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Spatial pattern of intertidal macroalgal assemblages associated with tidal levels

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Abstract

The zonation pattern of macroalgal assemblages was investigated from December 1995 to October 1996 on a semi-exposed, rocky intertidal shore at Chungdori (southwestern Korea) based on quantitative and qualitative estimates of species occurrences in 31 permanent quadrats. Variation in cover associated with tidal levels was described for 30 species (that could be discerned with the unaided eyes) including three green, five brown and 22 red algae. Macroalgae inhabiting intertidal zone exhibited distinct zonation patterns. The number of species increased with decreasing intertidal height and was independent of season. The community was dominated by five species (*Gloiopeltis furcata*, *Gelidium divaricatum*, *Ulva pertusa*, *Sargassum horneri*, *Hizikia fusiformis*). The intertidal assemblage at the study site can be divided into two groups based on the number of species and the population structure with the division occurring at the critical level of 34 cm above MLW (mean low water). *Gloiopeltis furcata*, *Gelidium divaricatum*, *Sargassum thunbergii*, *Monostroma grevillei*, and *Myelophycus simplex* were more abundant in the upper shore zone and rapidly declined in abundance with depth, relative to all other species. *Gelidium amansii*, *Pachymeniopsis elliptica*, *Hizikia fusiformis*, *Gigartina intermedia*, *Laurencia* sp., *Chondrus ocellatus*, *Corallina* spp. and *Gigartina tenella* became more dominant in the lower shore zone.

Introduction

Studies of macroalgal zonation patterns in southwestern Korea (e.g., Lee & Boo, 1982; Boo & Choi, 1989; Choi et al., 1989; Lee et al., 1991; Choi et al., 1994) have previously been restricted to qualitative descriptions of species distribution and seasonal variation with little understanding of the roles of environmental factors.

Zonation patterns of macroalgal assemblage in general are recognized to be the result of the effects of biological factors such as competition and grazing as well as physical factors such as wave action, aerial exposure, irradiance, temperature range and time available for nutrient exchange (see Lobban & Harrison, 1994). Physical parameters are important in the determination of upper reaches where conditions become increasingly harsh for macroalgae (Mathieson et al., 1981; Dring, 1982; Underwood & Jernakoff, 1984; Seapy & Littler, 1993; Chapman, 1995). Numerous studies have also shown that biotic factors such as competition and predation set the lower limits to the zonation of rocky intertidal macroalgae (Santelices et al., 1981; Dethier, 1982; Underwood & Jernakoff, 1984; Wolfe & Harlin, 1988). However, some investigators reported that grazing could have a significant role in the determination of upper limits of macroalgae (Lubchenco, 1980; Santelices et al., 1981).

Here we describe the results of a detailed study of intertidal macroalgal distribution at Chungdori, on the southwestern limit of the Korean Peninsula. No comparable spectrum of rocky intertidal systems has previously been examined with the level of sampling effort and resolution of data undertaken in this study in Korea. The scope of this work is such that spatial variation of the macroalgal populations has been assessed in terms of tidal levels and species assemblages. The aims of our study are to describe the zonation patterns of macroalgae commonly found in this intertidal community and to collect information on the distribution and zonation pattern of the algae by studying the percent cover of the macroalgae in relation to intertidal levels.

The rocky intertidal shore of Chungdori is subject to exceptionally high harvesting pressure by local fishers. The excessive usage (e.g., collecting, cultivation, trampling) may stress this interface between land and sea, making it particularly sensitive to disturbance. This creates some unique conservation and management problems. Hence, an understanding of the zonation pattern of intertidal macroalgae in Chungdori is important, not only in terms of an assessment of Korean shores, but also in the context of general resource management in southwestern Korea.

