

Benthic Diatom Assemblages in an Abalone (*Haliotis* spp.) Habitat in the Baja California Peninsula¹

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Abstract: Diatom assemblages from an abalone (rocky) habitat were sampled in April and November 1999 and in April 2000 on the western side of Isla Magdalena, B.C.S., México. Overall 236 taxa were recorded, including 10 new records, and 56 species that have been observed exclusively in this type of habitat in the Baja California peninsula. The rocky habitat surveyed is much more complex than expected because of different substrata (rock, fleshy macroalgae, crustose corallines, erect corallines) available for colonization by diatoms at Isla Magdalena. Although epilithic forms were identified, epiphytic diatoms were more abundant. Thus the potential diet for abalone and other grazers is more diverse than previously assumed (i.e., that mainly epilithic diatoms would be their potential food source). A variation in structure was observed between the two assemblages sampled in April because of a change in the species composition of the samples. Most of the rock surface was covered by macroalgae. Thus, the diatom associations consisted mainly of epiphytic forms. The high values of H' corresponded to high species richness (S), whereas higher dominance (λ) corresponded to low S . The highest estimated value of H' was 5.39 ($S = 82$) for the November 1999 rock-*Lithophyllum* assemblage. Similarity measurements, using Morisita's index, indicate that differences in species composition and in association structure may represent a distribution of diatom taxa according to available substrata within the habitat rather than a year-to-year or seasonal variation.

BENTHIC DIATOMS occupy a wide variety of substrata such as sediments, rocks, sea grasses, macroalgae, and animals (epizoic). From any substratum they can enter the food chain in the form of tychoplankton after being suspended by turbulence, becoming an important part of the diet for filter-feeding or-

ganisms. On rocky substratum, diatoms can be grazed directly by many species of mollusks: limpets, chitons, and abalone (Siqueiros Beltrones 2000, Siqueiros Beltrones and Valenzuela Romero 2001). Abalone is an economically important resource in several regions of the world.

Many of the ecological studies on abalone (*Haliotis* spp.) have been motivated by the collapse of the fishing industry in NW México about 30 yr ago (Salaz Garza and Searcy Bernal 1992). Since then, much attention has been focused on an aquacultural approach and on the early life stages of abalone, particularly on the feeding habits of small juveniles and postlarvae (Kawamura et al. 1995, Daume et al. 1997, 1999). Abalone farming, though, has relied heavily on empirical information, particularly in relation to the diatom-based diet of abalone postlarvae and juveniles, but seldom encompassing in situ observations.

The abalone postlarvae that settle on the

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crustose red algae that cover the rocky substratum begin to feed on it and remain there until reaching ≈ 6 mm length (Morse and Morse 1984). Studies on the in situ diet of abalone are few, and the need for using the diatoms found within the natural habitats of abalone for these purposes has only recently been addressed (Siqueiros Beltrones and Voltolina 2000, Siqueiros Beltrones 2002a,b). The postlarvae and juvenile abalone may feed mainly on the diatoms growing on this and other substrata of the rocky environment. Studies that underline the importance of certain diatoms in the postlarval diet (Daume et al. 1997, 1999) lack floristic information. Other preliminary studies though show that juvenile and adult abalone and chitons that graze on or upon the macroalgae found within abalone fishing sites have also ingested abundant epiphytic diatoms, and the potential diatom-based diet is represented by a high species richness (Siqueiros Beltrones 2000, Siqueiros Beltrones and Valenzuela Romero 2001). Other potentially exploitable mollusks such as chitons (*Stenoplax* spp.) also graze upon the diatom films in situ (Siqueiros Beltrones 2000).

We have no knowledge of any previous study that examines the structure of diatom assemblages of rocky habitats from abalone fishing sites. Most research on epilithic marine diatoms has focused on the growth forms and vertical stratification that result from the succession of species leading to the climax diatom community (Hudon and Bourget 1981, Korte and Blinn 1983, McLulich 1986, Hudon and Legendre 1987), and only one (Korte and Blinn 1983) relied on diversity indices to describe the diatom assemblages.

Based on preliminary observations, we found it necessary to provide a more detailed description of the diatom assemblages on the abalone habitat, which may eventually help us to understand the ecology of abalone and other grazers. Because abalone dwell in a rocky environment, our objective was to describe the structure of diatom assemblages growing on the rocky substratum of an abalone habitat, mainly epilithic forms, during spring (April) in two consecutive years and to compare it with assemblages from a different

season (November). However, much of the rocky substratum is occupied by red corallines, either crustose or erect forms, and by fleshy macroalgae. Thus, our observations were extended to include those substrata. Here we describe the structure of benthic diatom assemblages found in the abalone habitat that constitute potential diet, on the basis of species composition, diversity, and numerically dominant diatom taxa.

