Preliminary report on the epibenthic and benthic environment of San Ignacio Lagoon.

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Abstract

Monitoring of invertebrate species composition, and spatial patterns in the epibenthic vegetation can help to detect and mitigate impacts anthropogenic activities and large-scale environmental change. Here we present the preliminary results of an initial assessment of the epibenthic and benthic community in San Ignacio Lagoon, within the Viscaino Biosphere Reserve. In 2006 and 2007 we obtained benthic ponar grab samples from 44 and 67 sites and also recorded video clips of the epibenthic environment at 44 and 255 sites using an underwater camera throughout the lagoon. Seagrass (*Zostera marina* L.), algae and sea pens (Order: Pennatulacea) were detected in 34, 55 and 15 % of the 255 epibenthic videos in 2007. However in both years we observed few correlations between physical parameters, epibenthic vegetation and invertebrate densities. Non-parametric, univariate statistical analyses indicated that mollusc density was higher in areas with seagrass (Zosteraceae) in 2006 and molluscs were more abundant in northern sections of the lagoon. In 2006 annelid density appeared to be higher in substrates with a high proportion of shells and in 2007 worms and echinoderms were more likely to be observed in muddy substrate. When we conducted a multivariate principle components analysis, three components were extracted from our twelve variables that characterized the physical and biological conditions at the sea floor. These three components accounted for 73 and 58 % of the overall variability in twelve variables in 2006 and 2007. In 2006 a total of 11 different phyla were found in invertebrate samples and the most numerous taxa were echinoderms. Future areas of research and approaches to improve our methods are discussed.

Introduction

Monitoring of key ecosystem indicators is an important component of successful management in marine protected areas. Monitoring can help identify stresses on the environments which may lead to early mitigation of the problem and is also crucial to detect large-scale changes in environmental systems such as climate change so that resource managers can adjust conservation strategies (Stem et al., 2005). Moreover, with increasing funding constraints in park management or conservation, monitoring is necessary to evaluate the success of different management strategies and provides public and internal accountability for protected area (Salafsky & Margoluis, 1999).

The unique and diverse ecosystems within marine protected areas in Baja California are under increasing development pressure. In 2001 the Mexican government initiated a multi-million dollar development project (called "Nautical Ladder) to build 24 ports along the coast of Baja California (Álvarez-Castañeda et al., 2006). This will lead to much greater marine tourism traffic, enhancement of supporting infrastructure and a diverse range of potential ecological and socioeconomic impacts within coastal areas of Baja.

Although several studies have examined the ecology and population biology of the large charismatic megafauna in this area, such as whales, sea lions or sharks (Heckel et al., 2003; Urban et al., 2003; Rodríguez-Dowdell et al., 2007) there has been limited research conducted on other components of the ecosystem. Moreover, due to the tremendous funding and staff constraints in Mexican protected areas, there is limited resources for government-funded research to support ecological monitoring.

Marine benthic communities are excellent indicators of local ecological health because, unlike migratory species such as gray whales or sea lions, they generally have low mobility and thus can not simply relocate when there are changes in environmental quality. In addition, several macrofaunal taxa, such as polychaetes, are considered sentinel species that may be amongst one of the first groups to respond to anthropogenic change such as eutrophication, sewage pollution or fisheries (Díaz-Castañeda & Harris, 2004; Wear & Tanner, 2007). Although San Ignacio lagoon currently has relatively low human densities and thus limited anthropogenic pollution, the lagoon has had a long history of shellfish and finfish fisheries harvesting commercial important species such as lobster (*Panulirus* spp.), pismo clams (*Tivela stultorum*), abalone (*Haliotus* spp.), corvina (*Cynoscion* spp.), shark (Young, 2001) and occasionally shrimp (*Penaeus* spp.) at the mouth of the lagoon. In the 1980's during a particularly poorly managed fisheries, thousands of people worked at harvesting the Pacific calico clam (*Argopecten circularis*) in the lagoon until they were over-fished and completed depleted at the lagoon as well as in other coastal areas on the west coast of Baja (Young, 2001). Although these Pacific calico clam populations have returned in nearby Magdalena Bay, they have yet to return to San Ignacio lagoon. It is possible that the loss of these clams from the ecosystem may have contributed to long-term or permanent restructuring of the community, caused by changes in water turbidity or physical sediment characteristics. Benthic invertebrates are also important to examine in the context of ecosystem health because they can also play a key role in the nutrient cycling, pollution metabolism and energy flows through the marine food webs (Diaz-Castaneda et al., 2005; Nicolas et al., 2007). Epibenthic and benthic conditions can, in turn, have significant direct and indirect effects on fisheries, as well as species of conservation concern such as sea turtles (Kochs et al., 2006) or rays (Shepherd & Myers, 2005) that feed on the sea floor.