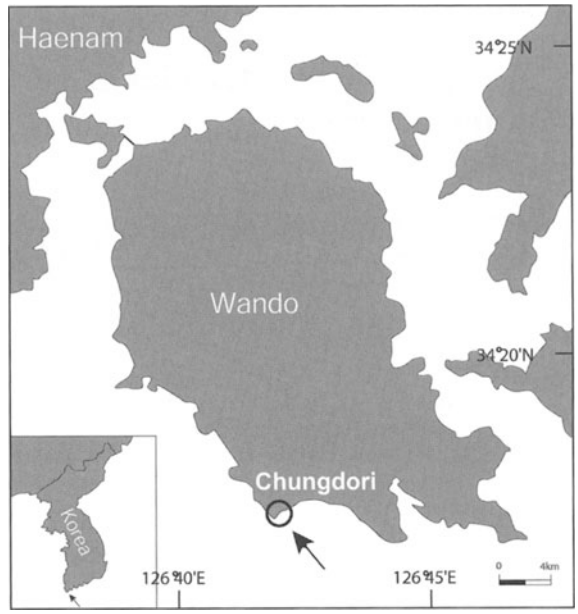

Figure 1. Map of Korea (insert) showing the general location of the study area (arrow) and Chungdori intertidal shores sampled in the present study (circle).

Study area

The study area is located on the southwestern coast of the Korean Peninsula (Fig. 1), on the south side of Wando Island (34° 17′ 59″ N, 126° 42′ 23″ E). The site is protected from oceanic wave surge but experiences strong tidal currents. The rocky intertidal zone consists of a platform, ca. 50 m in width, that extends from the base of a cliff to an abrupt drop-off into the subtidal zone.

The coast of Chungdori has a semi-diurnal tidal regime with a maximum tidal amplitude (at spring tide) of 3.2 m and a minimum (at neap tide) of less than 1.5 m (OHA ROK, 1995, 1996). Air temperature ranges from 2.4 °C in winter (February) to 26.3 °C in summer (August). There are large seasonal variations in rainfall with distinct dry and wet periods. From September to February average monthly rainfall normally does not exceed 100 mm. Monthly rainfalls are high from March to August (usually more than 80% of the total annual precipitation) with monthly rainfall frequently exceeding 150 mm. Monthly total hours of sunshine are higher during April and May (ca. 220 h per month) than during the rest of the year (80–200 h per month). Data on air temperature, rainfall and sunshine were obtained from the local meteorological institute (KMA, 1995, 1996). Seawater temperature varies from 7.5 °C (February) to 24.6 °C (August). Salinity is more or less stable throughout the year with extremes of 34.7‰ (May) and 32.7‰ (September).

Materials and methods

Qualitative and quantitative sampling of macroalgae was carried out from December 1995 to October 1996 using non-destructive permanent quadrat sampling. Seven censuses were performed at intervals ranging from 1 to 2 months. Thirty-one 50 × 50 cm randomly-scattered quadrats were sampled in the intertidal zone, spanning ca. 50 m of shore. The quadrat locations ranged from immediately above the highest intertidal level to just below the waterline at low water level.

To locate permanent quadrats, holes were drilled and metal studs cemented into the substratum at the upper and lower ends of the quadrats; this enabled the precise relocation of the quadrats during seasonal studies. Vertical height and emersion duration of each quadrat with respect to the mean low water (MLW) were determined (Table 1) using stadia rod, inclinometer and predictions of local tidal heights (OHA ROK, 1996). The difference in tidal height between the uppermost and lowermost quadrats was 126 cm.

Percent cover was used to quantify abundance of macroalgae. For every sample we identified species that could be discerned with the unaided eyes and visually estimated the cover of each species in a 0.25 m^2 quadrat. To aid estimate of % cover, each quadrat was subdivided into 25, 10 × 10 cm subquadrats us-

Table 1. Tidal height of the permanent quadrats above mean lower water (MLW) and emersion duration per day as measured in February 1996

