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Distribution of sea anemones (Cnidaria, Actiniaria) in Korea analyzed by environmental clustering

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Abstract

Using environmental data and the geospatial clustering tools LOICZView and DISCO, we empirically tested the postulated existence and boundaries of four biogeographic regions in the southern part of the Korean peninsula. Environmental variables used included wind speed, sea surface temperature (SST), salinity, tidal amplitude, and the chlorophyll spectral signal. Our analysis confirmed the existence of four biogeographic regions, but the details of the borders between them differ from those previously postulated. Specimen-level distribution records of intertidal sea anemones were mapped; their distribution relative to the environmental data supported the importance of the environmental parameters we selected in defining suitable habitats. From the geographic coincidence between anemone distribution and the clusters based on environmental variables, we infer that geospatial clustering has the power to delimit ranges for marine organisms within relatively small geographical areas.

Introduction

The coastal waters of the Korean peninsula have been divided into four biogeographic regions. In summarizing research to date, Kim (1986) characterized them (Fig. 1A) on the bases of water temperature, depth, tidal amplitude, turbidity, and substratum. The Yellow Sea (YS) and East Sea (ES) are cold-water areas, seasonally influenced by the Yellow Sea Cold and Liman currents, respectively, from the north; the Korea Strait (KS) and Cheju Island (CI) are influenced by the Tsuchima current, a branch of the Kuroshio current, which brings warm waters from the tropics year round. Because the major rivers of Korea flow into the YS, vast muddy intertidal areas occur along Korea's west coast.

Whether the environmental characteristics of the defined regions significantly affect the distribution of organisms, and thereby are appropriate for defining biogeographical regions, is unknown. We therefore tested whether four coastal regions of Korea could be defined using environmental variables and whether the regions correspond to animal occurrences. Using the *k*-means clustering tools LOICZView (Maxwell & Buddemeier, 2002; Maxwell, 2003) and DISCO (Smith & Maxwell, 2003), we analyzed the distribution of six environmental parameters, including two used by Kim (1986), water temperature, and tidal amplitude. To examine whether the resulting four regions had biological significance, we overlaid distribution data for 11 species of intertidal sea anemones (Cha & Song, 2001; Song & Cha, 2002).

A hierarchical clustering of the occurrence of all 20 Korean anemone species included in Cha & Song (2001) and Song & Cha (2002) (the 11

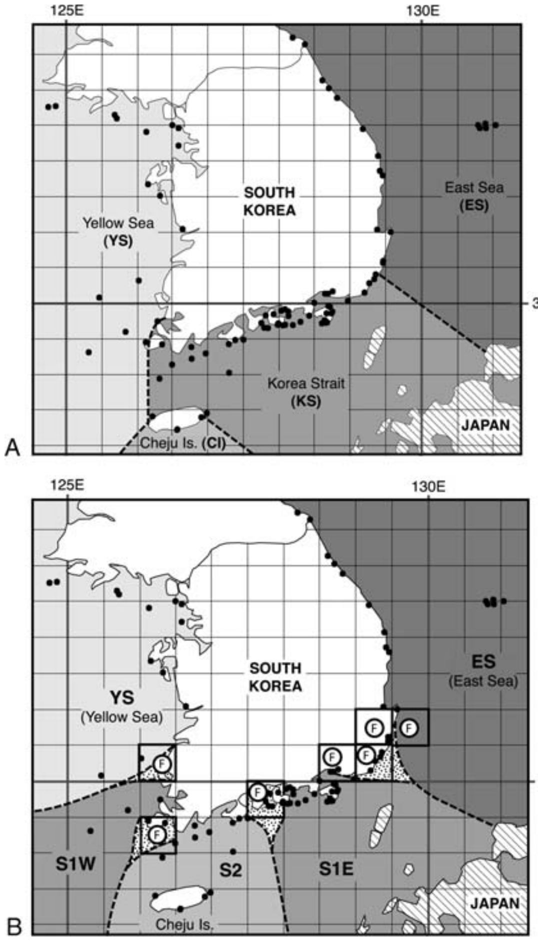

Figure 1. The southern Korean peninsula. Grid lines indicate the half-degree cells used for analysis; solid dots indicate anemone sample locations, which all fall in intertidal areas of the mainland and small islands. (A) The four coastal biogeographic regions of Korea used in analyses such as those of Kim (1986) and Song (1991). Adapted from Kim (1986) and Song (1991). (B) Biogeographic regions based on our environmental clustering and intertidal anemone distributions. Stippled areas indicate transitional zones where habitats and species characteristic of more than one region may occur. Boxed cells containing a circled F have multiple possible cluster memberships as shown by fuzzy clustering.

intertidal ones we used plus 9 subtidal ones) using Minitab resulted in four groupings (H.-R. Cha, unpublished). Thus Korean anemones appear to fall into four biogeographic regions, as Kim (1986) found for crustaceans and Song (1991) for scleractinian corals. However, in our analysis the details of the borders between them differ somewhat from those Kim (1986) postulated. The ecological significance of the pattern of clusters based on environmental parameters is supported by the distributions of the intertidal sea anemones.

