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Phytogeographic characterization of articulated coralline algae (Rhodophyta) in Japan

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From published floras, collections in herbaria, and our own field studies, the distributions of 35 species in ten genera of articulated Corallinaceae in Japan were plotted. Japan was divided into 14 coastal segments for purposes of understanding distributions of the genera and a few prominent species, such as *Corallina officinalis*. *Bossiella* is restricted to the north. Only *Corallina pilulifera* occurs in all the coastal segments. Present in mid and northern Honshu, but not in the extreme north and south of Japan, are *Calliarthron*, *Serraticardia*, *Yamadaea* and two species of *Corallina*, C. *sessilis* and *C. squamata*. From Kyûshû and Shikoku to northern Honshu occur *Marginisporum*, *Corallina officinalis* and, especially in the north, *Alatocladia*. *Amphiroa* and *Jania* have some species that reach into southern and western Hokkaido, and others that extend into the Ryûkyû Islands. *Cheilosporum* has been reported only from the Ryûkyû Islands and southern Japan. Research on the distributional and seasonal aspects of reproduction as well as nomenclature and taxonomy should be carried out. It would be interesting to study the patterns of articulated coralline phytogeography throughout the North Pacific Ocean.

Key Index Words: *Articulated Corallinaceae*; *geographic distribution*; *nomenclature*; *Rhodophyta*; *taxonomy*.

Japan, southern Australia, western North America, and eastern South Africa are major geographic areas endowed with a great diversity of articulated coralline algae (Corallinaceae, Rhodophyta). About 40 species have been recorded from Japan and, although our ongoing studies of these algae suggest that this is an inflated number, the flora is rich. OKAMURA (1936), based on the pioneering studies by YENDO (1902a, b 1905), included 38 species, and *Yamadaea melobesioides* SEGAWA (1955) and *Jania capillacea* HARVEY (TANAKA 1965) were later added to the Japanese flora. Of the 15 genera of articulated coralline algae currently recognized (JOHANSEN 1981) 10 occur in Japan. *Haliptilon* is notable for its absence, but it may be revealed in subsequent exploration in the southern islands.

The importance of the sea to the livelihood of the Japanese people has fostered many studies of regional marine floras, and these published papers include articulated coralline algae. These publications form one source of data for the present work. Second, numerous collections, both by us and others, are available in herbaria in Japan as well as in other countries. These specimens constitute our second source of data. By combining all the distributional information available to us we have been able to characterize the phytogeography of articulated coralline algae in Japan, and this is presented below.

A second goal of this work was to determine possible relationships that the distribution of articulated coralline algae may have with seawater temperature. Casual observations suggest that some genera are primarily present in colder waters, for example, *Bossiella* and *Corallina*, whereas others are more tropical, for example, *Amphiroa* and *Jania*. The presence of a wide range of temperatures from the south to north of Japan makes it important to do this in order to understand the phytogeography of these plants. The importance of coastal currents and seawater temperatures on the distribution of crustose coralline algae off Hokkaido was shown by ADEY *et al.* (1976). Although taxonomic studies have resolved most problems of systematics and nomenclature at the generic level, there are still many unresolved questions regarding the species reported from Japan. For example, the entity called *Corallina squamata* needs to be examined; the name is based on a European species recently transferred to *Haliptilon* (JOHANSEN *et al.* 1973). Therefore, the main goal of this paper is to characterize distribution of the genera, with data on the species ancillary. Studies currently under way are aimed at correcting the taxonomic and nomenclatural problems that still exist.

The ten genera of articulated Corallinaceae present in Japan are assigned to subfamilies and tribes (see JOHANSEN and SILVA 1978) according to the scheme below (JOHANSEN 1981).