This report summarizes work conducted by William Megill's research group between 2006 and 2007 on the soft-bottom seafloor in San Igancio Lagoon in the Pacific side of Baja California. San Ignacio Lagoon is one of the last remaining, relatively well protected and least developed coastal lagoons throughout Baja California (Ortega-Rubio et al., 2001). The lagoon is located in Viscaino Biosphere Reserve, which is a protected area with a joint mandate for conservation and socioeconomic development. Thus, reserve managers have a particularly challenging task of setting appropriate limits to economic activities that would promote development without significantly affecting the state of the environment. To establish such limits, managers must design methods to detect and quantify specific impacts caused by anthropogenic activities and quantify potential threats (Salafsky et al., 2002). Within this 2.8 million ha reserve, our research focused on San Ignacio Lagoon because it provides important habitat for species such as the gray whale (*Eschrichtius robustus*), bottlenose dolphin (*Tursiops truncatus*), California sea lion (*Zalophus californianus*), black turtle (*Chelonia agassizii*) and a suite of resident and migratory shorebirds (Danemann & de la Cruz-Agüero, 1993; Urban et al., 2003; Pérez-Arteaga et al., 2005; Sedinger et al., 2006). In addition to contributing to a greater understanding of an area with substantial conservation value, more information on the benthic environment is also beneficial in this lagoon because of the importance of invertebrate fisheries (molluscs and lobster) for the local communities (Young, 2001).

In this study we quantified the invertebrates in benthic substrate samples and obtained underwater camera footage of the sea floor, in order to provide a map and baseline data of the seafloor. We then examined univariate and multivariate relationships between physical parameters (salinity, depth and location), and epibenthic vegetation (seagrass and algae) and macrofaunal benthic invertebrates. At present, in San Ignacio Lagoon, there have been no extensive studies on the ecology and structure of the epibenthic and benthic communities. As part of this study we will also provide an inventory of the species found in the lagoon.

Changes in the spatial extent of entire epibenthic communities can occur due to factors such as pollution, variations in water turbidity, as well as fishing practices such as dredging. Consequently, another objective of our research was to create a map of the different epibenthic communities and overlay this with fishing and tourism activities in the area. Due to time constraints we have not been able to produce detailed maps of this area, however a follow-up report to this in September will include geographic information system (GIS) maps of the epibenthic communities in San Ignacio Lagoon.

Methods

All data was collected in 2006 and 2007 between 30 January and 29 March throughout San Ignacio Lagoon (26º46' / 27º00' North and 113º7' / 113º18' West). This lagoon extends 35 km inland and ranges from 2 to 6.5 km in width. The lagoon is bordered by sandy beaches, desert, salt flats and mangroves. There are currently five small fishing communities around the lagoon, some of the residents are also supported by gray whale watching tourism between December and March (Young, 2006).

