

DIVERSITY AND DISTRIBUTION OF MACROALGAE ASSOCIATED WITH ABALONE (*HALIOTIS* SPP.) HABITATS IN BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

Species diversity and distribution of macroalgae associated with abalone banks along the Pacific coast of Baja California Sur (B.C.S.) between Bahía Tortugas and Bahía Magdalena were studied. Six cooperative fishing areas (C) within the official fishing zones of B.C.S. were sampled. A total of 79 taxa was identified. Species richness by locality ranged from 12 taxa in C2–56 in the southernmost locality (C6). Diversity measures based on information theory (H') in the assemblages ranged from 2.83–4.85 in C2 and C6, respectively. However, a relative diversity index (J') showed C3 to be the most homogeneous assemblage ($S = 26$) with a maximum value of 0.878. This reflected in part the distribution of the important (frequent) species. Phaeophytes had overall higher frequencies, while rhodophytes showed the greatest number of taxa (58). Ten taxa had relative frequencies higher than three percent and were considered the most important taxa in the abalone habitats surveyed, mainly: *Eisenia arborea*, *Cystoseira osmundacea*, *Corallina officinalis* var. *chilensis*, *Gelidium robustum* and *Plocamium cartilagineum*. Classification analysis based on presence–absence of species roughly distinguished two groups; the first represented by cooperatives 1–4 and the second by C5 and C6, although at low similarity (Jaccard) levels. Considering species importance in the analysis (Morisita's index) a different classification resulted. The divergence of the groups may be due to differences in sampling dates, while the correspondence of assemblages from different dates indicates mainly sharing of important (long-lived) species (*E. arborea*, *C. osmundacea*, *C. officinalis* var. *chilensis*). The important taxa and species richness are the factors determining latitudinal structure variation.

Macroalgal species in marine rocky habitats play an important role in the life cycle of associated organisms, providing both shelter and their main food source. In their natural habitat, abalone (*Haliotis* spp.) feed chiefly on macroalgae after they have reached a size > 10 mm (Cox, 1962; Kawamura et al., 1995; 1998). Smaller abalones depend mostly on benthic diatoms for food (Ebert and Houk, 1984).

Different species of abalone are distributed worldwide and the macroalgae composition differs likewise. Brown and red algae are the main food sources and their proportions vary from one locality to another (Shepherd and Steinberg, 1992). In the wild, the diet of the abalone varies depending on the available macroalga species in their habitat (Leighton and Boolotian, 1963; Guzmán del Prío et al., 1972; 1991; Poore, 1972; Shepherd and Womersley, 1976; Barkai and Griffiths, 1986; Tutschulte and Connell, 1988; Serviere-Zaragoza et al., 1998).

In southern California, the principal components of the abalone habitat include brown algae such as *Macrocystis pyrifera* (L.) C. Ag., *Pelagophycus porra* (Lem.) Setch., *Laminaria farlowii* Setch., *Pterygophora californica* Rupr., *Egregia menziesii* (Turn.) Aresh., *Eisenia arborea* Aresh. and *Cystoseira osmundacea* (Turn.) C. Ag.; red algae, include articulated and crustose coralline algae, *Rhodymenia* spp., *Gelidium* spp., *Gigartina* spp., and *Plocamium* spp. (Dawson, 1960). Green algae do not represent a conspicuous part of

the algal flora of the near-shore areas south of Point Conception, California (Leighton, 1968).

Farther south along the Baja California coast the principal available macroflora of the abalone habitat is represented by brown algae *M. pyrifera*, *E. arborea* and other Laminariales; red algae: *Gelidium* spp., *Acrosorium* spp. and *Plocamium* spp., articulated coralline algae: *Bossiella orbigniana* (Dec.) Silva, *Corallina officinalis* L., *C. pinnatifolia* (Manza) Daws.; and the crustose corallines, *Lithothamnium* spp. and *Lithophyllum* spp.; the seagrass *Phyllospadix torreyi* S. Watson is also common (Guzmán del Prío et al., 1972; 1991). However, until now no floristic inventory was available for the abalone habitats in Baja California Sur (B.C.S.) that served as a reliable reference.

Four species of abalone can be found along the Pacific coast of Baha California Sur: *Haliotis fulgens* Philippi (green abalone), *H. corrugata* Wood (pink abalone), *H. cracherodii* Leach (black abalone) and *H. sorenseni* Bartsch (white abalone). Most of the Mexican abalone fisheries are based on the first species (Lelevier-Grijalva et al., 1989; Ramade et al., 1998). Northern hemisphere abalone feed primarily on the larger laminarian brown algae, although many species of red and green algae are also consumed (Leighton, 2000). Three species of Laminariales are used as principal feeds for abalone in aquacultural farms in California, Baja California, and Baja California Sur: *Egredia menziesii*, *Macrocystis pyrifera* and *Nereocystis luetkeana* (MacBride, 1998). In California, *Macrocystis* is a valuable food for young red abalone, but not for green abalone (Leighton, 1989); whereas, *Egredia* is effectively consumed by both species and is the diet of choice for feeding cultured green abalone (Leighton et al., 1981). In Mexico, the majority of feeding requirements for abalone rearing are met adequately with *Macrocystis*. There is currently little available information on abalone growth using specific algal diets in B.C.S. (Serviere-Zaragoza et al., 2001).