Subfamily Amphiroideae JOHANSEN
  Tribe Amphiroeae
    Genus *Amphiroa* LAMOUROUX
Subfamily Corallinoideae
  Tribe Corallineae
    Genera *Alatocladia* (YENDO) JOHANSEN
      Bossiella SILVA
      Calliarthron MANZA
      Corallina LINNAEUS
      Marginisporum (YENDO) GANESAN
      Serraticardia (YENDO) SILVA
      Yamadaea SEGAWA
  Tribe Janieae JOHANSEN et SILVA
    Genera *Cheilosporum* (DECAISNE) ZANARDINI
      Jania LAMOUROUX

Materials and Methods

Tabulations of the articulated coralline algae were made from more than 100 floras from many parts of Japan most published in the last 30 years. The papers are not listed.

Hundred of collections were determined and recorded. Specimens from the following herbaria were incorporated into determining the ranges: British Museum (Natural History), London (BM); Laboratoire de Botanique, Faculté des Sciences, Caen (CN); Clark University, Worcester, Massachusetts (CUW); Laboratory of Marine Botany, Faculty of Fisheries, Hokkaido University, Hakodate (HAK); Herbarium, Royal Botanic Gardens, Kew (K); Rijksherbarium, Leiden (L); Botanical Institute, Faculty of Science, University of Tokyo (TI); University of British Columbia, Vancouver (UBC); University of California, Berkeley (UC); U. S. National Museum, Smithsonian Institution, Washington, D. C. (US).

Our collections, mostly from Hokkaido, but also from places like Shikoku, Ryûkû and Izu Islands have helped fill out gaps in the ranges of several genera. These specimens are in CUW and HAK.

Temperature data are from a Marine Environmental Atlas compiled by Japan Oceanographic Data Center in 1978.

Results

This survey of the articulated coralline algae in Japan and the associated smaller islands will proceed in a counterclockwise direction and should be done with reference to Figure 1 and Table 1. At Soya Misaki, the northernmost point of Japan, there occur only two species of articulated coralline algae, one in *Bossiella* and the other in *Corallina*. *Corallina pilulifera* is the only species present in all the coastal segments used in this paper. Southward from Soya

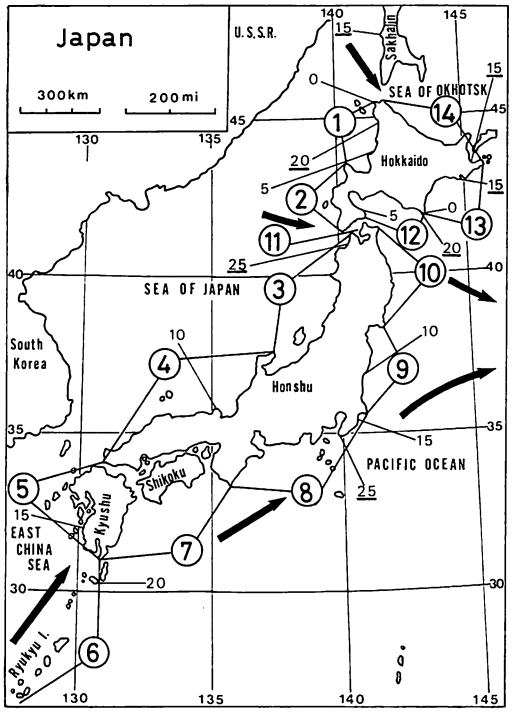

Fig. 1. Map showing coastal segments 1 to 14 (encircled) into which Japan has been divided for purposes of describing the distribution of articulated coralline algae. Segment 11 is Tsugaru Kaikyo between Hokkaido and Honshu. Also shown are maximum summer seawater temperatures (degrees Celsius underlined) and minimum winter seawater temperatures (degrees Celsius not underlined). The arrows indicate directions of surface current flow.

Table 1. List of coastal segments into which Japan was divided for purposes of plotting distribution. They are arranged counterclockwise with northernmost areas numbers 1 and 14. See Figure 1.