Materials and methods

We used environmental data from the database 'Biogeoinformatics of Hexacorallia' (Fautin & Buddemeier, 2003); they were obtained from various sources and gridded at half-degree resolution. Continuous variables investigated included mean and maximum monthly wind speed, mean, maximum and minimum monthly sea surface temperature (SST), mean and minimum monthly salinity, annual mean strength of the spectral signal in the chlorophyll wavelength band (SEAWIFS), and tidal amplitude. The parameters were chosen because they vary through the year and are potentially important to the occurrence of intertidal sea anemones. Equal weight was given to all.

Analysis used geospatial clustering (Maxwell & Buddemeier, 2002), a technique that groups spatially distributed multi-variable data points according to the similarity of their locations in multi-dimensional space. We used the clustering tools LOICZView (Maxwell, 2003) and DISCO (Smith & Maxwell, 2003). These web-based, graphical applications were developed in support of the Land–Ocean Interactions in the Coastal Zone (LOICZ) program, and use *k*-means clustering algorithms. The tools permit clustering, classification, and comparison of environments at regional and global scales, providing a similarity analysis of the values associated with the grid cells. The two applications are fundamentally similar, but LOICZView has a function to overlay data points on clusters, while DISCO offers a fuzzy clustering capability.

To test the biological significance of the cluster results for environmental data, we plotted distributions of the 11 intertidal sea anemone species in Korea inventoried by Cha & Song (2001) and Song & Cha (2002) based on surveys done from 1968 to 2000 at 84 intertidal localities (seven additional surveyed localities are subtidal). The species (and the number of locality points for each) are *Actinia equina* (7), *Anthopleura japonica* (26), *A. kurogane* (51), *A. midori* (38), *A. pacifica* (14), *Epiactis japonica* (13), *Flosmaris mutsuensis* (3), *Haliplanella luciae* (26), *Isanthus capensis* (2), *Paracondylactis* *hertwigi* (4), and *Urticina crassicornis* (5). Their localities are documented in the database 'Biogeoinformatics of Hexacorallia' (Fautin & Buddemeier, 2003). The locality data (see Fig. 1) for each species were uploaded to the LOICZView application, merged with the environmental data set, and plotted on the map using the 'merge' and 'overlay' functions of LOICZView. The same environmental data were also analyzed using the fuzzy *k*-means clustering package in DISCO, which provides a membership score for each cell in each cluster. This permits identification of localities that are intermediate between two or more clusters. In order to test the biogeographic regions proposed, we focused our attention on four-cluster tests because of Kim (1986) and because of Cha's unpublished data.

Results and discussion

Many combinations of variables yielded similar patterns; the variables we ultimately settled onto produce the results presented in Table 1, and the titles of the datasets in 'Biogeoinformatics of Hexacorallia' were tide range (scaled classes – TIDAL_RANGE), maximum windspeed (WINDSPEED_MAX), maximum SST (SST_MAX_MONTH), mean salinity (SALINITY_ANN_AVG), and the chlorophyll signal (CHLORA_SPAVGSTD). Kim (1986) also used tidal amplitude and SST in his analysis; because we dealt only with intertidal animals, we did not consider water depth or features of the sea floor, as Kim (1986) did.

Figure 1A and B contrast the borders of previously recognized areas with what we found. According to Kim (1986), three regions were initially recognized – the coasts of the East Sea (ES, the east side of the peninsula), the Korea Strait (KS, the south coast of the peninsula), and the Yellow Sea (YS, the west coast of the peninsula), including any islands lying offshore from them; a fourth region was created by separating Cheju Island (CI) from KS. The southern end of the peninsula, including Cheju Island, is primarily where our analysis (Fig. 1B) differs from previous ones: CI clusters with the south-central part of the Korean peninsula, as cluster S2 in our analysis, and our cluster S1 consists of regions in the southeastern (S1E) and southwestern (S1W) parts of the Korean peninsula and the islands off the southwest corner of the peninsula. Although cluster S1 is discontinuous, straddling S2 (Fig. 1B), S1E and S1W are more similar to each other than to any of their neighbors. YS and ES do not extend quite as far south in our analysis as in previous schemes. The environmental parameters associated with each cluster are shown in Table 1. Clusters S1 and