Quadrat no.	Tidal height above MLW (cm)	Emersion duration hours/day (h:m)
1	101.0	12:04
2	100.6	12:00
3	94.0	11:45
4	80.2	11:14
5	80.2	11:14
6	79.8	11:10
7	77.5	11:05
8	76.3	11:01
9	67.9	10:41
10	66.4	10:37
11	65.8	10:35
12	61.8	10:25
13	57.4	10:12
14	54.8	10:05
15	43.8	9:41
16	39.9	9:30
17	36.9	9:21
18	34.0	9:12
19	30.3	9:01
20	30.3	9:01
21	18.4	8:30
22	17.5	8:26
23	15.2	8:18
24	12.3	8:10
25	10.1	8:03
26	7.3	7:55
27	6.0	7:51
28	3.1	7:41
29	0.5	7:32
30	−7.8	7:07
31	−25.1	6:11

ing nylon thread. Percent cover for each taxon was determined by dividing the number of subquadrats occupied by the total number of subquadrats. Species which were observed within a subquadrat but did not (cover) half the space were arbitrarily assigned a cover value of 0.1. The present study was based on undisturbed, repetitively sampled quadrat data collected over a year at a single site. In addition, a photographimetric method modified from Littler & Littler (1985) had the advantage of being rapid and simple to use, thus enabling a greater number of samples to be taken per unit of time. When macroalgal assemblages had multiple layers, more than one photograph per quadrat was taken to quantify each stratum after upper strata had successively been moved aside. The only organisms removed from the permanent undisturbed quadrats were very small samples taken occasionally for purposes of identification.

Mean covers of each taxon were computed over the entire sampling period for use in plotting kite diagrams of taxon abundance as a function of tidal height. Significance of the vertical distribution pattern of the macroalgal assemblage was determined by a skew statistic using % cover data obtained from permanent quadrats. The Monte Carlo method was used for determining significances of skews (Sheppard, 1995a). The Monte Carlo method computes 1000 simulations, after which it is noted whether the real value falls within the most extreme 5% of the range of simulations (see Sheppard, 1995a, b). In the skew diagrams each horizontal line represents the skew of a species. Species were arranged (top to bottom) in the order of greatest skew towards the upper zone to greatest skew at the lower intertidal zone.

Results

Our observations were restricted to 30 macroalgae that could be discerned with the unaided eyes. Thirty species were present in the permanent quadrats, of which 22 were red, five brown and three green algae (Table 2). Species number showed only minor seasonal variation over the study period and ranged from 19 (May) to 24 (February) (Table 2). One green alga (*Ulva pertusa*), two brown algae (*Hizikia fusiformis* and *Sargassum thunbergii*) and nine red algae (*Gelidium amansii, G. divaricatum, Corallina* spp., *Carpopeltis affinis, Pachymeniopsis elliptica, Gloiopeltis furcata, Chondrus ocellatus, Gigartina tenella* and *Laurencia* sp.) were found throughout the entire sampling period.

The number of species varied in relation to tidal height (Fig. 2). The intertidal zone can be divided into two zones based on species number with the division occurring at quadrat No. 18, 34 cm above MLW. The lower zone (between 30 cm above MLW and 25 cm below MLW) showed much higher species number than the upper zone (between 34 cm and 101 cm above MLW). Accordingly, over the entire sampling period means of 4 and 12 species were present in the upper and lower intertidal zones. Macroalgal abundances were also unevenly distributed over the vertical range of the sampled intertidal, cover being much higher in

Table 2. Seasonality of 30 macroalgae at Chungdori, southwestern coast of Korea, between December 1995 and October 1996