1. Northwestern Hokkaido: Soya Misaki to Kamui Misaki
2. Southwestern Hokkaido: Kamui Misaki to Matsumae
3. Northwestern Honshu: Tappi Zaki to Suzu Misaki (plus Sado Island)
4. Southwestern Honshu: Suzu Misaki to Shimonoseki
5. Western Kyûshû: Shimonoseki to Sata Misaki (plus Tsushima Island)
6. Ryûkyû Islands
7. Eastern Kyûshû, Shikoku and Southern Honshu: Sata Misaki to Shiono Misaki
8. Southern Honshu: Shiono Misaki to Choshi
9. Eastern Honshu: Choshi to Kinkazan
10. Northeastern Honshu: Kinkazan to Shiriya Zaki
11. Tsugaru Kaikyo
12. Southern Hokkaido: Esan Misaki to Erimo Misaki
13. Eastern Hokkaido: Erimo Misaki to Nosappu Misaki
14. Northern Hokkaido: Nosappu Misaki to Soya Misaki

Misaki in segment one, there are two species of *Corallina* (Table 3) and one each of *Amphiroa* (Table 2), *Jania* (Table 4) and *Bossiella* (Table 5). In southwestern Hokkaido (segment 2) *Alatocladia* joins these genera, for a total of five. In northwestern Honshu (segment 3) eight genera have been recorded, leaving only *Cheilosporum* and *Yamadaea* not represented in this area (Table 5). In southwestern Honshu below Suzu Misaki (segment 4), there is a loss of three genera, *Bossiella, Calliarthron* and *Serraticardia* (Table 5). The same five genera are also present in segment 5, encompassing western Kyûshû. The Ryûkû Islands (segment 6), extending south to 26 N. latitude, boasts four genera: *Amphiroa, Jania, Corallina* and *Cheilosporum*. *Alatocladia* and *Marginisporum* disappear this far south, and *Cheilosporum* is recorded for the first time (Table 5). The last genus has only been recorded from segments 7 and 8 in Japan.

Returning to the main islands of Japan, six genera are present in the southeast (segment 7). Along with *Cheilosporum, Corallina, Jania* and *Amphiroa* in segment 7 are, again, *Marginisporum* and *Serraticardia*. North of Shiono Misaki in eastern Honshu there is a jump from six genera in segment 7 to nine genera in segment 8 (Table 5). In addition to the genera previously mentioned in segment 7 are *Alatocladia, Calliarthron* and, for the first time, *Yamadaea*. Segment 9 also marks the temporary disappearance of *Jania* in eastern Japan; it is absent in segment 9 and appears again in segments 10 and 11 (Table 4). North of Kinkwazan in segment 10 are eight genera, with the single species of *Jania* responsible for the increase

Table 2. The species of *Amphiroa* reported from Japan and the coastal segments (shown in Fig. 1) from which they have been recorded or from which specimens have been examined.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Amphiroa dilatata LAMOUROUX			3	4	5	6	7	8		10	11			
A. echigoensis YENDO			3	4				8	9	10	11			
A. ephedraea (LAMARCK) DECAISENE			3	4	5	6	7	8		10	11			
A. fragilissima (LINNAEUS) LAMOUROUX						6								
A. misakiensis YENDO[1)]			3	4	5		7	8		10				
A. pusilla YENDO				4		6		8		10				
A. rigida LAMOUROUX			3	4	5		7							
A. valonioides YENDO[1)]			3				7	8						
A. zonata YENDO[2,3)]	1	2	3	4	5		7	8			11			

Notes:
1) *Amphiroa misakiensis* and *A. valonioides* have recently been identified from western North America and hence are removed from the status of species endemic to Japan (NORRIS and JOHANSEN 1981).
2) *Amphiroa yendoi* DE TONI is excluded because of insufficient taxonomic data.
3) Specimens from western North America identified as *A. zonata* have been reinterpreted as *A. beauvoisii* LAMOUROUX (NORRIS and JOHANSEN 1981). It remains to be seen if *A. zonata* in Japan is a valid species.

