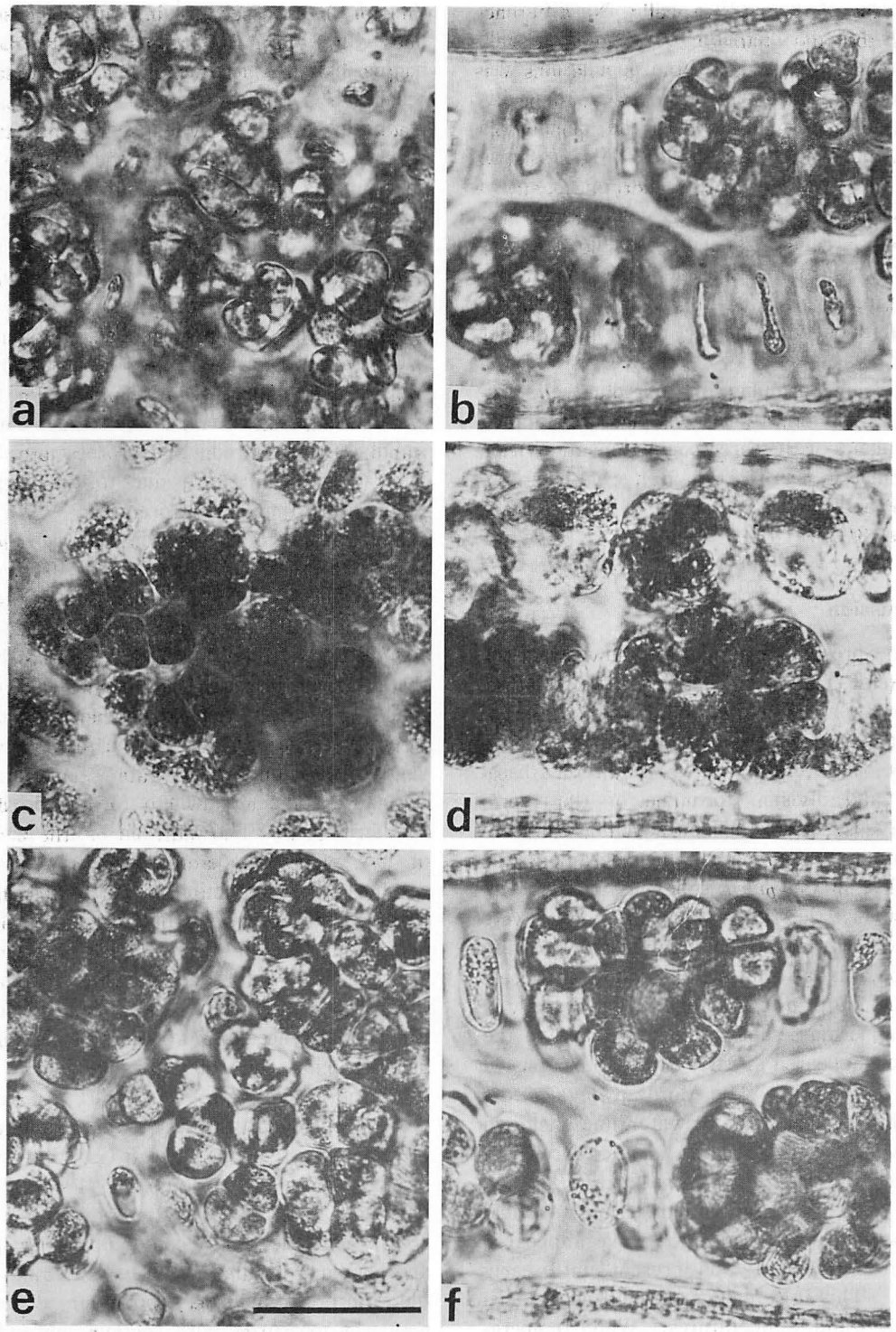

Fig. 9. Cystocarps of plants for the three populations. a-b, "Muroran Exposed" population; c-d, "Muroran Sheltered" population; d-f, "Otaru" population; a, c, e, surface view; b, d, f, cross section. a-b from the glutaraldehyde fixed specimens, others from the living plants. Scale in e is 50 μm and also applies to a-d and f.

Shape of vegetative cell: No difference in shape and diameter of vegetative cells among plants of the three populations was found in surface view. However, some difference in height between the populations was found in cross section. Fig. 7 shows the mean ratio of height/width of vegetative cells in cross section (100 cells were measured; 5 cells ×20 plants). The ratio was 1.18 in "Muroran Exposed", 1.11 in "Muroran Sheltered" and 1.04 in "Otaru". Thus, the populations with thicker thalli have higher cells.

Division formulae of reproductive structures: No difference was observed among the plants of the three populations in division formula, it was 64 (a/4, b/4, c/4) in antheridia and 16 (a/2, b/2, c/4) in cystocarps (Figs. 8-9).