Study Area

The sampling site (La Lobera) is off the southern tip of Isla Magdalena near the mouth of Bahía Magdalena, on the west coast of Baja California Sur between $24^{\circ} 15'$ and $25^{\circ} 20' N$ and $111^{\circ} 30'$ and $112^{\circ} 15' W$ (Figure 1). This latitude represents the southernmost distribution of *Haliotis* spp., specifically *H. fulgens*, although specimens of red abalone (*H. rufescens*) have also been collected in this area, far beyond their accepted limit of distribution (Siqueiros Beltrones and Valenzuela Romero 2001). Rocky substratum is characteristic of this site, and in the subtidal zone large and small rocks covered with macroalgae are common. As many as 56 species of macroalgae have been recorded for this area (Serviere-Zaragoza et al. in press). Common grazers found in this site are abalone, limpets, and chitons (*Stenoplax* spp.).

MATERIALS AND METHODS

The study comprised three samplings, all made at a depth between 4 and 10 m using scuba gear. Rocky substrata samples, which could be handled whole and represented the overall environment, were chosen. The selected rock samples showed the same condition as the dominant large reef rocks and similar smaller rocks, with much fleshy and coralline macroalgal cover. In April 1999, two medium-sized rocks, weighing approximately 3 and 5 kg and bearing erect corallines, were extracted. In November only one rock (≈ 5 kg) was collected, which had no macroalgae attached except for crustose corallines. In April 2000 a single rock (≈ 5 kg) was collected, again showing much macroalgae cover. Sur-

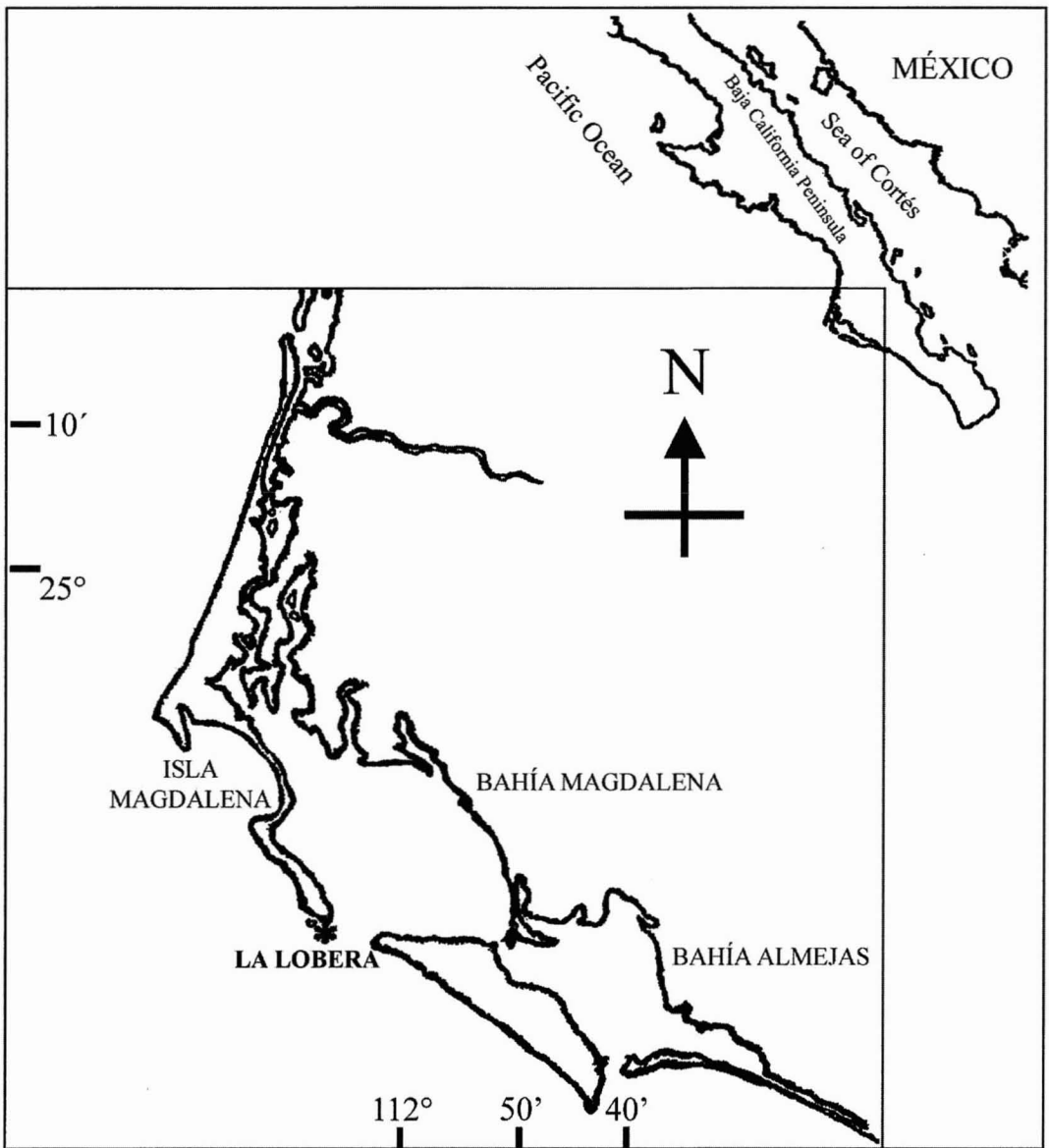


FIGURE 1. Location of study area and sampling site (La Lobera) off Isla Magdalena, Baja California Sur, México.