from seven to eight genera. Here *Bossiella* appears again, and *Yamadaea* is not recorded. Tsugaru Kaikyo (segment 11), including the shores of both Honshu and Hokkaido, contains eight genera. North of Esan Misaki (segment 12) on the Hokkaido coast there is a marked reduction to only three genera, these being *Alatocladia, Bossiella,* and *Corallina.* Thus, in a relatively short distance *Amphiroa Jania, Serraticardia, Calliarthron* and *Marginisporum* disappear from the flora (Fig. 5). On the coast of eastern Hokkaido north Erimo Misaki (segment 13) occur the same genera and along northern Hokkaido between Nosappu Misaki and Soya Misaki (segment 14) *Alatocladia* is lost leaving only *Bossiella cretacea* and *Corallina pilulifera* in the northern region (Table 5). A recent collection of *Alatocladia* between Kushiro and Nemuro at a depth of 5 m is the only record of this genus from segment 13.

Table 3. The species of *Corallina* reported from Japan and the coastal segments (shown in Figure 1) from which they have been recorded or from which specimens have been examined.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Corallina confusa YENDO								8	9	10	11			
C. kaifuensis YENDO			3	4						10	11			
C. officinalis LINNAEUS	1	2	3	4	5		7	8	9	10	11	12		
C. pilulifera POSTELS et RUPRECHT	1	2	3	4	5	6	7	8	9	10	11	12	13	14
C. sessilis YENDO			3					8	9	10	11			
C. squamata Linnaeus[1)]		2	3	4				8	9	10	11			

Notes:
1) Based on European plants *Corallina squamata* was transferred to *Haliptilon* (*H. squamatum* JOHANSEN, IRVINE et WEBSTER) in 1973. However, the Japanese plants considered under this name belong to *Corallina*; they have been called *Corallina* "X" until their true specific status can be determined (MASAKI *et al.* 1981).

Table 4. The species of *Jania* reported from Japan and the coastal segments (shown in Figure 1) from which they have been recorded or from which specimens have been examined.

Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jania adherens LAMOUROUX			3	4	5	6	7	8						
J. arborescens (YENDO) YENDO			3	4	5		7	8						
J. capillacea HARVEY						6	7							
J. decussato-dichotoma (YENDO) YENDO			3	4	5	6	7	8						
J. nipponica (YENDO) YENDO	1	2	3	4						10	11			
J. pumila LAMOUROUX						6								
J. radiata (YENDO) YENDO			3	4	5		7	8						
J. rubens (LINNAEUS) LAMOUROUX				4		6								
J. ungulata (YENDO) YENDO			3	4	5		7	8						
J. yenoshimensis (YENDO) YENDO								8			11			

Discussion

From the foregoing results it is possible to group the genera, and in some cases species, based on their distributions in Japan.

(1) *Restricted to the north.* The only genus in this category is *Bossiella* which occurs only in northern Honshu and in Hokkaido (Fig. 2). The single species in Japan, *B. cretacea,* is widespread in the north Pacific, having been recorded from the Kurile Islands (NAGAI 1941), Sakhalin (TOKIDA 1954), St. Lawrence Island (KJELLMAN 1889), Alaska (LINDSTROM 1977) and British Columbia and northern Washington (HAWKES *et al.* 1978). It is tempting to speculate that maximum summer temperatures above 25°C limit the spread of *B. cretacea* southward (see Figure 1). However, information on its reproductive behavior is needed before definitive statements on the relationships between seawater temperatures and distribution may be made. It may be that low temperatures, for example 10°C or below, are required for reproduction to succeed. Possibly *B. cretacea* responds to ambient seawater temperatures in a manner analogous to that of the crustose coralline *Clathromorphum circumscriptum* (STRÖMFELT) FOSLIE in the North Atlantic, which was found by ADEY (1973) to require temperatures below 2 to 3°C for part of the year. Photoperiod and light intensity may also play a role in conceptacle production.

(2) *Throughout Japan.* Only *Corallina pilulifera* is present in all coastal segments covered in the present work. It is unrealistic, however, to suggest that all the published reports refer to only one species, as circumscriptions of the small compact species of *Corallina* are unclear. It is unusual for populations in a species of red algae to live under conditions where temperature may range from as low as 0°C to more than 25°C (Fig. 1). Difficulties in identifying *C. pilulifera* are also suggested by reports of this species from such distant regions as Argentina (PUJALS 1963) and Ivory Coast in the eastern Atlantic Ocean (JOHN 1976).