Table 1. Environmental parameters associated with each biogeographic region from LOICZView and DISCO clustering analysis

Environmental cluster	ES		S1	
	Value	Std Dev	Value	Std Dev
WINDSPEED_MAX	8.86	0.149	8.90	0.244
SST_MAX_MONTH	26.71	0.384	28.05	0.488
SALINITY_ANN_AVG	33.74	0.095	33.37	0.487
TIDAL_RANGE	6	0.000	1.50	1.581
CHLORA_SPAVGSTD	3.28	2.161	4.25	1.275
	S2		YS	
	Value	Std Dev	Value	Std Dev
WINDSPEED_MAX	9.48	0.253	8.89	0.222
SST_MAX_MONTH	28.17	0.312	26.79	0.759
ALINITY_ANN_AVG	32.22	0.430	32.13	0.760
TIDAL_RANGE	10	0.000	8.61	2.54
CHLORA_SPAVGSTD	3.10	1.787	3.52	1.685

S2 differ from clusters ES and YS in having higher SST, cluster S1 has the lowest tidal amplitude and the highest chlorophyll values, and S2 has the highest tidal amplitude and windspeed values.

We used the DISCO fuzzy clustering routine to identify transitional cells (typically those with less than 50% 'membership' in any one cluster). We identified seven such cells (out of a total of 47), and used their occurrence in our evaluations of the relationship between anemone occurrence and specific clusters. Fuzzy boundary zones in Figure 1B are based on the locations of cells shown by fuzzy clustering to show partial membership in more than one cluster. Although the sample size is too small for detailed analysis, anemone species distributions support our revision of Korean coastal marine biogeography.

All of the 11 sea anemone species occur also in Japan and some have much greater geographic ranges. The most widely distributed species, *Haliplanella luciae* (Fig. 2C), was recorded from all four regions (Table 2), a distribution not unexpected in this cosmopolitan species (Fautin, 2003). The other species that also occur in all four regions are *Anthopleura kurogane* and *A. midori* (Fig. 2A and B, respectively; Table 2). Overlaying occurrences of the eight species having more restricted distributions on the environmental clusters (Fig. 2, Table 2) supports the clusters as reflecting differences important to anemone distribution. Of three of the four least broadly distributed species, two are burrowers – *Flosmaris mutsuensis* (Fig. 2H) and *Paracondylactis hertwigi* (Fig. 2I). They occur in the muddy YS and at a single site on the east coast, the former at the fuzzy boundary between S1 and ES, and the latter in the northeasternmost cell of S1. Whether the rarity of the least abundant species, *Isanthus capensis*, reflects the availability of suitable habitat in only a small portion of S1 (Fig. 2K) cannot be determined with the sparse data.

Epiactis japonica (Fig. 2G) occurs mainly and *Urticina crassicornis* (Fig. 2J) occurs exclusively in ES and the fuzzy boundary between ES and S1. In the analysis of Song & Cha (2002), although *Epiactis japonica* was recorded from both ES and KS, *Urticina crassicornis* was recorded only from ES.