Kelp availability year round has not generally been a problem for abalone aquaculturists. Difficulties have occurred during El Niño events, which cause the widespread destruction of *M. pyrifera* populations (MacBride, 1998; Ladah et al., 1999). It is necessary to determine which macroalgae species are available for each species of abalone and to assess their usefulness on the basis of controlled feeding and growth experiments. This will allow selection of adequate food sources for abalone under culture conditions. Recently, Serviere-Zaragoza et al. (1998) determined that the main components of macrophyte species in the gut contents of *H. fulgens* in B.C.S. were *E. arborea*, *Sargassum* sp., *Cryptopleura crista* Kylin, *Rhodomenia* sp. and the sea-grass *Phyllospadix torreyi*. The present study provides the first floristic inventory of macroalgae associated with abalone banks and describes their geographic distribution along the southern part of abalone range in BCS, Mexico. The study area includes two sites with *Macrocystis* beds and sites largely beyond its current distribution southerly.

STUDY AREA

The study area is located on the Pacific coast of Baja California in the southern part of the range of abalones, between Bahía Tortugas (27° 41.3' N and 114° 53.6' W) and Bahía Magdalena (24° 15' N and 111° 15' W). This includes three (II, III, IV) of the four fishing zones defined under governmental administrative management for the Baja California peninsula on the basis of differences in abalone growth and reproductive patterns (Fig. 1).

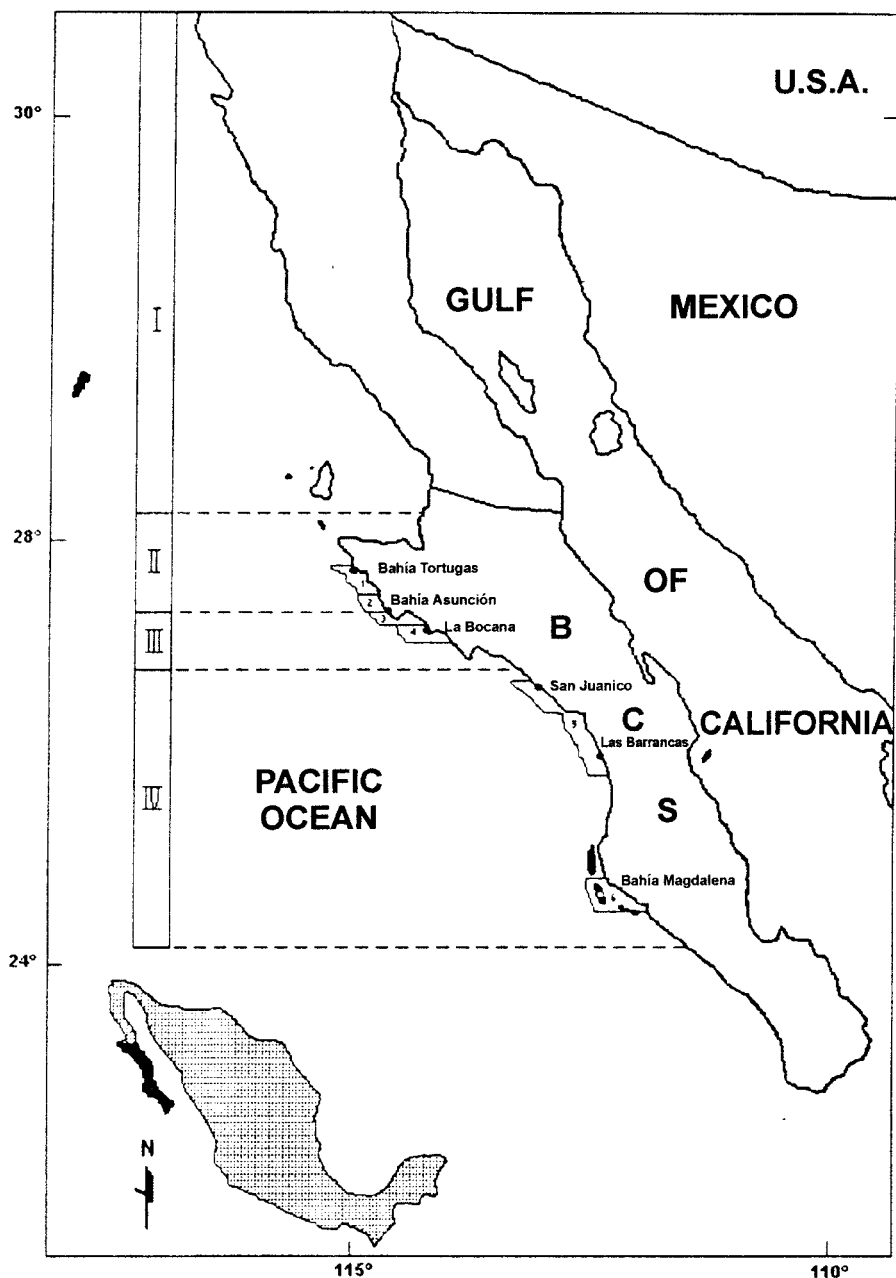


Figure 1. Sampling zones along Baja California Sur, Mexico. Zone II: 1 = Sociedad Cooperativa de Producción Pesquera Emancipación and 2 = S.C.P.P. California - San Ignacio. Zone III: 3 = S.C.P.P. Leyes de Reforma and 4 = S.C.P.P. Progreso. Zone IV: 5 = S.C.P.P. Puerto Chale and 6 = S.C.P.P. Magdalena.