(3) *Mid and northern Honshu.* Two genera, *Calliarthron* and *Serraticardia,* are common algae in Japan, but they are mostly restricted to north of Sado Island in the Sea of Japan and Kurushima Kaikyo in the Inland Sea (Fig. 2). Although present in Tsugaru Kaikyo, *Serraticardia* has not been reported from Hokkaido and *Calliarthron* only from the Hakodate area. *Serraticardia* is represented by a single species in Japan (Table 5), but there is one other species, *S. macmillanii* (YENDO) SILVA, in western North America from Alaska to Southern California (JOHANSEN 1976). The two species of *Calliarthron* in Japan are lumped together here; *C. yessoense* is often reported and *C.*

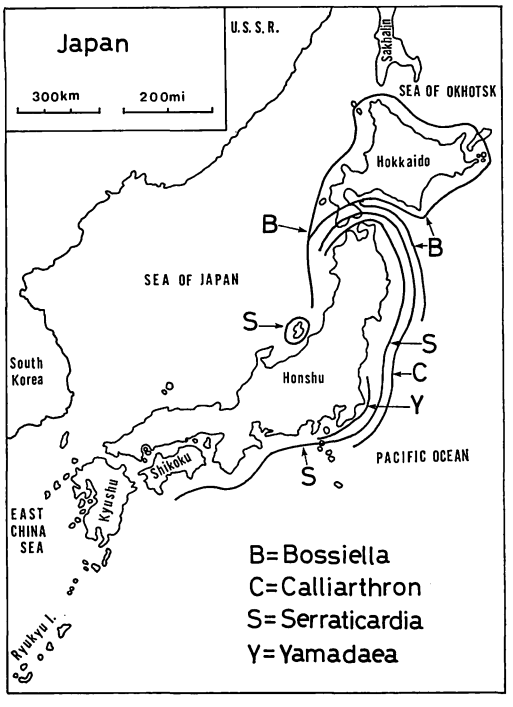

Fig. 2. Map of Japan showing distribution of *Bossiella*, *Calliarthron*, *Serraticardia* and *Yamadaea*.

latissimum only rarely. *Calliarthron* is also present in the form of a pair of species in California (JOHANSEN 1969). *Yamadaea melobesioides* has been recorded only from segments 8 and 9, but it may have been overlooked elsewhere because of its inconspicuous habit. Like *Serraticardia*, another species of *Yamadaea* (*Y. americana* DAWSON et STEELE) occurs in western North America (GARBARY *et al.* 1981).

Two morphologically compact species of *Corallina* that have habitually been called *C. sessilis* and *C. squamata* also fall into this group (Fig. 3). It is possible, however, that some of the records are actually of *C. pilulifera*, but until monographic work reveals the distinguishing features of these species definitive statements cannot be made. *Yamadaea* is even more restricted, being reported only from eastern Honshu (Fig. 2).

(4) *From Kyûshû and Shikoku to northern Honshu.* There are many records of *Marginisporum*, a genus endemic to Japan, through the main islands into Tsugaru Kaikyo, but, surprisingly, not into Hokkaido

Table 5. The genera in Japan containing 1 to 3 species and *Amphiroa*, *Corallina* and *Jania* as recorded in the coastal segments shown in Figure 1.

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Alatocladia modesta (YENDO) JOHANSEN		2	3	4	5			8	9	10	11	12	13	
Amphiroa	1	2	3	4	5	6	7	8	9	10	11			
Bossiella cretacea (POSTELS et RUPRECHT) JOHANSEN	1	2	3							10	11	12	13	14
Calliarthron[1]			3					8	9	10	11			
Cheilosporum jungermannioides[2] RUPRECHT in ARESCHOUG						6	7	8						
Corallina	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Jania	1	2	3	4	5	6	7	8		10	11			
Marginisporum[3]			3	4	5		7	8	9	10	11			
Serraticardia maxima (YENDO) SILVA			3				7	8	9	10	11			
Yamadaea melobesioides SEGAWA								8	9					
Total	4	5	8	5	5	4	6	9	7	8	8	3	3	2

Notes:

1) *Calliarthron* in Japan includes *C. latissimum* (YENDO) MANZA and *C. yessoense* (YENDO) MANZA.

