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Geographical and Seasonal Distribution of Arenicolous Marine Fungi along the Pacific Coast of the Bousou Peninsula

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Summary

Sea foam on sandy beaches was examined for trapped spores of arenicolous marine fungi at seven sites along the Pacific coast of the Bousou Peninsula (central Japan) in four seasons, and 26 species in 12 genera of arenicolous marine fungi were recorded. Their occurrence according to locality and season were investigated, and three geographical patterns were recognized: species occurring over the whole region, species occurring mainly at southern sites, and species occurring mainly at northern sites. Some of the species showing the latter two patterns changed their distribution according to the season. Geographical and seasonal distribution of the fungi was influenced by seawater temperature, which in turn is influenced by the distribution of the coastal waters derived from the warm and cold Pacific Ocean currents.

Keywords: arenicolous marine fungi, biogeography, distribution.

The Bousou Peninsula (Chiba Pref., central Honshu Island, Japan) faces the Pacific Ocean where the Kuroshio (the Japan Current, a warm current) meets the Oyashio (the Kurile Current, a cold current). The two ocean currents affect the climate of the Pacific coast of the peninsula (the Sotobou coast). It is well known that the marine flora and fauna, that is, biodiversities of seaweed, fish, invertebrates, etc. are determined by the effects of the currents, and that the warm and cold sea marine organisms that inhabit the Sotobou coast are adapted to its unique coastal environments (8, 14). However, no study has been done on the flora of marine fungi along the coast.

Geographical distributions of marine fungi have been studied mainly by plotting the records of fungi on a global map divided into climate zones, including tropical, subtropical, temperate, arctic, and antarctic (1, 2, 6). According to the distribution pattern, species of marine fungi are recognized as cosmopolitan, tropical to subtropical, temperate, etc., though accumulation of more data is still necessary for a precise understanding of the fungal distribution. In Japan, Nakagiri (10) and Tokura (13) reported the occurrence of arenicolous marine fungi from Japanese coasts and recognized three types of distribution: wide distribution throughout Japan, distribution mainly in northern Japan, and distribu-

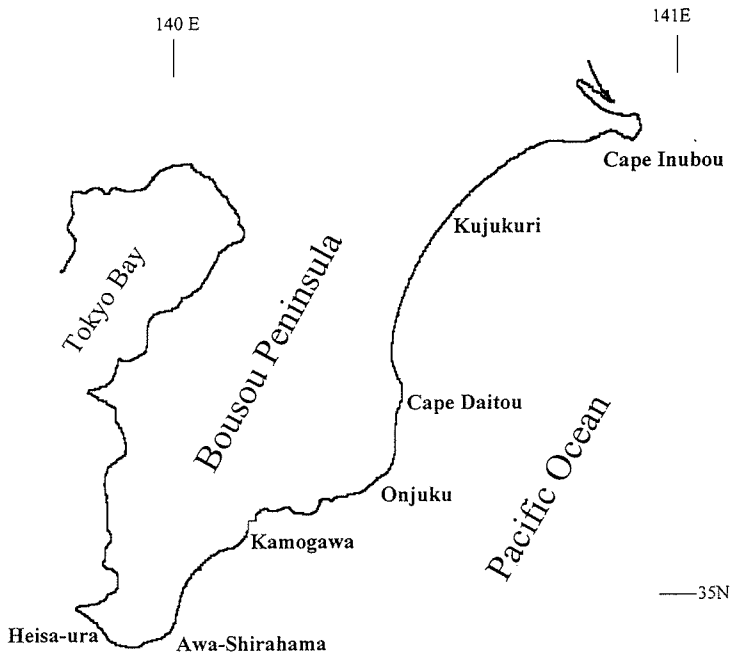

Fig. 1. Seven collection sites of sea foam along the Sotobou coast.

tion mainly in southern Japan. Although the seasonal distribution of marine fungi has been studied (4), no studies have focused on the relationship between fungal distribution and ocean currents, or on the seasonal change of fungal distribution along coasts where water temperature changes according to season and the influence of the currents.