MATERIALS AND METHODS

Sampling was carried out during the 1995 and 1996 annual evaluations of the Centro Regional de Investigaciones Pesqueras (CRIP-La Paz) program for abalone banks off the west coast of B.C.S. (León-Carballo and Munciño-Díaz, 1996). The sampling strategy during the abalone evaluations consisted of a random stratified sampling by blocks. Six fishing areas were surveyed at the same season (winter), each falling within the boundaries of the abalone fishing areas (cooperatives) located within the three fishing zones of B.C.S.: Zone II, Sociedad Cooperativa de Producción Pesquera (S.C.P.P.) Emancipación (C1, March 1995), and S.C.P.P. California-San Ignacio (C2, January 1996); Zone III, S.C.P.P. Leyes de Reforma (C3, February 1995), and S.C.P.P. Progreso (C4, January 1996), and Zone IV, S.C.P.P. Puerto Chale (C5, March 1996), and S.C.P.P. Bahía Magdalena (C6, March 1995; Fig. 1). At each cooperative, blocks 500 m long were defined parallel to the coast and along the intertidal and subtidal zones according to the length of the banks (0.9–17 m depth). At each block, an average of five random samples of 2×5 m were collected. In the sampling units (10 m²), representatives of each taxon observed were collected by divers using surface-supplied air. The material was deposited in plastic bags and fixed with a four percent formaldehyde-seawater solution. The numbers of blocks and sampling units were determined by the feasibility (environmental conditions) of work during five days. A total of 285 samples was collected.

Taxonomic determinations were based on external morphology, anatomy and reproductive structures observed under the microscope. The following references were used: Setchell and Gardner (1920), Dawson (1953; 1954; 1960; 1961; 1963a; 1963b), Abbott and Hollenberg (1976), Norris and Johansen (1981), Santelices and Hommersand (1997), and Riosmena Rodríguez and Siqueiros-Beltrones (1996).

The distribution for each taxon was recorded by fishing area (C1–C6) and their relative frequencies (RF) were determined likewise and for the whole area (total relative frequency, TRF). Frequencies were used to analyze the structure of the assemblages based on the information theory. Species diversity was estimated using Shannon's H' (\log_2) and a redundancy measurement ($1-J'$) was used as an estimate of dominance in the assemblages. These calculations consider both the species richness as well as the equitability (J' , or relative diversity) in their frequencies (Brower and Zar, 1984). The degree of similarity between cooperatives was measured on the basis of presence/absence of species using Jaccard's index, and Morisita's index which considers also their relative frequency (importance) in the assemblages (Magurran, 1988). These values were used to generate similarity dendrograms based on the classification module UPGMA according to the AnaCom (Community Analysis) package (De la Cruz Agüero, 1994).

RESULTS

SPECIES DIVERSITY.—Seventy-nine species of epilithic macroalgae associated with abalone banks were identified. Rhodophytes were highest in species richness with 54 species and four varieties. The rest of the macroalgae included 15 species of phaeophytes and six chlorophytes. The genera *Gelidium*, *Prionitis*, *Laurencia* and *Dictyota* with four species each were the best represented (Table 1). Macroalgae were collected mainly from rocky substratum with variable characteristics, most showing crevices, which offer protection to the abalone.

Relatively high values of diversity (H') were measured ranging from 2.83 (C2)–4.85 (C6), corresponding to the lowest and highest number of species (S), respectively. The highest value of relative diversity (J' , 0.878) and lower redundancy (dominance, 0.122) were observed in C3. This may be explained in terms of more important (frequent), or co-dominant taxa present in the assemblage (12) and $S = 26$. While in C2 the assemblage was dominated by few taxa (*Cystoseira osmundacea*, *Eisenia arborea*, *Macrocystis*

Table 1. Relative frequencies (RF) and total relative frequencies (TRF) of macroalgae species associated with abalone banks, and values of diversity of the assemblages by cooperative in B.C.S., Mexico. 1. Sociedad Cooperativa de Producción Pesquera (S.C.P.P.) Emancipación, 2. S.C.P.P. California - San Ignacio, 3. S.C.P.P. Leyes de Reforma, 4. S.C.P.P. Progreso, 5. S.C.P.P. Puerto Chale, 6. S.C.P.P. Magdalena. * = highly frequent species in the region.

Species/Cooperative	Zone II		Zone III		Zone IV		Total area
	1	2	3	4	5	6	
	RF	RF	RF	RF	RF	RF	TRF
Chlorophyta							
<i>Bryopsis pennata</i> Lamouroux var. <i>minor</i> J. Agardh						0.6	0.2
<i>Caulerpa fastigiata</i> Montagne						0.6	0.2
<i>Chaetomorpha antennina</i> (Bory de Saint-Vincent) Kützting						0.3	0.1
<i>Codium cuneatum</i> Setchell & Gardner		1.7	4.2	1.1	0.6		1.0
<i>Ulva californica</i> Wille						0.6	0.2
<i>Ulva taeniata</i> (Setchell) Setchell & Gardner				1.1		0.3	0.2
Phaeophyta							
* <i>Cystoseira osmundacea</i> (Turner) C. Agardh	8.2	20.3	17.8	22.0	5.8		9.0
<i>Dictyopteris undulata</i> Holmes						4.5	1.6
<i>Dictyota bartayresiana</i> Lamouroux						1.8	0.6
<i>D. binghamiae</i> J. Agardh						0.3	0.1
<i>D. divaricata</i> Lamouroux						3.3	1.2
<i>D. flabellata</i> (Collins) Setchell & Gardner	2.3	29.7	9.3	20.0	26.6	1.2	0.4
* <i>Eisenia arborea</i> Areschoug	1.2	7.6				12.9	17.0
<i>Macrocystis pyrifera</i> (Linnaeus) C. Agardh			0.8				1.0
<i>Pachydiction coriaceum</i> (Holmes) Okamura					2.3	0.3	0.2
<i>Padina caulescens</i> Thivy						0.6	0.6
<i>P. crispata</i> Thivy						0.3	0.1
<i>P. durvillaei</i> Bory de Saint-Vincent			0.8			1.2	0.5
<i>Sargassum horridum</i> Setchell & Gardner	2.3		2.5				0.5
* <i>S. sinicola</i> Setchell & Gardner		1.7		8.4	7.5	2.7	3.5
* <i>Spatoglossum howellii</i> Setchell & Gardner					15.0	1.5	3.4

Table 1. Continued.