Sampling methods

1) Ponar Sediment Grabs

In 2006 and 2007 we collected grab samples from the upper 10 cm of the surface of the sea floor using a Petite Ponar Grab (Wildco.) and also obtained video samples along transects of the epibenthic environment. In 2006, our sampling effort was focused at the mouth of the lagoon and so we did not have even coverage of the lagoon. In 2007 we obtained a more even coverage of the lagoon. In 2007, we devised a grid and sampled on the intersections of a grid and ensured that we did not sample in the same region of the lagoon over consecutive days. In 2007, to optimize spatial extent and resolution, at some of the sampling sites we obtained both epibenthic grab samples as well as an, underwater video sample (termed "Ponar sites") while at other sites we only obtained a video sample of the epibenthic environment (termed "Video sites").

In 2007 we selected sampling locations prior to departure and whenever possible sampled at the pre-selected location. Occasionally, we were not able to sample in these locations because of water depth, as well as current or wind conditions. We obtained all samples from a 5-7 meter open fibre glass boats. At each sampling area, we approximated water depth by measuring the length of the rope or camera cord required for the ponar or camera to reach the sea floor. We also used a Garmin geographical position system (GPS) to record the precise geographical coordinates of the sampling location.

The ponar had a maximum intake volume of 2.4 l, and a total sample area of 152 x 152 mm. Although the total sample area is consistent between different types of habitat, the total volume of the sample varied depending on the type of substrate. It was not possible to standardize the depth of penetration from the samples between different substrates. At each sampling station we obtained one to five grab samples. We pooled the contents of the multiple grab samples and divided the contents by the total volume of substrate sampled in each particular sampling site. Sample depth ranged from 2 to 8 cm and we omitted any of the samples that were outside of these values. For each grab site, we lowered the ponar off of the side of the boat. We then emptied the contents of the ponar into a graduated measuring jug and recorded the total volume of the sample after waiting for the substrate to settle. We removed any seagrass or algae from the sample and measured the packed volume of this vegetation in graduate vials. In addition, we visually assessed the percentage of shell or sand content in the substrate and sieved the contents in a 1 mm sieve. At each of the benthic sample sites we also measured water depth at 15 cm below the surface of the water, as well as salinity using a wide-range specific gravity meter (Deep Six Hydrometer, Coralife ®, in 2006) or a refractometer (in 2007) and temperature using a mercury thermometer.

The invertebrates that were captured in the sieves were then placed into vials with salt water and separated according to groups of similar taxa (eg. Small arthropods, large arthropods, molluscs, annelids). These samples were kept out of the sun to increase the chances that they would survive until we returned to the lab. Within 24 hours (and usually during the same day), we then photographed specimens using cameras with macro functions (Canon 350D with 55mm Macro lens, 6.3 MP; Traveller compact digital camera, 8.2 MP) and quantified the total number of invertebrates in each of the vials. These specimens were fixed in formalin and stored in 70 % ethanol, according to standard procedures (Eldredge & Smith, 2001).

2) Underwater videos

For each of the video sites we lowered an underwater video camera (Atlantis AUW 555) to the sea floor and obtained a 1 – 2 minute sample video which was recorded using a Canon VR10 camera. When we returned to the lab, we viewed these video clips and visually estimated the percent cover of algae, seagrass (at two heights > or <= 7 cm), sea pens (Order: Pennatulacea), sponges (Phylum: porifera) and coral (Class: anthozoa). In areas where we could see more than 40 % of the bottom substrate, we also visually estimated the percentage cover of shells and sand. This could be assessed by the shade and texture of the substrate. We analyzed the video samples in two ways, first we paused the video frame the instant that the camera contacted the sea floor and then estimated percent cover within the field of view. Second we observed the complete 1-2 minute video clip and estimated percent cover over a larger spatial area. The total area that was sampled in these larger spatial area samples varied depending on the current and depth at a particular location. However we attempted to reduce the amount of variability between sites by restricting sampling times to one minute on samples when the camera covered a greater spatial area, and two minutes on samples when the camera moved relatively slowly. In 2006 we did not quantify percentage cover of vegetation and instead only included presence or absence in the 2006 analysis.