Discussion

The present investigation showed that the plants of three local populations of *Porphyra variegata* and *P. tenuitasa* inhabiting different environments were similar in the thallus shape, structure of the rhizoidiferous basal part and division formulae of the reproductive structures, all of which are of considerable taxonomic significance among the species of *Porphyra* subgenus *Diploderma*. However, the following differences were found among the populations: the growing period, thallus length and thallus thickness.

The Muroran *P. variegata*, which grew in the uppermost subtidal zone exposed to the waves, appeared in early April and persisted until early July. The Muroran *P. tenuitasa* inhabiting near the low water line sheltered from the waves appeared in mid-March and lasted until late June. The Otaru *P. tenuitasa*, which grew in the uppermost subtidal zone weakly exposed to the waves, appeared before April and was present until early June. This difference may depend on different water temperatures. Water temperature in Otaru is higher than that in Muroran (Fig. 1). Additionally, water temperature of the sheltered site rises rather higher than that of the exposed one in spring and summer. In Otaru the release of spermatia begins in mid-April when the temperature reaches 6°C and the release of carpospores begins in early May when the temparature reaches 8°C. In Muroran the release of spermatia is delayed until mid-May when the temperature reaches 6°C and the release of carpospores occurrs in late May when the temperature is 8°C (Figs. 1, 3B). Thus, a minimum temperature of 6°C is required for the release of spermatia and a minimum of 8°C is required for the release of carpospores. Mature plants increase in abundance as the water temperature rises and they decay rapidly. This reproductive process proceeds more quickly in Otaru due to the higher temperature than in Muroran.

Fertile thalli of the Muroran *P. variegata* were 16.2 cm in mean length and 70-130 μm thick. The Muroran *P. tenuitasa* possessed thalli being 10.0 cm in mean length and 40-100 μm thick. The Otaru *P. tenuitasa* had thalli 11.3 cm in mean length and 30-80 μm thick. These differences also depend on different water temperature. The plants grow vegetatively until the water temperature rises to a sufficient level to form reproductive structures. The duration of the period of low water temperature in early spring results in the production of large and thick thalli. Thus, the Otaru plants have smaller and thinner thalli than those of Muroran. Consequently, differences in water temperatures among the three locations could account for the differences in morphological and phenological characters of the populations.

One herbarium specimen of *P. tenuitasa* determined by FUKUHARA was examined. It was collected by him at Usu, the type locality, near Muroran on 6 May 1963. The thallus is 11.6 cm long and 8.4 cm broad. It is 51-70 μm thick in the center of the thallus and similar in appearance to the plants of the "Muroran Sheltered" population. Thickness was measured with sections embedded in 20% glycerin. The measured thickness in this way is about 70-90% of the original thickness of the living specimen. Further-

more, two herbarium specimens of *P. tenuitasa* collected at Oshoro near Otaru on 25 April 1972 and determined by FUKUHARA were examined: (A) 17.6 cm long×8.4 cm broad; (B) 8.6 cm long×7.5 cm broad. They are 40-48 μm (A) and 27-33 μm (B) thick in the center of thalli and similar in appearance to the plants of the "Otaru" population. Thickness was measured as in the Usu specimen. Thus, the plants of "Muroran Sheltered" population and of "Otaru" population can be identified with *P. tenuitasa* described by FUKUHARA (1968).

According to FUKUHARA (1968), *Porphyra variegata* and *P. tenuitasa* are distinguished by the thallus thickness and structure of the rhizoidiferous basal part. *P. variegata* has thick thalli (80-200 μm thick) and rhizoidiferous bases which become distromatic abruptly, whereas *P. tenuitasa* has thin thalli (45-50 μm thick) and rhizoidiferous bases which become distromatic gradually (FUKUHARA 1968). However, the thallus thickness varies with individual plants and with habitat as mentioned above. No difference in the structure of the rhizoidiferous base between the two species has been found in the present study. It is concluded that *P. tenuitasa* circumscribed by FUKUHARA (1968) is included in the variation range of *P. variegata* whose morphological characters vary with habitat.

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清水　哲：紅藻フイリタサとウスバタサの分類学的研究

フイリタサとウスバタサは，葉状体の厚さと付着器の縦断面の細胞配列様式の差異によって区別されている。北海道の室蘭に両種が，小樽にウスバタサが生育する。そこで地域個体群を形態学的，生物季節学的に調査研究した結果，両種を区別する差は従来報告されていたように明瞭ではなく，体厚の頻度分布に差が見られるだけであった。体厚は環境によって変化し易い形質と考えられるので，ウスバタサはフイリタサと同種と考えるのが妥当であるとの結論に達した。(060 札幌市北区北10条西8丁目　北海道大学理学部植物学教室)