2) *Cheilosporum californicum* (DECAISNE) YENDO and *Cheilosporum frondescens* (POSTELS et RUPRECHT) YENDO are omitted for lack of taxonomic information. As reported from Japan neither species belongs to *Cheilosporum*.

3) *Marginisporum* includes *M. aberrans* (Yendo) JOHANSEN et CHIHARA in JOHANSEN, *M. crassissimum* (YENDO) GANESAN and *M. declinata* (YENDO) GANESAN.

(Fig. 2). Probably closely related to *Calliarthron* and *Serraticardia*, it extends considerably farther south and west. It would be interesting to discover why none of the three species of *Marginisporum* (Table 5), herein considered together, have crossed Tsugaru Kaikyo to Hokkaido.

Alatocladia should perhaps be included in group three rather than four, except that it has been reported from Tsushima (segment 4), Unlike *Marginisporum*, *Alatocladia* occurs in southern Hokkaido. Furthermore, its recent discovery at a depth of 5 m off eastern Hokkaido suggests that this genus is surprisingly widespread (Fig. 3) and does not fit clearly into any of our groups. The single species, *A. modesta*, is endemic to Japan.

Corallina officinalis, the species of this genus that is most easily recognized and thus most likely to be identified correctly, has a distribution that somewhat parallels that of *Alatocladia* (Fig. 3). Reported at Hirado off Kyûshû and extending into Hakodate and western Hokkaido, it occurs widely in the Sea of Japan. This species is worldwide in temperate area of the world (JOHANSEN 1981).

Three genera remain to be considered: *Amphiroa*, *Jania* and *Cheilosporum* (Fig. 4). The nine species of *Amphiroa* fall into two factions (Table 2). The species in the first faction extend into Tsugaru Kaikyo, with *A. zonata* even present in western Hokkaido (segments 1-2). In the second faction the species remain below the waterway separating Hokkaido and Honshu and therefore are treated in group five below. *Jania* with 10 species listed in Table 4, is similar, but the faction extending into Tsugaru Kaikyo includes only two species (Table 6).

(5) *Central Honshu and below.* Some of the species of *Amphiroa* and *Jania*, as well as the single species of *Cheilosporum*, *C. jungermannioides*, do not extend into northern Honshu, but are represented in the

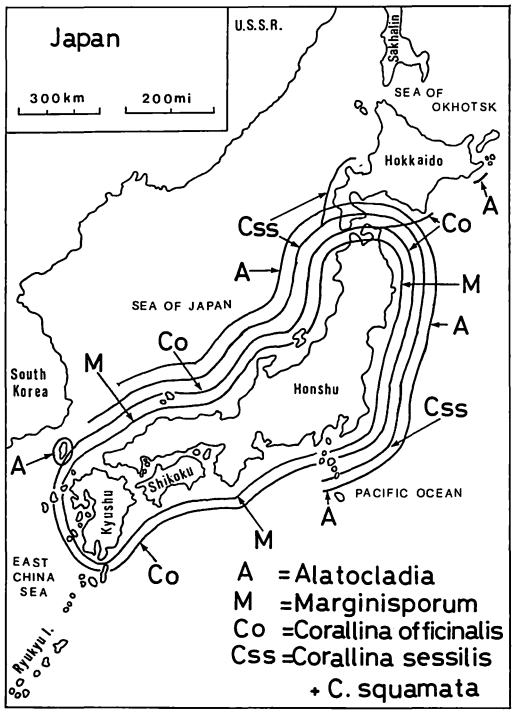

Fig. 3. Map of Japan showing distribution of *Alatocladia*, *Marginisporum*, *Corallina officinalis* and the species of *Corallina* placed in *C. sessilis* and *C. squamata*.