In 2006 and 2007 we sampled from 44 and 67 benthic ponar sampling sites. In 2007 we filmed the epibenthic environment in an additional 188 sites in which we obtained only video footage of the area. Although we also obtained underwater video footage in 2006, this video data has not yet been reanalyzed in order to include in the report.

3) Invertebrate species composition

In 2006 we identified specimens to its lowest taxonomic group, by examining the preserved samples under a light microscope, viewing the photographs to determine original specimen colours and using invertebrate keys (Smith & Carlton, 1975; Gotshall, 1994). We have not yet identified the invertebrate samples collected in 2007 and so for the analysis we grouped the invertebrates into phyla: Arthropods, Molluscs, Annelids, Nemertea, Cnidaria, and Echinodermata Arthropods. Nemertea and Annelids were pooled into one group and some of the very easily distinguishable taxa such as Sea pens (Family Pennatulidae), sea pansy (Family Renillidae, *Renilla koellikeri*), brittle stars (Family Ophiactidae) and sea cucumbers (Family Cucumariidae) were identified at lower taxonomic levels.

4) Statistical Analysis

Community characteristics

We examined how physical parameters, salinity and temperature varied according to latitude and longitude using an analysis of covariance with year as a fixed factor. Interaction terms were included in the model if they were significant.

We then examined a pearson's bivariate correlation of all variables to examine the relationships between the variables and provide an indication of appropriate methods to construct models between the physical parameters and the invertebrate densities. In this analysis we included both categorical and continuous data to view the data. To better understand how physical parameters influence the densities of invertebrates, we then used a non-parametric Mann-whitney test. Parametric statistical analysis was not possible because of the high frequencies of 0 counts for the invertebrates. We also recoded invertebrate densities into a binary (presence or absence) variable and ran binary logistic regression with stepwise backwards elimination using latitude, substrate type, algae percent cover and seagrass percent cover (from videos).

Finally we used a multivariate principal components analysis to examine the relationship between water depth, salinity, location, epibenthic vegetation and invertebrate species composition.

Taxonomic composition

For the 2006 invertebrate data, we pooled the data into phyla and then calculated community evenness from the Simpson's Index of diversity (Simpson, 1949). Evenness is a measure of biodiversity which ranges from 0 to 1 and reflects how equal populations are numerically.

For all statistical analysis we used SPSS (SPSS for Windows, Rel. 12.0.1. 2003. Chicago: SPSS Inc.). All data were tested for normality using the non-parametric Kolmogorov-Smirnov Test

Results

Salinity varied significantly by latitude (Year $F_{1,87} = -4.2$, $b_{2006} = -4.2$; $P < 0.0001$; Latitude $F_{1,87} = 44.4$, $P < 0.0001$, $b = 14.9$; $R^2 = 0.75$), longitude (Year $F_{1,87} = 183.8$, $b_{2006} = -4.1$, $P < 0.0001$, Longitude $F_{1,87} = 51.5$, $b = -4.1$, $P < 0.0001$ Fig. 2, $R^2 = 0.77$). Salinity varied between the years. This could be attributed to differences in the sampling device or to differences in the physical environment. Location appeared to have a different effect on temperature between the two years and there were significant interaction terms between latitude and temperature (Interaction term, $F_{1, 95} = 27.0$, $P < 0.0001$) as well as longitude and temperature (Interaction $F_{1, 95} = 13.10$, $P < 0.0001$).