The Sotobou coast is characterized by the fact that seasonal changes in the temperature of the seawater depend mainly on the influences of two ocean currents. Thus, we have investigated fungal occurrence on the Sotobou coast over the course of the year by examining sea foam samples. It is well known that spores of arenicolous marine fungi are trapped and accumulated in sea foam on sandy beaches, and that sea foam is a useful source of information on the mycoflora of the beach (3, 5, 7, 10). The purpose of this study is to estimate the geographical distribution of marine fungi along a stretch of ca. 150-km of the Sotobou coast and to examine how their distribution is influenced by the seasons and the ocean currents.

Material and Methods

Sea foam samples were collected from seven sites along the Pacific coast of the Bousou Peninsula (the Sotobou coast) (Fig. 1) in four months: March, September, December 1995, and June 1996. Because the temperature of seawater is lowest in February-March and highest in August-September, these months can be considered to correspond to winter (March), spring (June), summer (September), and autumn (December). The seven sites are, from north to south of the Sotobou coast, Cape Inubou, Kujukuri, Cape Daitou, Onjuku, Kamogawa, Awa-Shirahama, and Heisa-ura. Sea foam formed on sandy

Table 1. Occurrence of spores of marine fungi in sea foam from seven sites along the Sotobou coast in March 1995.

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Arenariomyces parvulus	+	+	+	++		+	
A. trifurcatus	+	++	++	+++	++	++	++
Carbosphaerella leptosphaerioides			+		++		
Ceriosporopsis halima		+		+	+	+	+
Corollospora angusta	+	+++	+	+++			
C. colossa			+				+
C. fusca	+			+	+	+	+
C. gracilis	+	++	++	++			
C. intermedia		+		++			+
C. maritima	++	+	++	++	++	++	++
C. pseudopulchella		+	+	++			
C. pulchella	+						
C. quinqueseptata		+++		+++			
Halosphaeria salina			+				
Halosphaeriopsis mediosetigera					+		
Lulworthia crassa	+		+				
Lulworthia sp.							+
Marinospora calyptrata					+		
Ondiniella torquata					+	+	
Torpedospora radiata		+				+	+
Trailia ascophylli							+
Nia vibrissa		+	+	+	+	+	
Asteromyces cruciatus		+		+			
Sigmoidea marina						+	
Species number 24	8	12	11	12	9	9	9

Data from sea foam samples collected on 13 March 1995. Relative abundance of spores is indicated as +, ++ and +++.

beaches at these sites was collected with a ladle and transported to the laboratory in bottles, which were cooled to prevent spore germination. The foam samples were examined under a microscope to identify spores of marine fungi, and some of spores were isolated and cultured to confirm their identification. The species identified from each site and in each season were compared to clarify the geographical and seasonal distribution of the arenicolous marine fungi of the Sotobou coast.

Results and Discussion

Occurrence of fungal spores in sea foam samples

The occurrence and abundance of marine fungi in foam samples collected from the seven sites in four seasons are listed in Tables 1-4. Thirty-three species of marine fungi including 12 genera and 26 species of arenicolous fungi were found in the foam samples. Though the presence or absence of spores in foam samples does not indicate directly the fungal distribution, these data probably give useful information on the relative activity of the arenicolous marine fungi in their natural habitats.

Table 2. Occurrence of spores of marine fungi in sea foam from seven sites along the Sotobou coast in June 1996.

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Arenariomyces parvulus	+	+	++	+	+	+	
A. trifurcatus	+	+++	+++	+	++	+	
Carbosphaerella leptosphaerioides	+	+	+		+		
Ceriosporopsis halima			+	+	+		
Corollospora angusta	+	+	+	+			
C. colossa	+	+	+				
C. fusca	++		+	+	+		
C. gracilis	+++	+++	+++	+++	++	+++	
C. intermedia		+					
C. maritima	++	++	++	+	+++	+++	++
C. pseudopulchella		+		+		+	
C. pulchella		+	+	+			
C. quinqueseptata	+	+++		++			
Halosphaeria appendiculata					+		
Halosphaeriopsis mediosetigera	+		+	+			
Lindra obtusa				+	+		+++
Lin. thalassiae	+	++					
Lulworthia crassa	+	+	+		+		
Lul. lignoarenaria				+			
Lulworthia sp.	+	+	+	+	++		
Marinospora calyptrata					+		
Ondineilla torquata					+		
Torpedospora radiata					+		
Trailia ascophylli	+						++
Nia vibrissa			+	+	+		+
Asteromyces cruciatus	+	+	+	++			
Varicosporina ramulosa	+	+++	+++	+			
Sigmoidia luteola			+	++	+		+
S. marina				++	+		+
Species number 28	16	16	17	19	17	5	6

Data from sea foam samples collected on 18–19 June 1996. Relative abundance of spores is indicated as +, ++ and +++.