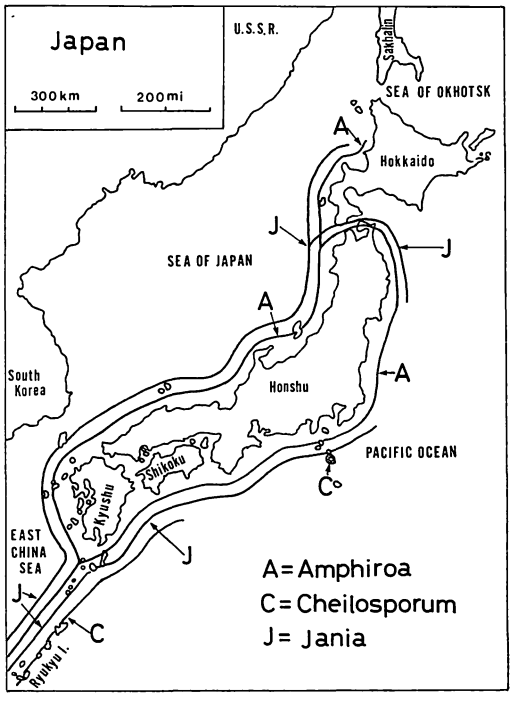

Fig. 4. Map of Japan showing distribution of *Amphiroa*, *Jania* and *Cheilosporum*.

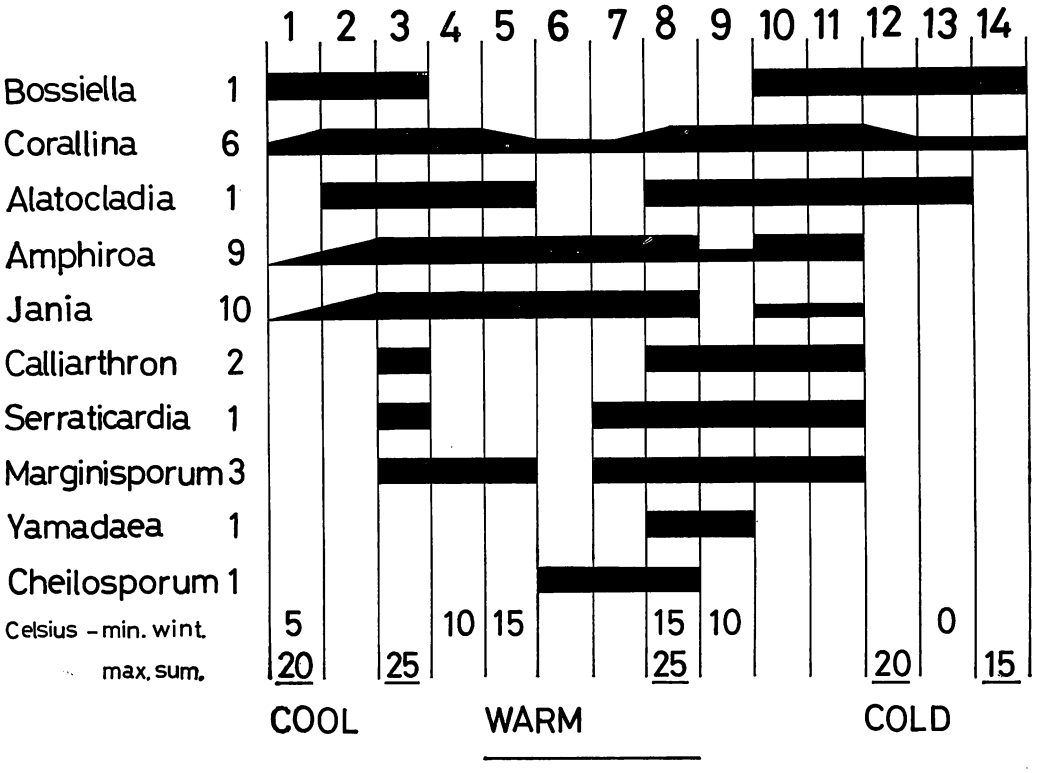

Fig. 5. Ranges of genera in the 14 coastal segments. Narrowing bars suggest that the number of species and specimens diminish appreciably. Following the genera are the numbers of species. At the bottom are some indications of seawater temperatures; minimum winter temperatures and maximum summer temperatures in degrees Celsius.