Species/Cooperative	Zone II		Zone III		Zone IV		Total area
	1	2	3	4	5	6	
	RF	RF	RF	RF	RF	RF	TRF
Phaeophyta							
<i>Daya pedicellata</i> (C. Agardh) C. Agardh var. <i>nudicaulis</i> Dawson					1.7	0.9	0.6
<i>Erythrocyctis saccata</i> (J. Agardh) Silva						0.3	0.1
Rhodophyta							
<i>Acrosorium venulosum</i> (Zanardini) Kylin					5.2	1.5	1.4
<i>Ahnfeltiopsis concinna</i> (J. Agardh) Silva & DeCew	1.2		0.6		0.3		0.3
<i>Amphiroa beauvoisii</i> Lamouroux			4.2				0.5
<i>A. misakiensis</i> Yendo			0.8	2.1	1.2	1.2	1.0
<i>A. vanbosseae</i> Lemoine					1.2	0.3	0.3
<i>Bossiaella orbigniana</i> (Decaisne) Silva	10.6	2.5	3.4	2.1			2.0
<i>Callophyllis violacea</i> J. Agardh var. <i>epiphytica</i> Dawson	1.2	0.8	0.8			0.9	0.6
<i>Carpopeltis bushiae</i> (Farlow) Kylin					1.2		0.3
<i>Ceramium procumbens</i> Setchell & Gardner	1.2						0.2
<i>Coeloseira parva</i> Hollenberg						0.3	0.1
* <i>Corallina officinalis</i> Linnaeus var. <i>chilensis</i> (Decaisne) Kützing		14.4	5.9	6.3	3.5	9.9	7.5
<i>C. polysticha</i> Dawson						0.3	0.1
* <i>C. vancouveriensis</i> Yendo	16.5		10.2	2.1		1.5	3.6
<i>Cryptopleura corallinara</i> (Nott) Gardner			1.7	2.1			0.4
* <i>C. crispa</i> Kylin	14.1		4.2	2.1	4.0	1.8	3.5
<i>C. dichotoma</i> Gardner						0.3	0.1
<i>Chondria nidifica</i> Harvey					3.5	0.6	0.9

Table 1. Continued.

Species/Cooperative	Zone II		Zone III		Zone IV		Total area
	1 RF	2 RF	3 RF	4 RF	5 RF	6 RF	
Rhodophyta							
<i>Gelidiopsis variabilis</i> (Greville) Schmitz						0.6	0.2
<i>Gelidium nudifrons</i> Gardner				8.4		2.4	1.7
<i>G. purpurascens</i> Gardner						5.1	1.8
<i>G. pusillum</i> (Stackhouse) Le Jolis						0.3	0.1
* <i>G. robustum</i> (Gardner) Hollenberg & Abbott	25.9	13.6	8.5		2.3	4.8	7.4
<i>Gracilaria textorii</i> (Suringar) De Toni var. <i>cunninghamii</i> (Farlow) Dawson			2.5	1.1	1.7	0.3	0.9
<i>G. veleroae</i> Dawson					0.6		0.1
<i>Gracilariopsis lemaneiformis</i> (Bory de Saint- Vicent) Dawson, Acleto and Folvick					2.9		0.5
<i>Gymnogongrus martinensis</i> Setchell & Gardner	1.2		3.8		1.8		0.3
<i>G. chiton</i> (Home) Silva & DeCew					2.3		0.8
<i>Gymnogongrus</i> sp.					1.2	0.3	0.4
<i>Haliptilon gracile</i> (Lamouroux) Johansen	2.3		0.8				0.3
<i>Herposiphonia plumula</i> (J. Agardh) Hollenberg						1.2	0.4
<i>Heterosiphonia erecta</i> Gardner			0.8			1.2	0.5
<i>Hypnea johnstonii</i> Setchell & Gardner						0.3	0.1
<i>Jania crassa</i> Lamouroux					0.6		0.1
<i>Laurencia gardneri</i> Hollenberg						0.3	0.1
<i>L. masonii</i> Setchell & Gardner						0.6	0.2
<i>L. pacifica</i> Kylin						0.6	0.2
<i>L. snyderiae</i> Dawson						1.2	0.4
<i>Leptocladia binghamiae</i> J. Agardh				5.3			0.5
<i>Leptofaucheia pacifica</i> Dawson			0.8				0.1
<i>Mazzaella affinis</i> (Harvey) Fredericq				1.1			0.1
<i>Nienburgia anderssoniana</i> (J. Agardh) Kylin	1.2			1.1		0.3	0.3

Table 1. Continued.

ZONE		Zone II			Zone III			Zone IV			Total area
Species/Cooperative		1	2		3	4		5	6		TRF
		RF	RF		RF	RF		RF	RF		
Rhodophyta											
<i>Ozophora clevelandii</i> (Farlow) Abbott					0.85						0.1
* <i>Plocamium cartilagineum</i> (Linnaeus) Dixon		2.3	5.1		3.4	1.1		1.7	7.8		4.6
<i>Porphyra perforata</i> J. Agardh		1.2									0.1
<i>Prionitis cornea</i> (Okamura) Dawson		1.2			1.7				0.9		0.6
<i>P. filiformis</i> Kylin			0.8						4.2		1.6
* <i>P. lanceolata</i> (Harvey) Harvey		2.3	1.7		2.5	5.3			5.4		3.2
<i>P. linearis</i> Kylin								2.3	0.9		0.8
<i>Pterocladiaella capillacea</i> (Gmelin) Santelices & Hommersand									5.7		2.1
<i>Pterosiphonia dendroidea</i> (Montagne) Falkenberg									0.3		0.1
<i>Reticulobotrys catalinae</i> Dawson									0.3		0.1
<i>Rhodomenia californica</i> Kylin		2.3							1.5		0.8
<i>R. dawsonii</i> Taylor						6.3		2.3	0.3		1.2
<i>R. pacifica</i> Kylin		1.2			2.5						0.4
<i>Tayloriella borealis</i> (Dawson) Dawson								0.6			0.1
<i>Weeksia howellii</i> Setchell & Gardner					4.0						0.4
Number of species		20	12		26	19		27	56		
Number of samplings		31	40		32	24		70	88		
Diversity (H')		3.41	2.83		4.13	3.53		3.88	4.85		
Relative diversity (J')		0.790	0.789		0.878	0.831		0.817	0.836		
Redundancy (1 - J')		0.210	0.211		0.122	0.169		0.173	0.164		