face temperature was measured using a bucket thermometer. Samplings were done during La Niña cool water conditions in the region (Durazo et al. 2001).

All erect macroalgae and grazers were removed from the rocks. The exposed rock and crustose algae were brushed using a tooth-

brush to remove the diatoms. Fresh samples were observed to determine if diatoms were alive. Few specimens were dead. Both the brushed-off material and the macroalgae were then treated with nitric acid and alcohol (Siqueiros Beltrones 2002b). Each macroalgae species was identified and treated

as a different substratum. The cleaned samples were mounted on permanent slides using Melmount (RI = 1.7). Taxonomic determination was done using phase-contrast microscopy (1,000 \times), based on classic and recent literature: Peragallo and Peragallo (1897–1908), Schmidt et al. (1874–1959), Hustedt (1955, 1959, 1961–1966), Hendey (1964), Simonsen (1987), Moreno et al. (1996), Siqueiros Beltrones (2000), Siqueiros Beltrones and Valenzuela Romero (2001), and Siqueiros Beltrones (2002*b*). Nomenclature at the genus level was updated based on Round et al. (1990). The identification of macroalgae was based on Setchell and Gardner (1920), Abbott and Hollenberg (1976), Norris and Johansen (1981), and Serviere-Zaragoza et al. (in press).

Association Structure Analysis

The structure of a species assemblage is composed largely within the concept of species diversity. This was estimated for each sample using information theory indices such as Shannon's diversity measurement (H'), Pielou's index (J') for evenness, and the redundancy index (REDI) for dominance, as in Brower and Zar (1984), all using log 2. As complementary information for better describing the association structure (Siqueiros Beltrones 1990, 2002*b*), we also calculated values for Simpson's dominance (λ) and diversity ($1 - \lambda$). The assemblages from each substratum and date were explored for similarity using presence and absence of species and the numerical importance of each species using Morisita's index (Brower and Zar 1984). The relative abundances for each taxon used for computing the ecological indices were based on a minimum sample size of 500 valves. A repetition was included in all the calculations to observe the degree of variation within a sample.

RESULTS AND DISCUSSION

In spite of the utmost importance of diatoms in the ecology of a valuable resource such as abalone, almost no in situ observations have

been made on the species composition and structure of the diatom taxocoenosis living in the abalone habitat constituting their potential diet. Thus, our study (in part exploratory), determined the structure (i.e., species composition, diversity, and numerically dominant taxa) of the diatom assemblages in the abalone habitat. This also gave us an idea of the conditions of the abalone dwelling grounds. Figure 2 shows the collected 5-kg rock with several of the common grazers such as *Haliotis* sp. and *Stenoplax* spp. (chitons). The surveyed substrata consisted of bare rock, the red crustose coralline algae *Lithophyllum* sp., and other macroalgae identified to genus or species level, such as *Amphiroa vanbosseae* Lemoine (erect corallines), fleshy rhodophytes (*Cryptopleura crispa* Kylin, *Pterocladia* sp., *Acrosorium venulosum* (Zanardini) Kylin, *Dasya sinicola* (Setchel & Gardner) Dawson), and laminar phaeophytes (*Padina durvillaei* Bory and *Dictyota* sp.). In both samplings, cool-water conditions were detected, with 17°C measured for the first sample and 19°C for the second and third. Although samplings were done during a La Niña year (Durazo et al. 2001), common upwelling events in the area may also have caused the observed low temperatures (Gárate-Lizárraga and Siqueiros Beltrones 1998).

A total of 236 diatom taxa was identified, including rocky and macroalgal substrata, with 89 additions for the Isla Magdalena inventory. This species richness is among the highest recorded (Siqueiros Beltrones 2002*b*), albeit in part because of the time dedicated to making the species inventory. Ten taxa are new records. For these types of habitats exclusively, 56 species have now been recorded for the Baja California Peninsula (Table 1). Although the potential diet for abalone and other similar grazers would most likely resemble a typical assemblage from their natural habitat, other more widely distributed taxa may be more common in this particular habitat where they may be dominant.