Taxa	Dec	Jan	Feb	Apr	May	Jul	Oct
Green algae							
Monostroma grevillei Wittrock		+	+	+	+	+	+
Ulva pertusa Kjellman	+	+	+	+	+	+	+
Codium adhaerens (Cabrera) C. Agardh	+	+	+			+	
Brown algae							
Leathesia difformis (L.) Areschoug			+				
Ishige okamurae Yendo	+					+	+
Myelophycus simplex (Harvey) Papenfuss		+	+	+	+	+	+
Hizikia fusiformis (Harvey) Okamura	+	+	+	+	+	+	+
Sargassum thunbergii (Roth) Kuntze	+	+	+	+	+	+	+
Red algae							
Porphyra sp.				+			
Gelidium amansii (Lamouroux) Lamouroux	+	+	+	+	+	+	+
Gelidium divaricatum Martens	+	+	+	+	+	+	+
Gelidium sp.							+
Pterocladia capillacea (Gmelin) Bornet	+	+	+	+	+		
Corallina spp.	+	+	+	+	+	+	+
Carpopeltis affinis (Harvey) Okamura	+	+	+	+	+	+	+
Carpopeltis cornea (Okamura) Okamura			+	+		+	+
Grateloupia turuturu Yamada					+		
Pachymeniopsis elliptica (Holmes) Yamada	+	+	+	+	+	+	+
Prionitis patens Okamura	+						
Gloiopeltis furcata (Postels et Ruprecht) J. Agardh	+	+	+	+	+	+	+
Callophyllis adhaerens Yamada			+	+			
Gracilaria verrucosa (Hudson) Papenfuss	+	+					
Gymnogongrus flabellifomis Harvey	+	+	+	+	+		
Chondrus ocellatus Holmes	+	+	+	+	+	+	+
Gigartina intermedia Suringar	+	+	+	+		+	+
Gigartina tenella Harvey	+	+	+	+	+	+	+
Campylaephora hypnaeoides J. Agardh					+		
Acrosorium uncinatum (Turner) Kylin	+	+	+			+	+
Laurencia sp.	+	+	+	+	+	+	+
Symphyocladia latiuscula (Harvey) Yamada	+	+	+		+	+	+

the lower region (Fig. 3). The mean cover of macroalgae was 39.1% and 69.6% in the upper and lower zones, respectively, over the whole assessment period (Fig. 3).

The highest cover was contributed by the brown alga, *Hizikia fusiformis* (16.7%). Only four other species contributed mean cover values over the study period greater than 2.0%, two turf-forming red algae, *Gloiopeltis furcata* (10.7%) and *Gelidium divaricatum* (5.6%), the brown alga *Sargassum thunbergii* (5.7%) and the sheet-like green alga, *Ulva pertusa* (5.6%).

Macroalgal cover was averaged over the study period as a function of intertidal height to depict prevailing patterns of zonation (Fig. 4). The upper zone was dominated by *Gloiopeltis furcata, Gelidium divaricatum* and *Ulva pertusa*. Other upper zone species, *Sargassum thunbergii* and *Hizikia fusiformis*, generally occurred in the upper intertidal, although they were present throughout the entire vertical range. *Pachymeniopsis elliptica*, *Chondrus ocellatus*, *Gigartina tenella* and *Laurencia* sp. were restricted to the lower region, especially the lowermost part which was dominated by *Gelidium amansii*.