The marine fungi show three patterns of occurrence: 1) species occurring at all the seven sites throughout the year, 2) species occurring mainly at sites north of Onjuku, and 3) species occurring mainly at sites south of Onjuku. As an example, Table 5 summarizes the three patterns of occurrence found in data of December 1995. The first pattern was shown by *Corollospora maritima* Werdermann and *Arenariomyces trifurcatus* Höhnk (Table 6a, b), whose ascospores occurred abundantly in the foam samples collected from the seven sites in all seasons. Both species are known as globally cosmopolitan marine fungi (1). The second pattern was shown by *Lindra obtusa* Nakagiri & Tubaki, *Ceriosporopsis halima* Linder, and *Nia vibrissa* Moore & Meyers (Table 7a, b, c). They occurred mainly to the north of Onjuku, but in March and December, the low temperature seasons, their distributions extended southward. This phenomenon suggests that they prefer lower temperature. In contrast, *C. quinqueseptata* Nakagiri, *Varicosporina ramulosa* Meyers & Kohlmeyer and *C. gracilis* Nakagiri & Tokura appeared mainly in the

Table 3. Occurrence of spores of marine fungi in sea foam from seven sites along the Sotobou coast in September 1995.

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Arenariomyces parvulus	+	+	++	+		++	++
A. trifurcatus	++		++	++	+	+++	+++
Carbosphaerella leptosphaerioides	++		+		+	+	++
Ceriosporopsis halima			+		+	+	++
Corollospora angusta	+	+	+	+			
C. colossa	++		++	+			+
C. fusca			+	+		+	+
C. gracilis	+++	++	++	+++	+	+	++
C. intermedia	+	+		++	+		+
C. lacera	+		+		+		+
C. luteola				+			
C. maritima	+++	+	+++	++	+	+++	+++
C. pseudopulchella	+	+	++	+	+		+
C. pulchella	+			+			
C. quinqueseptata	++	+++		+++			
Halosphaeria appendiculata						+	+
Halosphaeriopsis mediosetigera	+		+	+		+	++
Lindra obtusa		+		+			+
Lin. thalassiae	+	+		+		+	
Lulworthia crassa	+	+	++				++
Lul. lignoarenaria	+				+	+	++
Lulworthia sp.			+				
Marinospora calyptorata					+		+
Torpedospora radiata					+	+	++
Nia vibrissa			++			++	++
Anguillospora marina		+					
Asteromyces cruciatus	+	+		+			
Clavatospora bulbosa			+		+	+	
Varicosporina prolifera	++	+					+
V. ramulosa	++	+	+	+			+
Sigmoidia marina							+
Species number 31	19	14	17	17	12	14	22

Data from sea foam samples collected on 18-19 September 1995. Relative abundance of spores is indicated as +, ++ and +++.

southern regions, showing the third pattern of occurrence (Table 8a, b, c). In the low temperature seasons, especially in March, their spores appeared only at southern sites. However, their distributions extended northward in the higher temperature seasons. This indicates their preference for higher temperature.

Occurrence of teleomorph and anamorph states of *C. pulchella* Kohlmeyer, I. Schmidt & Nair and *C. intermedia* I. Schmidt were also examined (Table 9). Though no clear pattern of the occurrence was observed, their anamorphs, *Clavatospora bulbosa* (Anastasiou) Nakagiri & Tubaki and *V. prolifera* Nakagiri, appeared frequently in the higher temperate season, though the teleomorphs were prevalent in cooler seasons and at northern sites. This accords with a phenomenon that anamorphs are prevalent in seasons and regions of higher temperature, and teleomorphs are prevalent in seasons and regions of lower temperature (11).

Table 4. Occurrence of spores of marine fungi in sea foam from seven sites along the Sotobou coast in December 1995.