During the quantitative analysis, only 150 taxa were accounted for in all samples, and three were found exclusively as epiphytes of fleshy macroalgae (*Cocconeis pellucida* (Kütz-

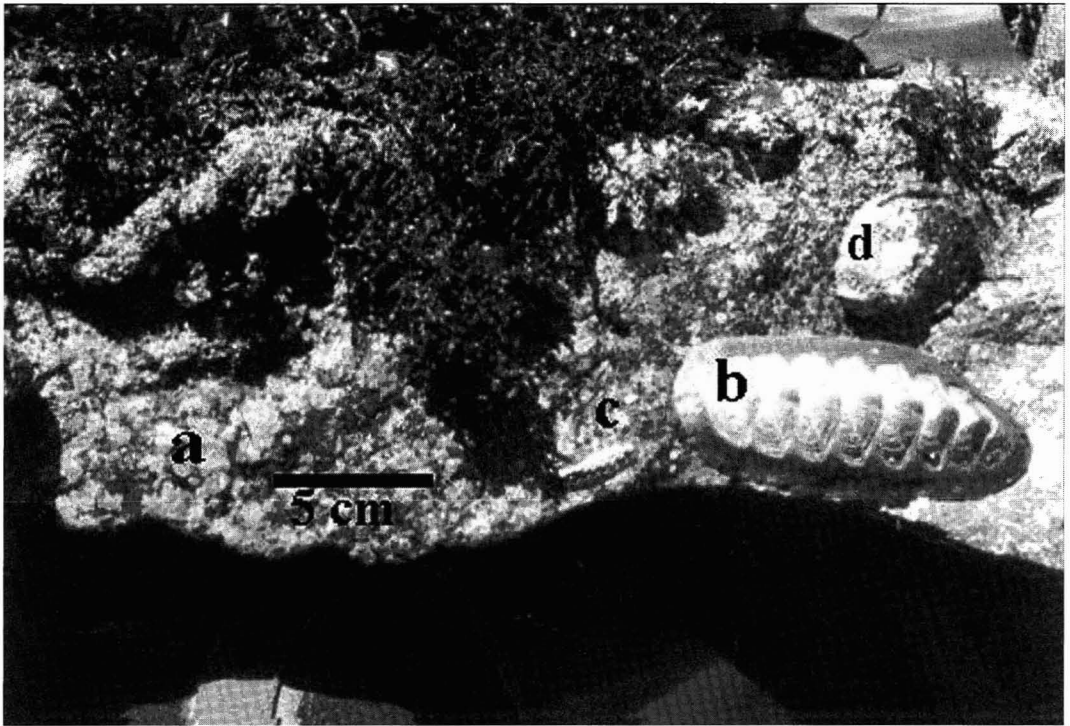


FIGURE 2. Rock (≈ 5 kg) collected at La Lobera off Isla Magdalena, B.C.S., México, showing macroalgal cover characteristic of the rocky substrata in this abalone habitat. *a*, Crustose algae (*Littobryllum* sp.); *b*, large chiton (*Stenoplax* sp.); *c*, small chiton; *d*, abalone (*Halotis* sp.); *e*, fleshy red algae.

ing) Peragallo, *Navicula schonkenii* Hustedt, and *Nitzschia pellucida* Grunow ex Cleve & Grunow). In the April 1999 samples, from a substratum consisting of crustose and erect corallines, the most abundant species were *Biddulphia biddulphiana* (Boyer) J. E. Smith as an epiphyte of *Amphiroa vanbosseae*, and *Hyalodiscus scoticus* (Kützing) Grunow. Other conspicuous taxa were *Triceratium pentacrinus* f. *quadrata* Hustedt, *Grammatophora hamulifera* Kützing, and *Amphitetras antediluviana* (Ehrenberg) Kützing. Although no fleshy macroalgae were collected, most taxa were recorded as epiphytes of the crustose and erect corallines.

In April 2000, the collected rock showed extensive fleshy macroalgae cover. The dominant species was *Rhoicosphenia marina* var. *intermedia* A. Schmidt, epiphytic on *Dasya*

sinicola and *Amphiroa vanbosseae*. Other abundant taxa were *Cocconeis scutellum* Ehrenberg, *C. scutellum* var. *parva* Grunow ex Cleve, *C. diminuta* Pantockzec, *C. dirupta* Gregory, *C. dirupta* var. *flexella* Janisch, *C. discrepans*, *C. peltoides* Hustedt, *Grammatophora hamulifera*, *G. marina* (Lyngbye) Kützing, and *G. oceanica* Ehrenberg.