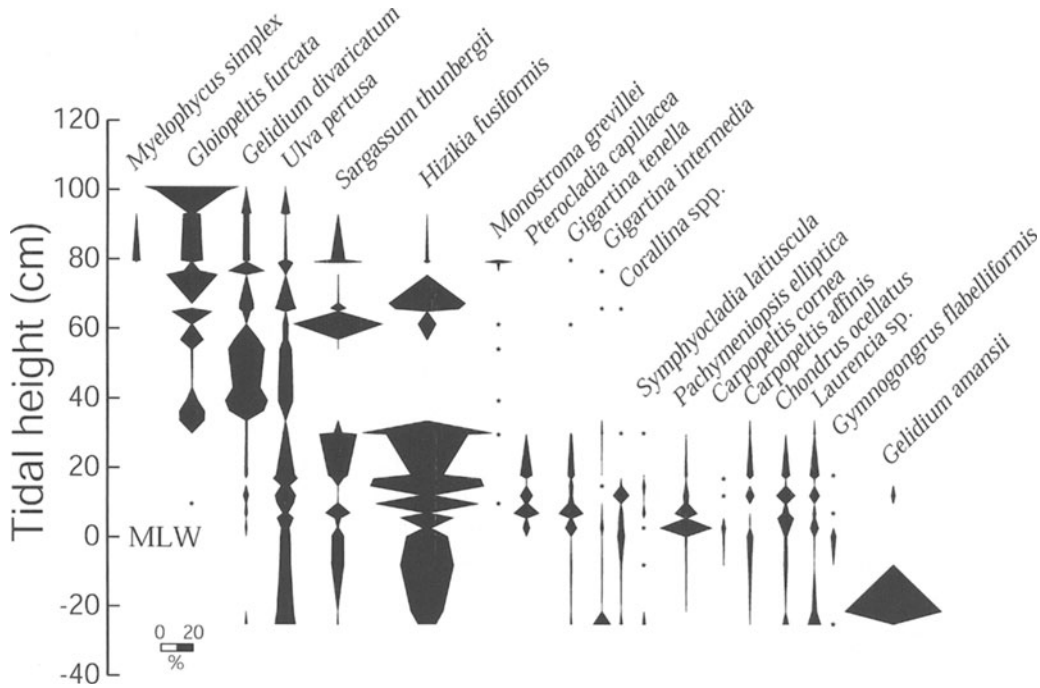

Figure 4. Kite diagram illustrating the abundance (% cover) and distribution of 19 macroalgae on the Chungdori intertidal zone. Cover values below 0.1% are designated with *.

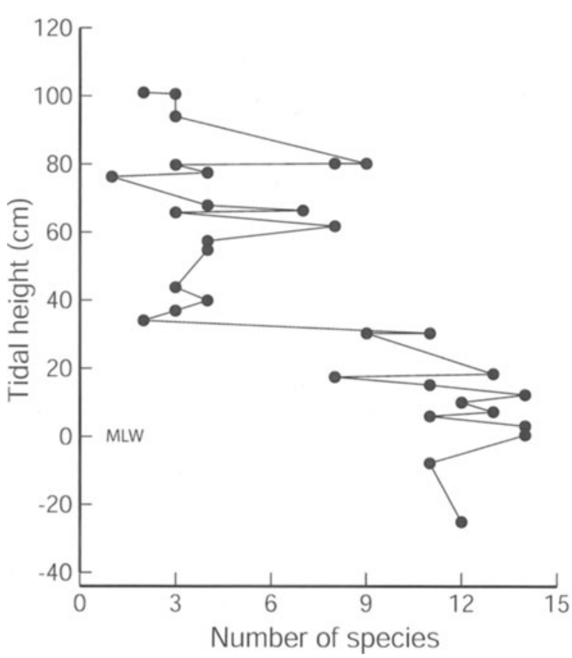

Figure 2. The number of species for each permanent quadrat along the tidal levels.

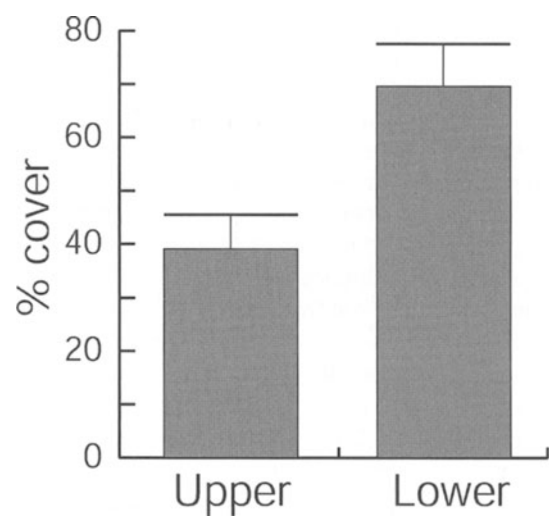

Figure 3. Mean differences in macroalgal cover (± S.D; $n = 7$) associated with different tidal levels.

Patterns of zonation were determined objectively by skew analysis of the permanent quadrat samples using the % cover data for the macroalgal assemblages (Fig. 5). The red alga *Gloiopeltis furcata* showed a strong skew ($p < 0.05$) towards upper zone while *Gelidium amansii* showed an equally strong and significant skew to the lower intertidal zone. Other upper shore species such as *Gelidium divaricatum*, *Sargassum thunbergii*, *Monostroma grevillei* and *Myelophycus simplex*, and seven other lower species also showed significant skews to the upper and lower zones, respectively.