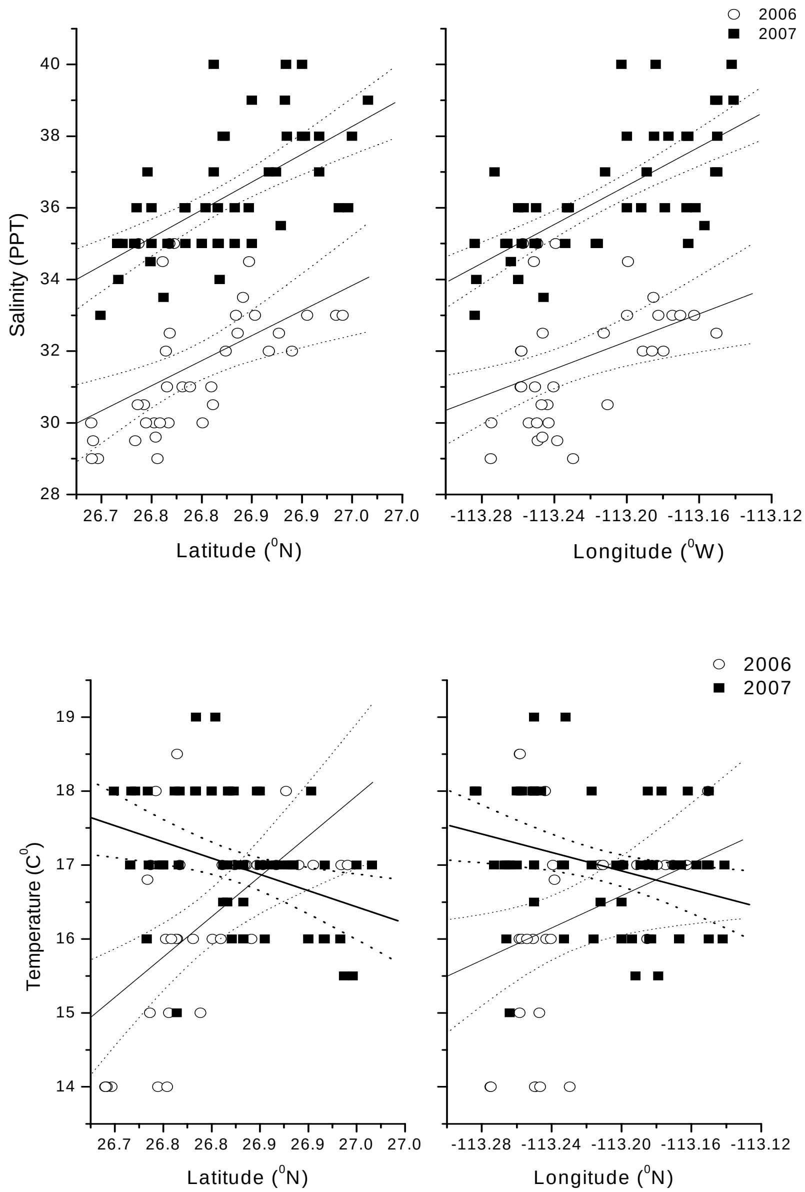

Fig. 1. The effect of location on salinity (top) and temperature (bottom) in 2006 and 2007. Dotted lines represent 95 % confidence intervals and solid lines represent the line of best fit. For temperature, latitude (2006: $P = 0.001$, $b = 10.8$; 2007: $P = 0.006$, $b = -4.4$) and longitude (2006: $P = 0.026$, $b = 10.9$; 2007: $P = 0.013$, $b = -6.2$).

Habitat types and invertebrate communities

Seagrass (*Zostera*), algae and sea pens (Order: Pennatulacea) were detected in 34, 55 and 15 % of the 255 epibenthic videos in 2007. Comparable data was not calculated in 2006 because sampling sites were not evenly distributed throughout the lagoon.

The proportion of sample sites with arthropods and molluscs were higher in areas with seagrass. High densities of these taxa have also been observed in other protected bays and estuaries with seagrass along the Pacific coast. The high density of molluscs are largely attributed to *Nassarius* gastropods, which have been observed in seagrass beds British Columbia to Costa Rica (Ricketts et al., 1985). Cnidarians were less likely to be found in environments with seagrass and relatively more abundant in sandflats with algae (Ricketts et al., 1985)(Fig.2). Echinodermata, were more frequently observed in areas with algae, rather than seagrass. Cucumaria (sea cucumbers) are frequently observed in sandflats in bays and estuaries (Ricketts et al., 1985). In 2007 there was no obvious relationship between percent cover of algae and seagrass in underwater camera epibenthic footage and the number of invertebrates of each phylum (Fig. 3).