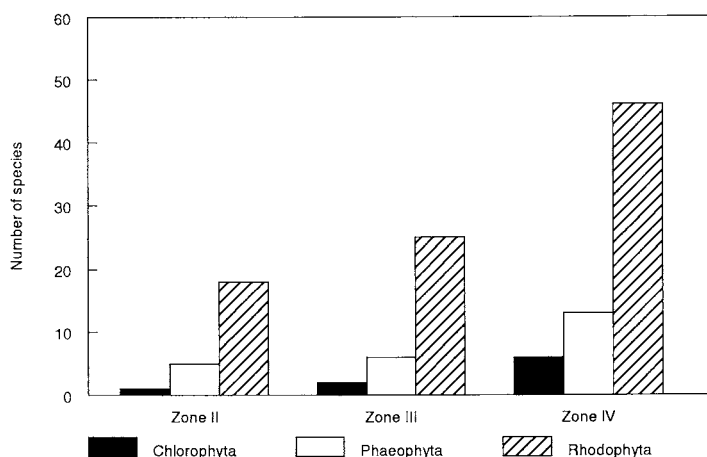


Figure 2. Number of species of macroalgae by zone along the coasts of Baja California Sur, Mexico.

pyrifer, *Corallina officinalis* var. *chilensis*, *Gelidium robustum* and *Plocamium cartilagineum*), C6 showed a typical diverse association with few (nine) highly frequent species vs. many less frequent taxa, and many (22) rare ones.

DISTRIBUTION AND FREQUENCY.—The number of macroalgae species by zone along the B.C.S. coast increased southward. Zone II yielded 24 species, zone III—33 and zone IV—65, including 56 species collected in the Magdalena cooperative (C6) alone, which is the southernmost locality surveyed. Rhodophytes contributed the greatest number of species in each zone (Fig. 2).

For the whole study area (region), the total relative frequency varied between 0.1–17.0%. Sixty-nine taxa had frequency values lower than three percent TRF, while the other taxa showed corresponding high values of frequency, thus being the most important species in abalone habitats along Baja California Sur. These species were the brown algae: *Cystoseira osmundacea*, *E. arborea*, *Sargassum sinicola* and *Spatoglossum howelli*; and the rhodophytes *Corallina officinalis* var. *chilensis*, *C. vancouveriensis*, *Cryptopleura crista*, *Gelidium robustum*, *P. cartilagineum* and *Prionitis lanceolata* (Table 1). Within the cooperatives, RF varied between 0.3–29.7% (Table 1).

SIMILARITY.—Classification analysis using presence/absence of species (Jaccard) roughly (low similarity) discriminated two groups: the first one represented by cooperatives 1–4, and the second by C5 and C6 (0.277). Other pair-wise comparisons yielded higher values 1–3 (0.438), 2–4 (0.348), although still at low similarity levels (Fig. 3). These assemblages apparently were not continuous in terms of species composition. The similarity between cooperatives 5 and 6 was very low in spite of being located within the same zone, because nine species from C5 were not collected in C6, and 38 species present in the samples from C6 did not occur in C5. Although sites C1 and C3 share 14 taxa, the same as C3 with C6, the high species richness in the later accounts for the low similarity measured. Overall, C6 yielded 26 taxa not accounted for in the rest of the sampling sites.

Similarity based on Morisita's index produced a different classification (Fig. 4), which represents differences between the assemblages based on important (more frequent) species. The C2 and C4 (1996), and C3 (95) assemblages show a high similarity. These sites share important, long-lived species, mainly *C. osmundacea*, *E. arborea*, *C. officinalis*

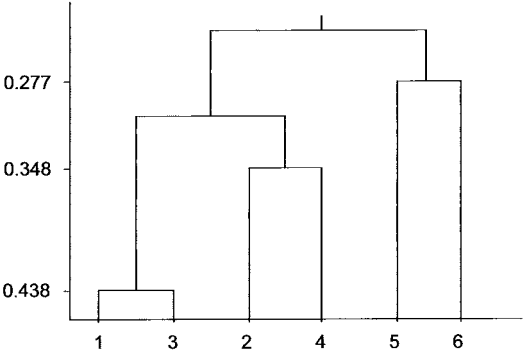


Figure 3. Similarity dendrogram based on Jaccard's index, by cooperative, for the macroalgal assemblages associated with abalone banks in Baja California Sur, Mexico. 1. Sociedad Cooperativa de Producción Pesquera (S.C.P.P.) Emancipación, 2. S.C.P.P. California-San Ignacio, 3. S.C.P.P. Leyes de Reforma, 4. S.C.P.P. Progreso, 5. S.C.P.P. Puerto Chale y 6. S.C.P.P. Magdalena.