Discussion

Previous observations at several localities on the southwestern coast of Korea suggest that *Gloiopeltis furcata*, *Gelidium divaricatum*, *Ulva pertusa*, *Caulacanthus okamurae* and *Enteromorpha* spp. are dominant in the high intertidal zone, and *Ulva pertusa*, *Chondria crassicaulis* and *Sargassum thunbergii* in the mid intertidal zone. The lower intertidal zone is dominated by *Sargassum thunbergii*, *Ulva pertusa*, *Corallina* spp. *Sargassum* spp., *Ecklonia cava* and *Undaria pinnatifida*, and most of these species appear to be able to grow in the subtidal zone (Kang et al., 1980; Lee & Boo, 1982; Lee et al., 1983, 1991; Boo & Choi, 1989; Choi et al., 1989, 1994; Kim & Lee, 1995; Kim, 1999).

Past studies on the macroalgae at the present site have only consisted of qualitative observations (e.g., Choi et al., 1989), and recorded a total of 119 macroalgal taxa in the intertidal zone. Although we considered 30 taxa as representative of the macroalgal assemblage in this study, there were no previously unreported species. In addition, species occurring in this study were also common in the intertidal zone along the southwestern coast of Korea. Kim (1999) suggested that differences in intertidal macroalgal assemblages on the southwestern coast of Korea were caused by differences in substrate stability and suspended sediments. The substrata of the study site consist primarily of massive bed rocks with relatively low turbidity waters. This may permit a high diversity of macroalgae in this study site.

There was a large spatial difference in species number from the macroalgal assemblage of Chungdori, the number being higher in the low tidal zone. The subdivision of the intertidal zone into upper and lower zones can be partly correlated with the gradient of physical factors such as emersion: immersion duration, and possibly tolerance of desiccation. The algae in the upper zone experience more than 9 h per day of aerial exposure suggesting harsh physical factors prevail in this zone during low tides, which may explain why this zone is composed of only a few algae.

In contrast to the relatively poor macroalgal cover on the southwestern coast of Korea (see Kim, 1999), the cover at this study site was relatively high and, as discussed above, it was likely to be effected by substrate condition supporting the macroalgal assemblage. There was also a dramatic decrease in the percent cover of macroalgae with increasing tidal heights. Especially, the cover value abruptly increased in the lower zone (between 30 cm above MLW and 25 cm below MLW). Spatial changes of the abundance may also be related to a critical time for emersion duration.

Most of the macroalgal cover in the upper zone consisted of turf-forming growths of *Gloiopeltis furcata* and *Gelidium divaricatum*, and the thick leathery brown algae *Sargassum thunbergii* and *Hizikia fusiformis*. *Gelidium amansii* as well as *Hizikia fusiformis* were generally found in the lower zone. The overall zonation pattern described above matches well with previous reports in other locations, e.g. Uido Island (Choi et al., 1994), Neobdo Island (Kim & Lee, 1995) and Hawon-Pando (Kim, 1999) on the southwestern coast of Korea. However, *H. fusiformis*, *Ulva pertusa* and *S. thunbergii* can extend their vertical distribution substantially, modifying the limits of intertidal algal zonation.

Kite diagrams are historically perhaps the most common way to show zonation patterns along rocky shores. However, these methods do not by themselves show whether or not the distributions are statistically significant. Skew analysis reflects the zonation pattern observed in the present study site. The vertical distribution of some intertidal macroalgae at Chungdori can be assigned significantly into the upper zone or lower zone. *Gloiopeltis furcata*, *Gelidium divaricatum*, *Sargassum thunbergii*, *Monostroma grevillei* and *Myelophycus simplex* can be assigned to the upper zone, with *Gelidium amansii* and seven other species to the lower zone.