Table 6. Species of *Amphiroa* and *Jania* (1) extending into Tsugaru Kaikyo (segment 11) and (2) those not recorded this far north.

Reported in Tsugaru Kaikyo	*Reported below Tsugaru Kaikyo*
Amphiroa dilatata	*Amphiroa fragilissima*
A. echigoensis	*A. pusilla*
A. ephedraea	*A. rigida*
A. misakiensis	*A. valonioides*
A. zonata	
	*Jania adherens**
Jania nipponica	*J. arborescens*
J. yenoshimensis	*J. capillacea*
	J. pumila
	J. radiata
	J. rubens
	J. ungulata

* Includes *J. decussato-dichotoma*

south and, some of them, in the Ryûkyû Islands. It is noteworthy that this element contains no genera other than *Amphiroa, Jania* and *Cheilosporum.*

The current patterns around Japan (Fig. 1) lead to conditions that are tropical in the southern islands and boreal in Hokkaido. Surface temperatures for coastal Japan shown in Figure 1 serve to illustrate the wide ranges that sessile marine organisms must tolerate. Also winter sea ice may play a role in algal distribution in northern Hokkaido. The relative ranges of the genera are summarized in Figure 5.

The results presented in this paper lead to five conclusions: (1) Some of the genera and a few of the species of articulated coralline algae in Japan exhibit distributional patterns that could have been generally

predicted on teh basis of their distributions in other parts of the world: *Amphiroa, Jania, Bossiella cretacea, Cheilosporum, Serraticardia, Calliarthron,* and *Yamadaea.* (2) Two genera are endemic to Japan, and no prior data on distribution were available: *Alatocladia* and *Marginisporum.* (3) The presence of several genera in Japan and also in California (JOHANSEN 1976) suggest that interesting comparisons may be made between the articulated coralline floras on the two sides of the Pacific Ocean (see HOMMERSAND 1972): *Calliarthron, Serraticardia, Bossiella, Amphiroa, Corallina, Jania,* and *Yamadaea.* (4) Studies of the seasonality and distribution of reproduction would certainly reveal more about the biology of articulated coralline algae in Japan. The pioneering work of CHIHARA (1972a, b, 1973a, b) on reproductive cycles and spore germination could profitably be extended to bear on the phytogeography of these algae as could also research on reproductive organs (see MURATA and MASAKI 1978). (5) An inescapable conclusion is that taxonomic and nomenclatural studies are sorely needed. In order to successfully undertake regional studies on a species level the entities reported from Japan must be understood with reference to species in other parts of the world.

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正置富太郎* • 秋岡英承 • H. W. ジョハンセン***: 日本産有節サンゴモの植物地理学的特性**

日本産有節サンゴモ10属35種の地理的分布を日本全沿岸を14に区分して考察し次の結果を得た。(1) イソキリは北方種である (2) ピリヒバは全国各地に生育する (3) エゾシコロ, オオシコロ及びサビモドキの3属とサンゴモ属2種のミヤヒバ, ミヤヒバモドキは南北の両端を除いて分布する (4) 九州から本州北部にかけてヘリトリカニノテ属とサンゴモが生育し, このうち北の地方にはヤハズシコロが出現する (5) カニノテ属とモサズキ属の分布は北海道南岸と西岸に達するものと沖縄諸島に及ぶものがある (6) ヒメシコロ属は南方種で沖縄諸島と日本南岸にのみ報告がある。(*041 函館市港町 3—1—1 北海道大学水産学部 **040 函館市八幡町 1—2 北海道教育大学函館分校 *** Department of Biology, Clark University, Worcester, Massachusetts 01610 USA.