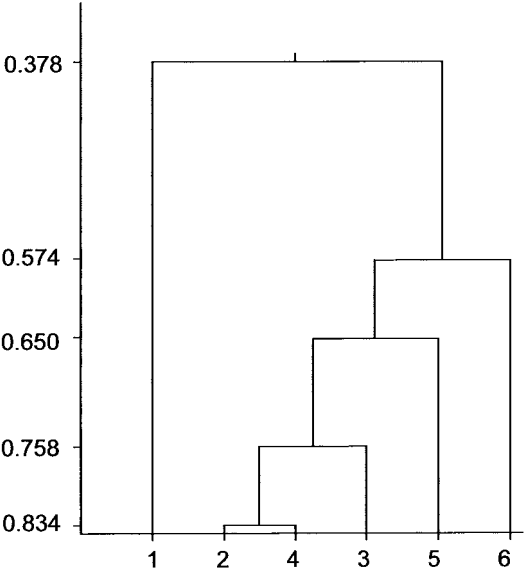


Figure 4. Similarity dendrogram based on Morisita's index, by cooperative, for the macroalgal assemblages associated with abalone banks in Baja California Sur, Mexico. 1. Sociedad Cooperativa de Producción Pesquera (S.C.P.P.) Emancipación, 2. S.C.P.P. California-San Ignacio, 3. S.C.P.P. Leyes de Reforma, 4. S.C.P.P. Progreso, 5. S.C.P.P. Puerto Chale y 6. S.C.P.P. Magdalena.

var. *chilensis* in spite of the different sampling dates. Of the twelve taxa recorded at C2, Eight are included in C4 (six are important). This explains the high values of similarity measured with this index. The marked dissimilarity of C1 with the other assemblages, contrary to the Jaccard's outcome, indicates that it does not share its important species (Table 1) with the other assemblages or it does in very different proportions.

DISCUSSION

DIVERSITY AND DISTRIBUTION.—In California and Baja California, *M. pyrifera* is the most important component of the coastal flora based on its abundance, and is considered a principal food source for local abalone species (Guzmán del Prío et al., 1972; Leighton, 1989). However, *M. pyrifera* is distributed as far south as the northern limit of B.C.S., while two abalone species reach approximately 600 km further south to Bahía Magdalena. In this area, *E. arborea* is the dominant macroalga. This species together with *Sargassum* spp., *C. crispa* and *Rhodymenia* sp. have been found to be among the main constituents in the gut contents of *H. fulgens* in B.C.S. (Serviere-Zaragoza et al., 1998) and are some of the most frequent taxa recorded in this survey.

Although less diversified, the phaeophytes were the best-represented group according to their frequencies in this study. The most important species, based on their high frequency, may be considered the characteristic flora for the rocky substrata within abalone habitat along the coasts of B.C.S. These species had a wide distribution range and are among the 19 taxa considered as dominant on the northern Baja California coasts (Guzmán del Prío et al., 1972). In both areas red algae are more diverse, while phaeophytes represent a greater biomass (Serviere-Zaragoza, pers. obs.). Comparatively, in southern California brown algae dominate most abalone rocky habitats (Dawson et al., 1960; Foster and Schiel, 1985). However, in central and northern California red algae are abundant. In Australia and New Zealand, rhodophytes are also abundant throughout the abalone distribution areas (Poore, 1972; Shepherd and Womersley, 1976, 1981), while in the South Africa coasts the phaeophyte *E. maxima* and the rhodophyte *Pterosiphonia cloiophylla* are the dominant macroalgae where *H. midae* is found (Barkai and Griffiths, 1986).

The floristic analysis of a benthic community in abalone habitats should provide a first insight into the community structure and the potential abalone-plant trophic relations as proposed by Guzmán del Prío et al. (1991). Food preferences may not be related to abundance or frequency of species. To assess abalone preferences it is necessary to estimate the abundance determinations of both the local macroalga taxa and of stomach contents at the same locality, or by direct observations of abalone feeding habits in laboratory assays.

The high values of diversity measured according to information theory, reflect both the high number of species and/or their equitability. This could be interpreted in terms of choices in abalone grazing that depends on macroalgae as their food source. Although the diet an abalone consumes in the field must be seen as a compromise to the need to consume a balanced diet, and such factors as food availability, avoidance of chemical deterrents and an inability to consume tough food (Fleming, 1995). *Eisenia arborea*, *Sargassum* spp., *C. crispa* and *Rhodymenia* sp. were mentioned as an important part of the gut contents in *H. fulgens* (Serviere-Zaragoza et al., 1998). Thus, *C. osmundacea*, *P. cartilagineum*, *P. lanceolata* and *G. robustum* should also be evaluated as natural potential food sources for the three main abalone species present in the area (*H. fulgens*, *H. corrugata* and *H. rufescens*). Many macroalgae species in the area are highly epiphytised by diatoms that may be enriching the abalone diet, while the importance of the highly frequent corallines has to be focused in terms of their abundant epiphytic diatoms and that are consumed by young abalone (Siqueiros-Beltrones, 2000), besides being an important substratum for the settlement of abalone larvae (Morse and Morse, 1984).

SIMILARITY.—Important species and the species richness are the factors determining structure variation between the assemblages, although two of the frequent species in the region had high frequency values in all three zones. The low similarity values may respond to the discontinuous distribution of uncommon species, mostly rhodophytes. This has been observed recently further south (Rodríguez-Morales and Siqueiros-Beltrones, 1999) where sporadic taxa are the main cause of temporal differences in species composition. The similarity analysis based on both presence/absence and frequency of taxa suggests that important species are homogeneously distributed throughout most of the study area and differences increase due to presence/absence of less frequent taxa. This is further confused by the differences in the sampling dates. Nevertheless, important taxa found exclusively in one of the zones suggest differences in the environmental conditions southward. This in spite of the higher number of samplings in the southernmost sites perhaps explaining the higher number of taxa in C6 (56) with 88 samplings, which is not the case in C5 where 70 sampling accounted for only 27 taxa. The later also contrasts with the 26 taxa in C3 with only 32 samplings.