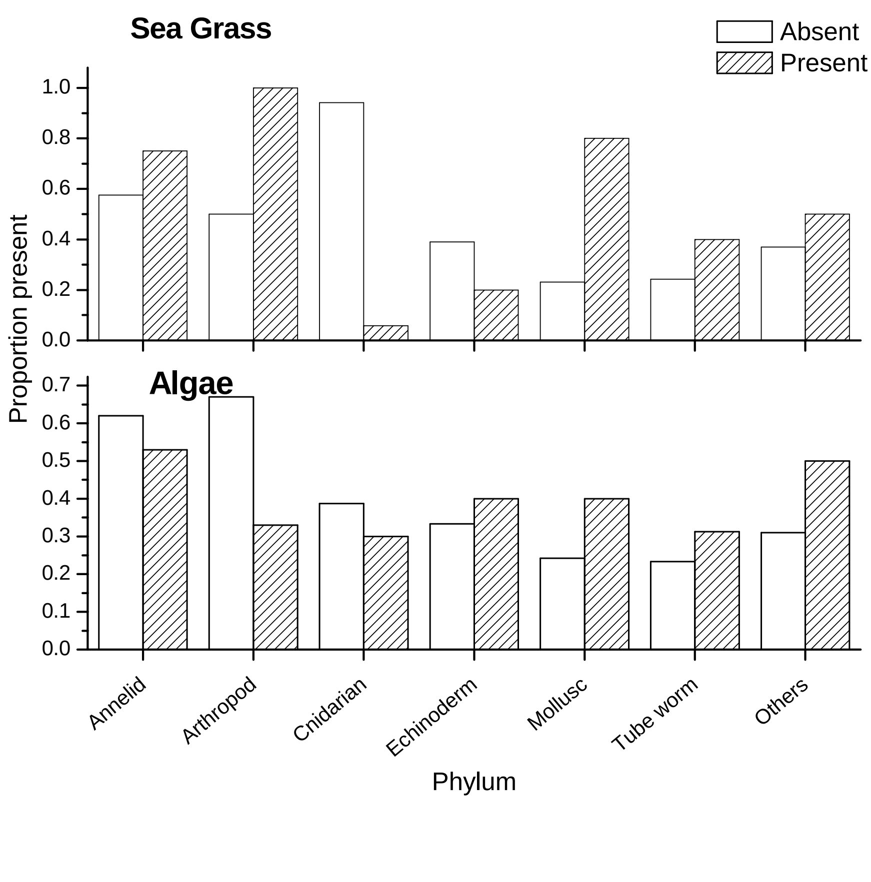

Fig. 2. The relationship between the presence (or absence) of seagrass and algae on underwater videos and the proportion of benthic invertebrate sampling sites (N = 44) in which we found at least one individuals of a particular phylum in 2006.