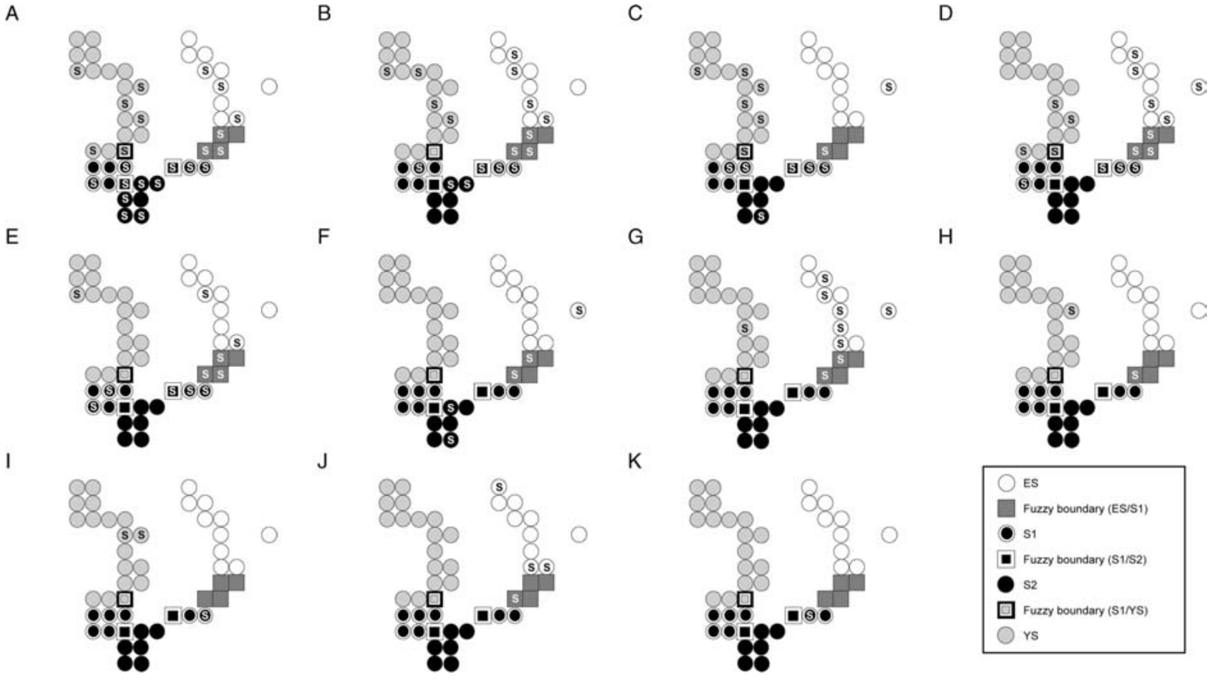

Figure 2. Species distributions of intertidal sea anemones overlain on the four biogeographic regions. The cells labeled with 'S' indicate localities at which specimens were collected or observed. (A) *Anthopleura kurogane*, (B) *Anthopleura midori*, (C) *Haliplanella luciae*, (D) *Anthopleura japonica*, (E) *Anthopleura pacifica*, (F) *Actinia equina*, (G) *Epiactis japonica*, (H) *Flosmaris mutsuensis*, (I) *Paracondylactis hertwigi*, (J) *Urticina crassicornis*, (K) *Isanthus capensis*.

Table 2. Occurrence of sea anemones by biogeographic region

Species (number of localities: map in Fig. 2)	LOICZView classification							According to Cha & Song (2001) and Song & Cha (2002)			
	ES	F (S1/ES)	S1	F (S1/YS)	YS	F (S1/S2)	S2	ES	YS	KS	CI
Anthopleura kurogane [51: A]	3	8	14	2	6	8	10	+	+	+	+
Anthopleura midori [38: B]	5	6	12		8	2	5	+	+	+	+
Haliplanella luciae [26: C]	1	2	10	1	7	3	2	+	+	+	+
Anthopleura japonica [26: D]	9	4	6	1	5	1		+	+	+	
Anthopleura pacifica [14: E]	2	4	4		2	2		+	+	+	
Actinia equina [7: F]	2	2					3	+		+	+
Epiactis japonica [13: G]	9	3			1			+	+	+	
Flosmaris mutsuensis [3: H]		1			2				+	+	
Paracondylactis hertwigi [4: I]			1		3				+	+	
Urticina crassicornis [5: J]	4	1						+			
Isanthus capensis [2: K]			2							+	

Columns labeled ‘F’ show occurrences with fuzzy boundaries between the two regions on either side of the F column. Distributions are plotted in Figure 2.

This difference reflects two issues: the slight shift northward in the line between ES and the region adjacent to it in our scheme relative to the previous one, and the difficulty in determining the border precisely.

In addition to YS and ES, *Anthopleura japonica* (Fig. 2D) and *A. pacifica* (Fig. 2E) occur in both disjunct parts of cluster S1, but not in intervening cluster S2 (Table 2). Their disjunct distribution supports dividing KS into two regions, S1 and S2. The environmental similarity of Cheju Island and the part of the mainland coast immediately north of it is supported by the distribution of *Actinia equina* (Fig. 2F, Table 2), which was placed by Song & Cha (2002) into ES, KS, and CI, but in our analysis occurs only in S2 and ES plus the fuzzy boundary between S1 and ES.

We conclude that the previous schemes for classifying coastal biogeographic regions in Korea were based on biologically important features, especially tidal amplitude and SST. Like Kim (1986) and Song (1991), we found good correspondence between distribution of animals and these features. Having more detailed environmental data than they and the ability to do geospatial clustering, we were able to adjust the borders of the regions more precisely; we should be able to do an even better job with more finely gridded environmental data. Despite the sparse data on species occurrence and the coarseness of the 0.5° environmental data grid, this study confirms that geospatial clustering can be applied to range data for species within relatively small geographical ranges.

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