All of the taxa not in Table 1 have been recorded in earlier surveys of the area (Siqueiros Beltrones 2000, Siqueiros Beltrones and Valenzuela Romero 2001, Siqueiros Beltrones 2002b). These, and most other species, are mainly epiphytic on the observed macroalgae, either fleshy forms or erect corallines. From the 97 species found in the 2000 sampling, these substrata harbored 60 species, of which six were common or abundant then. Seventeen taxa were uncommon, except

TABLE 1

Benthic Diatom Taxa from the Baja California Peninsula Recorded Only from Rocky and Algal Substrates Found Within Abalone Fishing Sites

1. *Achnanthes manifera* Brun, Foged (1984), p. 14, pl. 32, fig. 11.
2. *Achnanthes pseudogroenlandica* Hendeby (1964), p. 177, pl. 28, figs. 9–12.
3. *Actinocyclus octonarius* var. *tenellus* (Brébisson), Hendeby (1964), p. 84; Moreno et al. (1996), p. 17, pl. 6, figs. 13–15.
4. *Actinopterychus adriaticus* Grunow, Desikachary (1988), p. 2, pl. 421, fig. 7.
5. *Actinopterychus campanulifer* Schmidt, Moreno et al. (1996), p. 18, pl. 6, fig. 17.
6. *Amphitetras antediluviana* (Ehrenberg) Kützing, Hustedt (1959), p. 811, fig. 472.
7. *Anaulus birostratus* Grunow, Peragallo and Peragallo (1908), p. 369, pl. 90, figs. 13–14.
8. *Auliscus punctatus* Bailey, Schmidt et al. (1874–1959), pl. 89, fig. 14.
9. *Biddulphia balaena* Ehrenberg, Peragallo and Peragallo (1908), p. 380, figs. 380–382.
10. *Caloneis aemula* (A. Schmidt) Cleve, A. Cleve (1955), p. 91, fig. 1126.
11. *Caloneis* cf. *lauta* Carber & Bailey-Watts, Kramer and Lange-Bertalot (1997), p. 389, pl. 173, figs. 2–3.
12. *Caloneis linearis* (Grunow) Boyer, Witkowski et al. (2000), p. 166, pl. 160, fig. 12.
13. *Campylodiscus fastuosus* Ehrenberg, Hendeby (1964), p. 290, pl. 40, fig. 13.
14. *Cocconeis contermina* A. Schmidt, Schmidt et al. (1874–1959), pl. 196, fig. 21.
15. *Cocconeis costata* var. *pacifica* (Grunow) Grunow, Romero and Rivera (1996).
16. *Cocconeis discrepans* A. Schmidt, Witkowski et al. (2000), p. 106, pl. 41, figs. 35–40.
17. *Cocconeis distans* Gregory, Schmidt et al. (1874–1959), pl. 193, fig. 36.
18. *Cocconeis fumminensis* (Grunow) Peragallo, Hustedt (1959), p. 341, fig. 794.
19. *Cocconeis pediculus* Ehrenberg, Hustedt (1959), p. 350, fig. 804.
20. *Cocconeis speciosa* Gregory, Witkowski et al. (2000), p. 115, pl. 36, fig. 10.
21. *Cyclotella stylorum* Brightwell, Moreno et al. (1996), p. 61, pl. 18, fig. 10.???
22. *Cymbellonitzschia* sp. 1.
23. **Dimeregramopsis furcigerum* (Grunow) Ricard, Witkowski et al. (2000), p. 29, pl. 11, fig. 10.
24. *Diplomenora cocconeiformis* (A. Schmidt) Blazé, Round et al. (1990), p. 408, figs. a–d.
25. *Diploneis decipiens* var. *typica* A. Cleve (1953), p. 77, figs. 645a,b.
26. *Diploneis exemta* (A. Schmidt) Cleve, Peragallo and Peragallo (1908), p. 112, pl. 15, fig. 16.
27. **Diploneis fusca* (Gregory) Cleve, Hustedt (1959), p. 654, fig. 1053.
28. *Diploneis lacrimans* var. *coarctata* (A. Schmidt) Hustedt (1959), p. 630, fig. 1040.
29. **Diploneis lineata* (Donkin) Cleve, Hustedt (1959), p. 677, fig. 1069.
30. *Diploneis nitescens* (Gregory) Cleve, Hustedt (1959), p. 640, fig. 1047.
31. **Diploneis papula* (A. Schmidt) Cleve, Hustedt (1959), p. 679, fig. 1071a–c.
32. **Diploneis papula* var. *constricta* Hustedt (1959), p. 679, fig. 1071d.
33. *Diploneis serratula* (Grunow) Hustedt (1959), p. 643, fig. 1049.
34. *Diploneis splendida* (Gregory) Cleve, Cleve (1953), p. 71, fig. 633.
35. **Fallacia* cf. *cryptolyra* (Brockmann) Stickle & Mann, Hustedt (1961–1966), p. 534, fig. 1570; Round et al. (1990), p. 668.
36. *Fallacia forcipata* var. *nummularioides* (Grunow) n. var., Schmidt et al. (1874–1959), pl. 70, figs. 30–31.
37. *Gephyria media* Arnott, Schmidt et al. (1874–1959), pl. 231, figs. 18–21.
38. *Grammatophora marina* var. *undulata* Ehrenberg, Peragallo and Peragallo (1908), p. 354, pl. 87, fig. 23.
39. *Licnophora ehrenbergii* (Kützing) Grunow, Desikachary (1988), p. 12, pl. 610, figs. 1–10.
40. *Navicula* (*Fallacia* ?) *applicitoides* Hustedt, Hustedt (1961–1966), p. 388, fig. 1473A.
41. *Navicula* (*Fallacia* ?) *schonkenii* Hustedt (1961–1966), p. 379, fig. 1467.
42. **Nitzschia pellucida* Grunow ex Cleve & Grunow, Witkowski et al. (2000), p. 399, pl. 191, figs. 1–7.
43. *Okedenia inflexa* (Brébisson) Eulenstein, Peragallo and Peragallo (1908), p. 215, pl. 49, figs. 1, 2.
44. **Pleurosigma diversistriatum* Meister, Foged (1975), p. 50, pl. 17, fig. 3.
45. *Podocystis americana* (Bailey), Peragallo and Peragallo (1908), p. 261, pl. 68, fig. 11.
46. *Podosira stelliger* (Bail.) Mann, Desikachary (1988), p. 12, pls. 601, 602, figs. 1–13.
47. *Pseudogomphonema kamtschaticum* (Grun.) Medlin, Schmidt et al. (1874–1959), pl. 213, figs. 46–51; Round et al. (1990), p. 699.
48. *Rhabdonema adriaticum* Kützing, Hustedt (1959), p. 23, fig. 552.
49. *Rhoicosphenia adolphi* Schmidt et al. (1874–1959), pl. 213, figs. 20–23.
50. *Rhoicosphenia marina* var. *intermedia* Schmidt et al. (1874–1959), pl. 213, figs. 36–39.
51. *Thalassionema nitzschioides* cf. *inflata* Heiden, Moreno et al. (1996), pl. 32, fig. 15.
52. **Toxarium undulatum* Bailey, Moreno et al. (1996), pl. 32, fig. 8.
53. *Triceratium parallellum* (Ehr.) Greville, Schmidt et al. (1874–1959), pl. 75, figs. 3–5.
54. *Triceratium parallellum* var. *balearica* Grun., Schmidt et al. (1874–1959), pl. 81, fig. 2.
55. *Triceratium pentacrinus* (Ehr.) Wallich., Foged (1984), p. 102, pl. 23, fig. 4.
56. *Triceratium pentacrinus* f. *quadrata* Hustedt, Navarro (1982), p. 18, pl. 10, figs. 4–6.