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Arenariomyces parvulus	+	+	+	++	++	+	
A. trifurcatus	++	++	++	++	+++	+++	+++
Carbosphaerella leptosphaerioides	+				++		+
Ceriosporopsis halima					++		+
Corollospora angusta	+++	+++	++	+++	+		
C. colossa					+	+	+
C. fusca	+		+			+	+
C. gracilis	++	+	++	++	+	++	++
C. intermedia	+	++					
C. lacera	+						
C. luteola	+			++			
C. maritima	+++	++	+++	++	++	+++	+++
C. pseudopulchella				+			+
C. pulchella		+					
C. quinqueseptata	+	+++					
Halosphaeriopsis mediosetigera	+				+		
Lindra obtusa		+		+			+
Lulworthia crassa	+				+		
Lulworthia sp.	++	+			++	+	
Ondiniella torquata					+		
Torpedospora radiata						+	
Trailia ascophylli							+
Nia vibrissa		+		+	++		
Asteromyces cruciatus	+						
Clavatospora bulbosa					+		
Varicosporina ramulosa		+		+			
Sigmoidia luteola							+
S. marina				+			
Species number 28	15	12	6	11	14	8	11

Data from sea foam samples collected on 10-12 December 1995. Relative abundance of spores is indicated as +, ++ and +++.

Numbers of species found at the seven sites are summarized in Table 10. The total number of species was highest in September and lowest in March. This is attributed mainly to the fluctuating species number of deuteromycetes, which decrease in winter and increase in summer (see right column of Table 10). The annual total number of species was greatest at Onjuku, which indicates that the distribution areas of fungi preferring higher temperature and those preferring lower temperature may overlap at Onjuku. Similarity of the species profile between each site and Heisa-ura (the most southern site) or Cape Inubou (the most northern site) was calculated (see the lower column of Table 10). Higher similarity values to Heisa-ura are seen at the southern sites, Onjuku, Kamogawa and Awa-Shirahama, while the species profiles of the sites north of Onjuku are more similar to that of Cape Inubou than that of Heisa-ura. This strengthens the suggestion that there is a boundary between the distributions of particular species of marine fungi around Onjuku. The seasonal change of occurrence in particular species (see Tables 7 and 8) indicates that this boundary moves northward in summer and

Table 5. Three occurrence patterns of marine fungi observed in data of December 1995.

Species	Heisaura	Awa-Shirahama	Kamo-gawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
1) Occurring at all sites							
Arenariomyces trifurcatus	++	++	++	++	+++	+++	+++
Corollospora gracilis	++	+	++	++	+	++	++
C. maritima	+++	++	+++	++	++	+++	+++
2) Occurring mainly at north of Onjuku							
Ceriosporopsis halima					++		+
Corollospora colossa					+	+	+
C. pseudopulchella				+			+
3) Occurring mainly at south of Onjuku							
Corollospora angusta	+++	+++	++	+++	+		
C. intermedia	+	++					
C. quinqueseptata	+	+++					
C. luteola	+			++			

Table 6. Occurrence pattern of marine fungi appearing at all sites in all seasons.

a. ***Corollospora maritima***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	+	+	+	+	+	+	+
Jun.	+	+	+	+	+	+	+
Sep.	+	+	+	+	+	+	+
Dec.	+	+	+	+	+	+	+

b. ***Arenariomyces trifurcatus***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	+	+	+	+	+	+	+
Jun.	+	+	+	+	+	+	-
Sep.	+	-	+	+	+	+	+
Dec.	+	+	+	+	+	+	+

southword in winter.

Cultural properties and distribution of the marine fungi

Hyphal growth and reproduction of the fungi found show a close correlation to their occurrence patterns. *Corollospora maritima*, one of the fungi showing wide distribution from Cape Inubou to Heisa-ura throughout the year, is known to show good hyphal growth and ascomata formation over a wide range of temperature (10-35°C, optimum 30°C) (9). In contrast, *L. obtusa*, which appeared mainly in the region north of Onjuku,

Table 7. Occurrence pattern of marine fungi appearing mainly north of Onjuku.

a. ***Lindra obtusa***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	−	−	−	−	−	−	−
Jun.	−	−	−	+	+	−	+
Sep.	−	−	−	+	−	−	+
Dec.	−	+	−	+	−	−	+

b. ***Ceriosporopsis halima***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	−	+	−	+	+	+	+
Jun.	−	−	+	+	+	−	−
Sep.	−	−	+	−	+	+	+
Dec.	−	−	−	−	−	−	+

c. ***Nia vibrissa***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	−	+	+	+	+	+	−
Jun.	−	−	+	+	+	−	+
Sep.	−	−	+	−	−	+	+
Dec.	−	+	−	+	+	−	−