Although the entire area between Punta Eugenia and Bahía Magdalena is considered a transitional biogeographical zone that includes temperate and tropical biota (Dawson, 1951), the groups may be coupled with differences in temperature because in this region the water temperature decreases northward. The northern area has an annual mean temperature of 19°C (± 0.7) and a salinity of 34.06 (± 0.06), while in zone IV the mean annual temperature is 22.2°C (± 0.9) and the mean salinity is 34.46 (± 0.07 ; Lynn and Simpson, 1987). The more tropical conditions in the southernmost cooperative (C6) are correlated with the highest values of species richness and diversity measured and with the presence of species that are more broadly distributed in the tropics such as *Chaetomorpha antennina*, *Dictyota divaricata* and *Pterocladia capillacea*. In contrast, in the northern cooperatives (C1 and C2) the temperate species *M. pyrifera* is frequent.

Variations in oceanic conditions in the area are attributed in part to the Costa Rica Current and the California Current, which converge in this zone with different degrees of influence according to the season. Nearshore biota are also strongly influenced by upwelling and cyclical occurrences of El Niño and La Niña conditions. The presence and distribution of macroalga species are determined by water temperature, upwelling events and irradiance (Dawson, 1951; Dawson et al., 1960), all of which are important in this zone. Thus, the particular combination of these factors and the biogeographical gradient of the study area may account for the observed latitudinal differences in species composition.

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LITERATURE CITED

- Abbott, I. A. and H. Hollenberg. 1976. Marine algae of California. Stanford University Press, Princeton, N.J. 827 p.
- Barkai, R. and C. L. Griffiths. 1986. Diet of the South African abalone *Haliotis midae*. S. Afr. J. Mar. Sci. 4: 37–44.
- Brower, J. E. and J. H. Zar. 1984. Field and laboratory methods for general ecology. Wm. C. Brown. Co. Pub., Dubuque. 226 p.
- Cox, K. W. 1962. California abalones, family Haliotidae. Calif. Fish and Game Fish. Bull. 118: 130 p.
- Dawson, E. Y. 1951. A further study of upwelling and associated vegetation along Pacific Baja California, Mexico. J. Mar. Res. 10: 39–58.
- _____. 1953. Marine red algae of Pacific Mexico. Part. 1. Bangiales. Pac. Exp. 17: 1–165.
- _____. 1954. Marine red algae of Pacific Mexico. Part. 2. Cryptonemiales. Pac. Nat. 17: 241–397.
- _____. 1960. Marine red algae of Pacific Mexico. Part. 3. Pac. Nat. 2: 1–125.
- _____. 1961. Marine red algae of Pacific Mexico. Part. 4. Gigartinales. Pac. Nat. 2: 191–343.
- _____. 1963a. Marine red algae of Pacific Mexico. Part. 8. Ceramiales: Dasyaceae, Rhodomelaceae. Nova Hedwigia 6: 400–481.
- _____. 1963b. Marine red algae of Pacific Mexico. Part. 6 Rhodymeniales. Nova Hedwigia. 5: 437–476.
- _____, M. Neushul and R. D. Wildman. 1960. Seaweeds associated with kelp beds along southern California and Northwestern Mexico. Pac. Nat. 1: 25–81.
- De la Cruz-Agüero, G. 1994. Sistema de análisis de comunidades. Versión 3.0. Departamento de Pesquerías y Biología Marina. CICIMAR-IPN. México. 99 p.
- Ebert, E. E. and J. L. Houk. 1984. Elements and innovations in the cultivation of red abalone *Haliotis rufescens*. Aquaculture 39: 375–392.
- Fleming, A. E. 1995. Digestive efficiency of the Australian abalone *Haliotis rubra* in relation to growth and feed preference. Aquaculture 134: 279–293.
- Foster, M. S. and D. R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish. Wildl. Serv. Biol. Rep. 85: 152 p.
- Guzmán del Próo, S., S. De La Campa de Guzmán, and J. Pineda-Barrera. 1972. Flora macroscópica asociada a los bancos de abulón (*Haliotis* spp.) en algunas áreas de la costa occidental de Baja California. Memorias del IV Congreso Nacional de Oceanografía. 257–263.
- _____, S. R. Mille-Pagaza, R. Guadarrama-Granados, S. De La Campa-de Guzmán, J. Carrillo-Laguna, A. Pereira-Corona, J. Belmar-Pérez, M. de J. Parra-Alcocer and A. C. Luque-Guerrero. 1991. La comunidad bentónica de los bancos de abulón (*Haliotis* spp.; Mollusca: Gastropoda) en Bahía Tortugas, Baja California Sur, México. An. Esc. Nac. Cienc. Biol., Mex. 36: 27–59.
- Kawamura, T., T. Saido, H. Takami and Y. Yamashita. 1995. Dietary value of benthic diatoms for the growth of post-larval abalone *Haliotis discus hannai*. J. Exp. Mar. Biol. Ecol. 194: 189–199.
- _____, R. D. Roberts and H. Takami. 1998. A review of the feeding and growth of postlarval abalone. J. Shellfish Res. 17: 615–625.
- Ladah, L. B., J. A. Zertuche-González and G. Hernández-Carmona. 1999. Giant kelp (*Macrocystis pyrifera*, Phaeophyceae) recruitment near its southern limit in Baja California after mass disappearance during ENSO 1997–1998. J. Phycol. 35: 1106–1112.
- Leighton, D. L. 1968. A comparative study of food selection and nutrition in the abalone, *Haliotis rufescens* Swainson, and the sea urchin, *Strongylocentrotus purpuratus* (Stimpson). Ph.D. Diss., University of California, San Diego. 197 p.
- _____. 1989. Abalone (genus *Haliotis*) mariculture on the North American Pacific coast. Fish. Bull. U.S. 87: 689–702.