* New records in this study.

TABLE 2

Diversity Values Estimated for 12 Samples (and Repetitions) from an Equal Number of Substrata Collected from a Rocky Habitat at Isla Magdalena, B.C.S., during April and November 1999 and April 2000

Sample ^a	n	S	H'	1 - λ	J'	λ
17-April-99S	505	65	4.48	0.906	0.75	0.094
17-April-99SR	502	57	3.93	0.855	0.68	0.145
17-April-99L	504	30	2.65	0.739	0.55	0.261
17-April-99LR	501	42	3.29	0.812	0.61	0.188
12-Nov-99	506	82	5.39	0.966	0.85	0.034
12-Nov-99R	509	76	5.12	0.953	0.82	0.047
14-April-00	504	66	4.98	0.953	0.83	0.047
14-April-00R	500	57	4.77	0.951	0.83	0.049
<i>Padina</i> -00	500	20	1.91	0.614	0.45	0.386
<i>Padina</i> -00R	500	17	1.71	0.552	0.43	0.448
<i>Cryptopleura</i> -00	502	17	1.83	0.591	0.46	0.409
<i>Cryptopleura</i> -00R	500	14	1.52	0.467	0.41	0.533
<i>Dasya</i> -00	500	28	2.76	0.775	0.58	0.225
<i>Dasya</i> -00R	508	23	2.81	0.795	0.63	0.205
<i>Amphiroa</i> -00	503	30	3.34	0.855	0.69	0.145
<i>Amphiroa</i> -00R	500	31	3.21	0.832	0.66	0.168
<i>Acrosorium</i> -00	500	17	2.11	0.701	0.53	0.299
<i>Acrosorium</i> -00R	500	15	1.94	0.636	0.51	0.364
<i>Pterocladia</i> -00	503	17	1.74	0.491	0.43	0.509
<i>Pterocladia</i> -00R	501	15	1.61	0.475	0.42	0.525
<i>Dictyota</i> -00	500	11	0.99	0.274	0.31	0.726
<i>Dictyota</i> -00R	506	11	1.03	0.289	0.32	0.711
<i>Amphiroa</i> -99	499	25	2.16	0.531	0.47	0.469
<i>Amphiroa</i> -99R	500	21	2.17	0.543	0.51	0.457

Note: n, number of specimens; S, number of species; H', Shannon's diversity; 1 - λ, Simpson's diversity; J' Pielou's evenness; λ, Simpson's dominance.