Table 8. Occurrence pattern of marine fungi appearing mainly south of Onjuku.

a. ***Corollospora quinqueseptata***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	−	+	−	+	−	−	−
Jun.	+	+	−	+	−	−	−
Sep.	+	+	−	+	−	−	−
Dec.	+	+	−	−	−	−	−

b. ***Varicosporina ramulosa***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	−	−	−	−	−	−	−
Jun.	+	+	+	+	−	−	−
Sep.	+	+	+	+	−	−	+
Dec.	−	+	−	+	−	−	−

c. ***Corollospora gracilis***

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	+	+	+	+	−	−	−
Jun.	+	+	+	+	+	+	−
Sep.	+	+	+	+	+	+	+
Dec.	+	+	+	+	+	+	+

shows its optimum growth at 20°C and conidia are produced well at under 20°C. Hyphal growth of this species is depressed at above 25°C (9). On the contrary, *V. ramulosa*, which appeared mainly at the southern sites, shows a preference for higher temperature (above 25°C, growth optimum at 35°C) in culture. Conidium production and sclerocarp (degenerated ascoma) formation occur from 20°C to 40°C (9). Thus, the cultural prop-

Table 9. Occurrence pattern of teleomorph-anamorh species.

a. ***Corollospora pulchella*** **(T)-** ***Clavatospora bulbosa*** **(A)**

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	T	-	-	-	-	-	-
Jun.	-	T	T	T	-	-	-
Sep.	T	-	A	T	A	A	-
Dec.	-	T	-	-	A	-	-

b. ***Corollospora intermedia*** **(T)-** ***Varicosporina prolifera*** **(A)**

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou
Mar.	-	T	-	T	-	-	-
Jun.	-	T	-	-	-	-	-
Sep.	A	A	-	T	T	-	A
Dec.	T	T	-	-	-	-	-

Table 10. Number of species of marine fungi appearing in sea foam collected at seven sites on the Sotobou coast.

	Heisa-ura	Awa-Shirahama	Kamogawa	Onjuku	Cape Daitou	Kujukuri	Cape Inubou	Total	Asco.	Deutero.	Basidio.
Mar.	8	12	11	12	9	9	9	24	21	2	1
Jun.	16	16	17	19	17	5	6	28	23	4	1
Sep.	19	14	17	17	12	14	22	31	24	6	1
Dec.	15	12	6	11	14	8	11	28	22	5	1
Total species in four seasons	58	54	51	59	52	36	48				
Total different species in year	23	22	21	23	25	19	24	33			
Species similarity* to Heisa-ura	-	76	73	78	63	57	72				
Species similarity to Cape Inubou	72	70	71	72	86	78	-				

*Species similarity (%) = no. of common species between A and B X 2/species no. of A + species no. of B X 100

erties of the marine fungi accord with their appearance in the natural habitats.

Environmental factors and fungal appearance

Seawater temperature

Seawater temperature of the Sotobou coast is influenced by the climate and the ocean currents. Figure 2 is a graph of the monthly average temperature of seawater at four locations along the Sotobou coast [data from Shimizu (12)]. It shows that seawater temperature at Choushi (close to Cape Inubou) is lower than at other southern locations, especially in winter. The difference in temperature between Choushi and other places is about 2°C in summer, but more than 4°C in winter. Thus, the seawater temperature becomes similar in summer along the Sotobou coast, but in winter it differs greatly