- _____. 2000. The biology and culture of the California abalones. Dorrance Publ., Pittsburg. 216 p.
- _____. and R. A. Booloottian. 1963. Diet and growth in the black abalone, *Haliotis cracherodii*. Ecology 44: 227–238.
- _____, M. Byhower, J. Kelly, G. N. Hooker and D. E. Morse. 1981. Acceleration of development and growth in young green abalone (*Haliotis fulgens*) using warmed effluent seawater. J. World. Maricult. Soc. 12: 170–180.
- Lelevier-Grijalva, A., M. Ortiz-Quintanilla, J. González-Avilés, G. León-Carballo, J. Turrubiates-Morales and M. Reinecke-Reyes. 1989. Análisis biológico pesquero del stock de abulón en la península de Baja California durante las temporadas de pesca 1981–1988; evaluación y diagnóstico. Secretaría de Pesca. Instituto Nacional de Pesca. CRIP Ensenada/La Paz. Mexico. 137 p.
- León-Carballo, G. and M. Muciño-Díaz. 1996. Pesquería del abulón. Pages 15–41 in M. Casas-Valdéz and G. Ponce-Díaz, eds. Estudio del potencial pesquero y acuícola de Baja California Sur. SEMARNAP, Gobierno del estado de Baja California Sur, FAO, Instituto Nacional de Pesca, UABCS, CIB, CICIMAR, CET del Mar. Mexico.
- Lynn, R. J. and J. J. Simpson. 1987. The California current system: The seasonal variability of its physical characteristics. J. Geophys. Resour. 92: 12,947–12,966.
- Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton Univ. Press, Princeton. 179 p.
- MacBride, S. C. 1998. [Current status of abalone aquaculture in the Californias. J. Shellfish Res. 17: 593–600.](#)
- Morse, A. N. C. and D. E. Morse. 1984. Recruitment and metamorphosis of *Haliotis* larvae induced by molecules uniquely available at the surface of crustose red algae. [J. Exp. Mar. Biol. Ecol. 75: 191–215.](#)
- Norris, J. N. and H. W. Johansen. 1981. Articulated coralline algae of the Gulf of California, Mexico, Part. I: *Amphiroa* Lamoroux. Smith. Contrib. Mar. Sci. 9: 1–28.
- Poore, G. C. 1972. Ecology of New Zealand abalones *Haliotis* spp. 3. Growth. J. Mar. Freshw. Res. 6: 11–22.
- Ramade-Villanueva, M., D. B. Lluch-Cota, S. E. Lluch-Cota, S. Hernández-Vázquez, A. Espinoza-Montes and A. Vega-Velázquez. 1998. An evaluation of the annual quota mechanism as a management tool in the Mexican abalone fishery. J. Shellfish Res. 17: 847–851.
- Riosmena-Rodríguez, R. and D. A. Siqueiros-Beltrones. 1996. [Taxonomy of the genus *Amphiroa* \(Corallinales, Rhodophyta\) in southern Baja California, Mexico. Phycologia 35: 135–147.](#)
- Rodríguez-Morales, E. O. and D. A. Siqueiros-Beltrones. 1999. Time variations in a subtropical macroalgal assemblage from the Mexican Pacific. Oceanides 13: 11–24.
- Santelices, B. and M. Hommersand. 1997. [Pterocladiaella, a new genus in the Gelidiaceae \(Gelidiales, Rhodophyta\). Phycologia 36: 114–119.](#)
- Serviere-Zaragoza, E., D. Gómez-López, D. and G. Ponce-Díaz. 1998. The natural diet of the green abalone (*Haliotis fulgens* Philippi) in the southern part of its range, Baja California Sur, Mexico, assessed by an analysis of gut contents. J. Shellfish Res. 17: 777–782.
- _____, A. Mazariegos-Villareal, G. Ponce-Díaz and S. Montes-Magallón. 2001. Growth of juvenile abalone, *Haliotis fulgens* Philippi, fed different diets. [J. Shellfish Res. 20: 689–694.](#)
- Setchell, W. A. and N. L. Gardner. 1920. The marine algae of the Pacific coast of North America. Univ. Calif. Publ. Botany. 8: 139–374.
- Shepherd, S. A. and H. B. S. Womersley. 1976. The subtidal algal and seagrass ecology of St. Francis Island, South Australia. Trans. Royal Soc. S. Austr. 100: 177–191.
- _____. and _____. 1981. The algal and seagrass ecology of Waterloo Bay, South Australia. [Aquat. Bot. 11: 305–371.](#)
- _____. and P. D. Steinberg. 1992. Food preferences of three Australian abalones species with a review of the algal food of abalone. Pages 169–181 in S. A. Shepherd, M. J. Tegner and

- S. A. Guzmán del Proó, eds. Abalone of the world: biology, fisheries and culture. Proc. 1st Intern. Symp. Abalone. Fishing News Books, Oxford.
- Siqueiros-Beltrones, D. A. 2000. Benthic diatoms associated with abalone (*Haliotis* spp.) on a rocky substratum from Isla Magdalena, Baja California Sur, Mexico. *Oceánides* 15: 35–46.
- Tutschulte, T. C. and J. H. Connell. 1988. Feeding behavior and algal food of three species of abalones (*Haliotis*) in southern California. *Mar. Ecol. Prog. Ser.* 49: 57–64.

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