^a R, repetition; S, small rock.

for *Gomphonemopsis pseudoexigua* (Simonsen) Medlin, which has also been recorded as abundant on *Macrocystis pyrifera* (L.) C. Agardh (Siqueiros Beltrones et al. 2001), whereas the remaining 43 (not abundant) taxa occurred exclusively on the rock-*Lithophyllum* substratum.

In the November 1999 assemblages, the dominant taxa (*G. hamulifera* and *G. oceanica*) were not abundant and the samples had a high species richness. The substratum consisted of crustose and erect corallines, and bare rock. However, a change in species composition was noticeable from the April 1999 samples where *B. biddulphiana* was the most conspicuous taxon.

Species diversity values varied according to substratum from $H' < 1$ to $H' > 5$. The high values of diversity indicate the potential of these types of habitats, which reflects the heterogeneity of the available substrata and in

turn promotes high species richness. Overall, the values of diversity and dominance were strongly influenced by species richness (S). The higher values of H' corresponded with the higher S, and the higher dominance (λ) with the lowest species numbers (Table 2). Except for a low value of 2.65 (S = 30), diversity was high for the assemblages living on the rock-*Lithophyllum* substratum. The observed differences in diversity were also caused by variations in evenness between the assemblages collected in April 1999 versus April 2000 (Table 2).

Most of the lower values of diversity corresponded to the assemblages from the macroalgae thalli, showing both a lower species richness and a higher dominance. This was caused by high abundances of certain taxa, such as *G. pseudoexigua* (on *Padina* sp.) and *Cocconeis peltoides*, *C. diminuta*, and *C. dirupta* var. *flexella* on all macroalgae species, except

Amphiroa vanbosseae from the April 1999 sampling, in which *B. biddulphiana* was the dominant taxon.

Using Morisita's grouping technique (Figure 3), four groups of diatom samples appear to be discriminated. This may be caused mainly by substratum, because the epiphytic assemblages from April 2000 appear well segregated from the rock-*Lithophyllum* samples, and the *P. durvillaei* sample, the November 1999 and April 2000 assemblages, and in April 1999 when no fleshy macroalgae were present. The similarity between a sample and its repetition based on their relative abundances reached maximum similarity for the *Pterocladia* and *Dictyota* assemblages. This, along with the low values of diversity because of high dominance (REDI), indicates that the species responsible for the observed similarities are mainly abundant taxa, and the fleshy macroalgae are a common substratum for the most important diatom species. Thus, although the *P. durvillaei* assemblage appears segregated, the difference is small and can be attributed to the abundance of *G. pseudoexigua*. From this, differences in the species composition and in the association structure may be better explained on the basis of the diatom taxa distribution within the habitat caused by the type of substratum, rather than by seasonal or year-to-year variation.

The rocky habitat surveyed in the abalone fishing site off Isla Magdalena is much more complex because of the different substrata (rock, fleshy macroalgae, crustose corallines, erect corallines) available for colonization by diatoms. Although the April and November 1999 assemblages had no fleshy algae cover, *Lithophyllum* sp. covered much of the rock. Thus diatom species found here are actually epiphytes. The potential diet for abalone and other grazers is more diverse than previously assumed (i.e., that epilithic diatoms would be their main food source [Siqueiros Beltrones and Voltolina 2000, Siqueiros Beltrones 2002a]). The heavy epiphytism observed in the macroalgae from this habitat suggests that the epiphytic diatoms may be the most important food source for young and adult abalone and chitons in their rocky habitat, rather than the epilithic forms.

These observations are consistent with observations on certain macroalgae from abalone fishing sites farther north, which exhibit distinct assemblages of conspicuous diatoms (i.e., *Macrocystis pyrifera* is covered mainly by *Cocconeis costata* var. *pacifica* Grunow [recorded as *Cocconeis* cf. *britannica* in Siqueiros Beltrones et al. 2001], along with several other species). Likewise, a specimen of *Plocamium cartilagineum* (L.) Dixon was heavily epiphytized by large forms, such as *Gephyria media* Arnott, *Rhabdonema adriaticum* Kützing, *Porosira* sp., and other small naviculoids (Siqueiros Beltrones et al. 2003). These are common and conspicuous large forms that would provide more food value per cell ingested. Some have been observed in the gut contents of abalone juveniles and chitons from the same site together with the abundant *Cocconeis* (epiphytic) species (Siqueiros Beltrones 2000).

Furthermore, several macroalgae species are known to be ingested by green abalone (McBride 1998, Serviere-Zaragoza et al. 1998) and pink abalone (Guzmán del Próo et al. 2003), and epiphytic diatoms may well be ingested along with their host. Although some observations may not confirm this (Guzmán del Próo et al. 2003), other current studies show that many epiphytic diatom taxa are in fact ingested by abalone and chitons together with their fleshy macroalgal hosts (e.g., *P. cartilagineum* and *M. pyrifera* [Siqueiros Beltrones et al. 2003]).