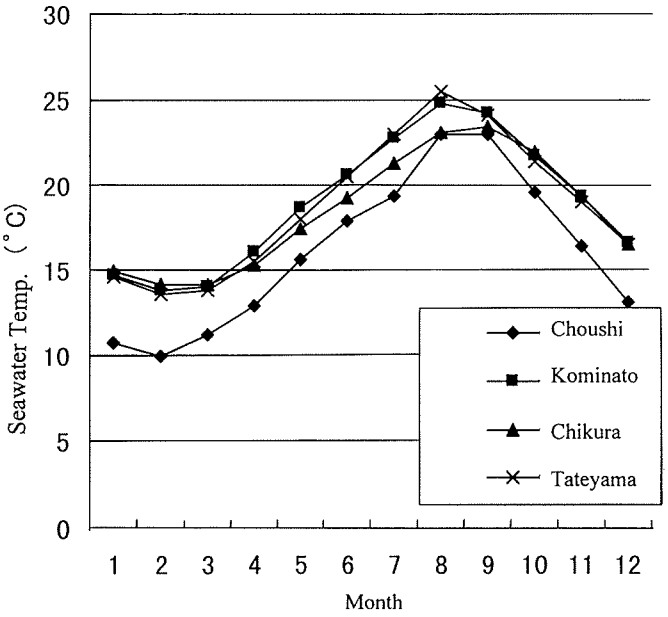

Fig. 2. Monthly average temperature of coastal seawater at four locations, Choushi (close to Cape Inubou), Kominato (close to Onjuku), Chikura (close to Awa-Shirahama) and Tateyama (close to Heisa-ura). [Data from Shimizu (12).]

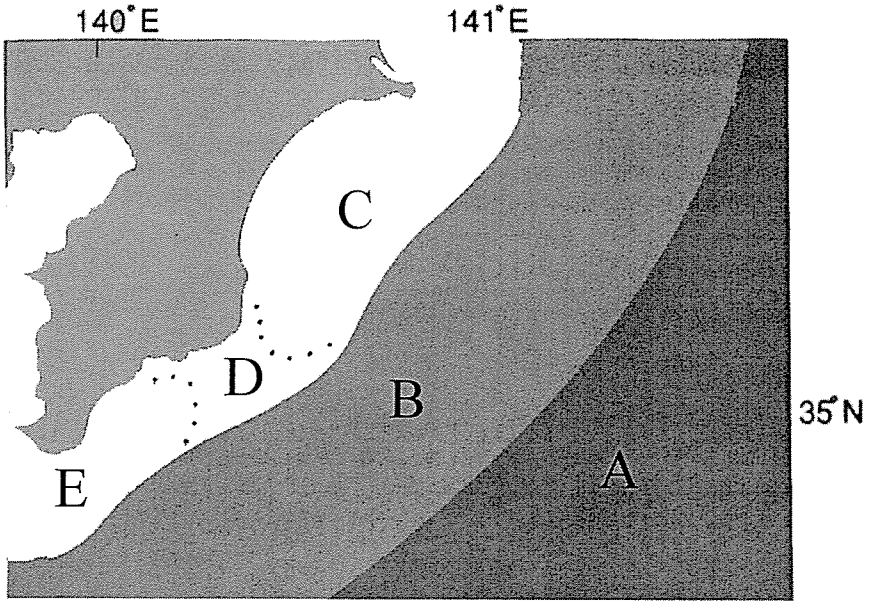

Fig. 3. Schematic illustration of the distribution of coastal waters off the Bousou Peninsula (A, Kuroshio water; B, Mixed water; C, Kujukuri coastal water; D, Sotobou-Kujukuri mixed coastal water; E, Sotobou coastal water).

between the north and the south. This may explain why the number of species found at the northern sites is similar to that at the southern sites in summer, but less in other seasons (Table 10).

Distribution of seawater area

Figure 3 schematically shows distribution of offshore coastal waters of the Bousou Peninsula. The northern coast of the Sotobou is washed by Kujukuri coastal water, which is derived from the Oyashio and has lower temperature and salinity. On the other hand, the southern coast is washed by Sotobou coastal water, which is derived from Kuroshio and has higher temperature and salinity. The coast around Onjuku is influenced by Sotobou-Kujukuri mixed coastal water (12). These coastal waters influence on the seawater temperature of the Sotobou coast and their distribution shifts northward in summer and southward in winter according to the strength of the original ocean currents. Thus, the distribution of the coastal waters influences the geographical and seasonal distribution of marine fungi along the coast.

In conclusion, the above observations indicate that: 1) there are three patterns of occurrence of marine fungi inhabiting the Sotobou coast, namely, the whole region, the area north of Onjuku, and the area south of Onjuku; 2) certain marine fungi have their distribution boundaries around Onjuku, where a boundary of the coastal waters is located; 3) the properties of hyphal growth and reproduction of the marine fungi accord well with their occurrence pattern; 4) complex coastal environments due to the influence of the different types of the coastal water produce a high diversity of marine fungi along the Sotobou coast; and 5) these investigations on the geographical and seasonal change of occurrence of marine fungi give useful information on the distribution of each species of marine fungi inhabiting the coasts.

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