Other studies of macroalgal community on the southwest and south coasts of Korea showed fairly dramatic seasonal fluctuations in the abundance of macroalgal species inhabiting rocky shore (Lee et al., 1991; Choi et al., 1994; Kim et al., 1998; Kim, 1999). The greater seasonal variation observed by all of these authors may be explained by greater changes of air and water temperatures in their study areas. The rocky intertidal zone of Chungdori received little direct solar radiation due to shading by the cliff on the western side of the site. The presence of the cliff may explain why the abundance of macroalgae showed only minor

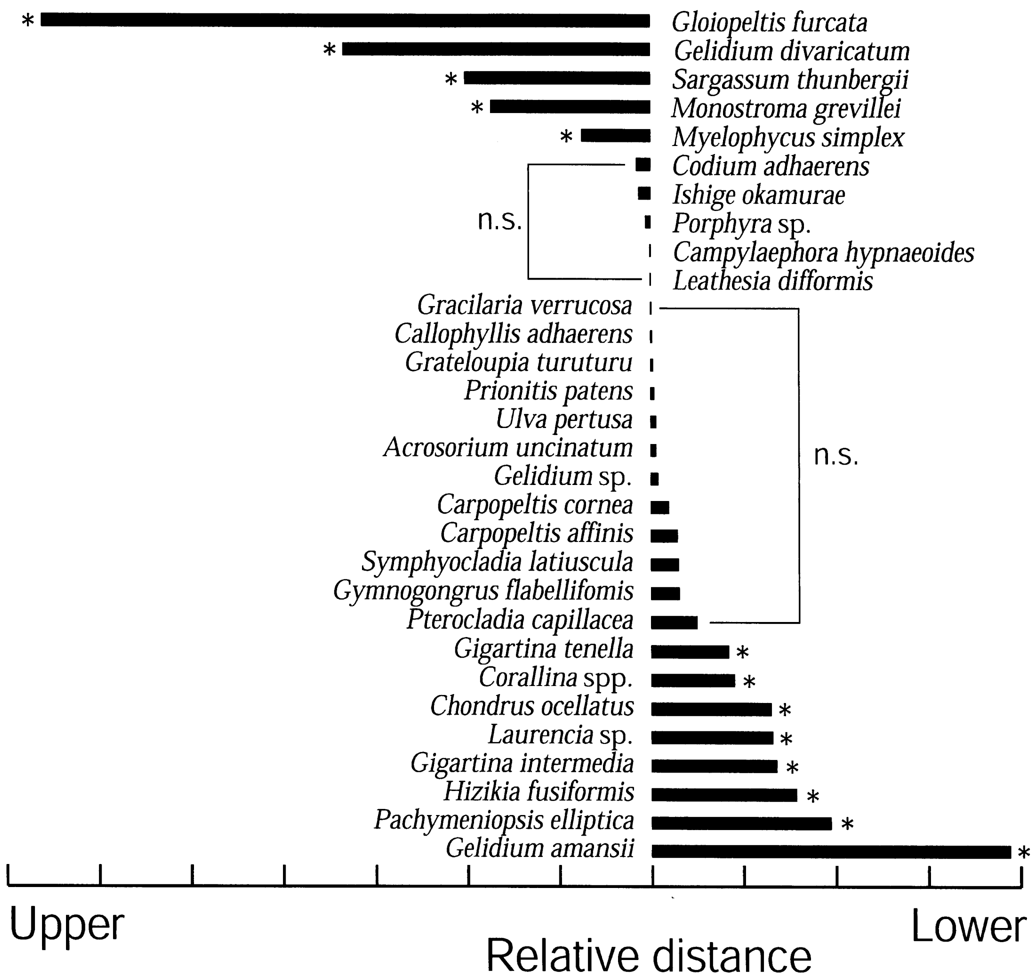

Figure 5. Skew diagram of quantitative distribution of 30 macroalgae along the tidal levels on the Chungdori intertidal zone. The results of Monte Carlo statistics for species distribution along the tidal levels are shown. Level of significance: $p < 0.05$, n.s.: not significant.

seasonal variation within permanent quadrats over the study period.

Based on the review of intertidal community structure in Korea, this study represents the most thorough investigation to date of ecological descriptions in understanding the structure of a rocky intertidal community. Although the roles of competition, predation and recruitment in determining algal zonation patterns in this study were not investigated, these factors probably accounted for the spatial and temporal distribution patterns at this site.

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