This type of research requires sampling rocks from the subtidal zone in sites of difficult access, and regulatory laws oblige one to be selective in whatever is extracted for study. Although the sampling design for this type of studies may be improved, the information generated yields insight into the diatom-grazer relationship that can be applied in aquaculture projects. This is the first study that describes the structure of diatom assemblages from rocky habitats where abalone dwell. Eventually, this information may be used to attain more efficient management of these resources (abalone and chitons), either under culture conditions or for the in situ restoration of their populations.

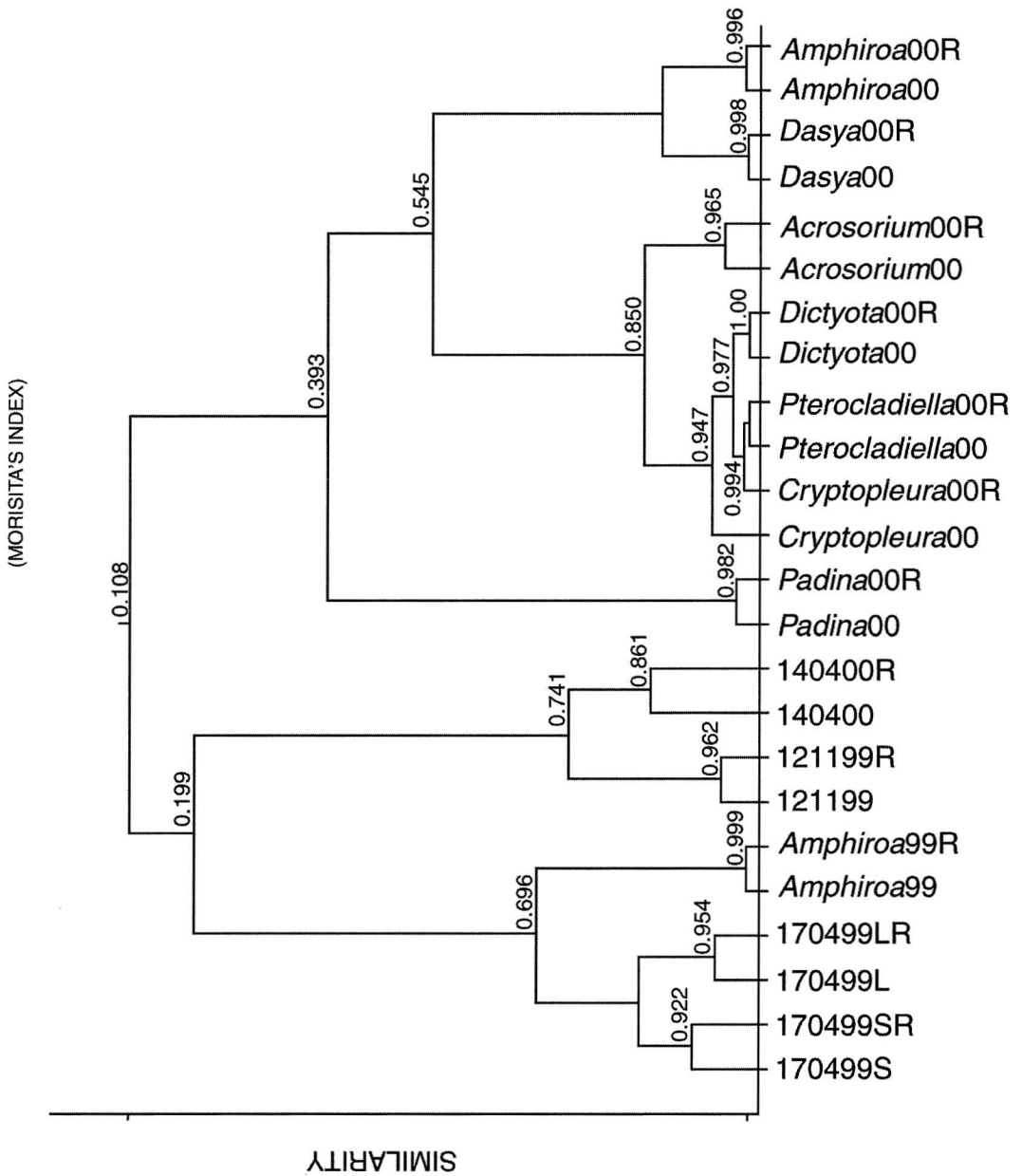


FIGURE 3. Similarity between diatom samples representing assemblages found in an abalone rocky habitat off Isla Magdalena, Baja California Sur, México, based on presence or absence and relative abundances of the taxa (Morisita's index). Symbols explained in Table 2.

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