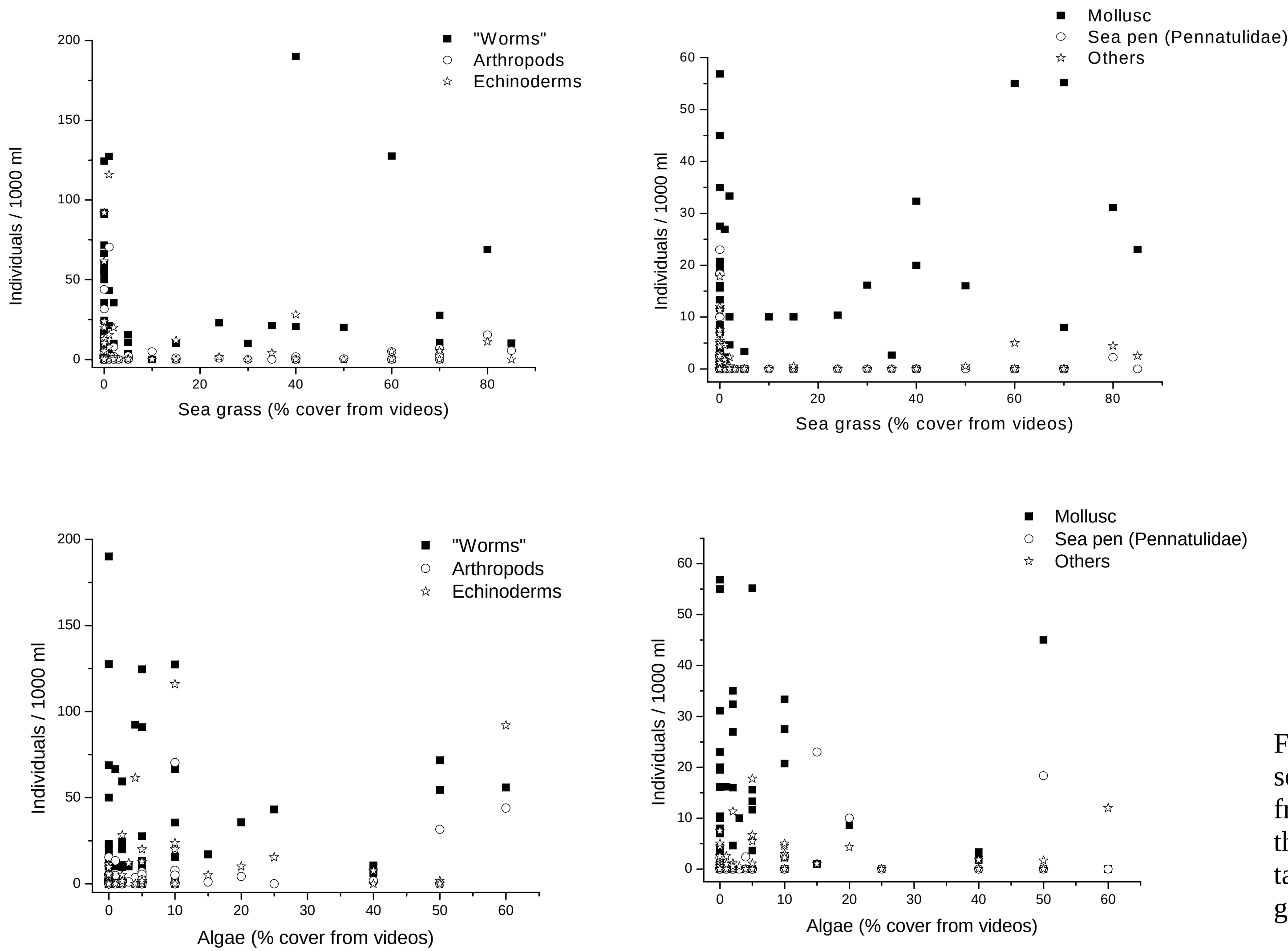

Fig. 3. The relationship between seagrass and algae percentage cover from underwater video cameras and the number of individuals of each taxonomic category found in ponar grab samples.

In 2006 annelids and arthropods appeared to be more likely to be present in areas with shells as substrate (Fig. 4). However substrate did not have a statistically significant effect on the densities of any of the invertebrate taxa (Kruskal-Wallis test: Annelid, P = 0.213; Arthropod, P = 0.087; Cnidarian, P = 0.509; Echinodermata, P = 0.153; Mollusc, P = 0.406; Other, P = 0.400).

In 2007, we did not sample any areas with only shells as substrates. Worms and echinoderms were more likely to be observed in muddy substrate. Substrate had a significant effect on worm (Kruskal-Wallis test P = 0.006), echinodermata (P = 0.029) and sea pen density (P = 0.033) but not on arthropod (P = 0.063), mollusc (P = 0.067) or “other” invertebrate taxa density (P = 0.218).

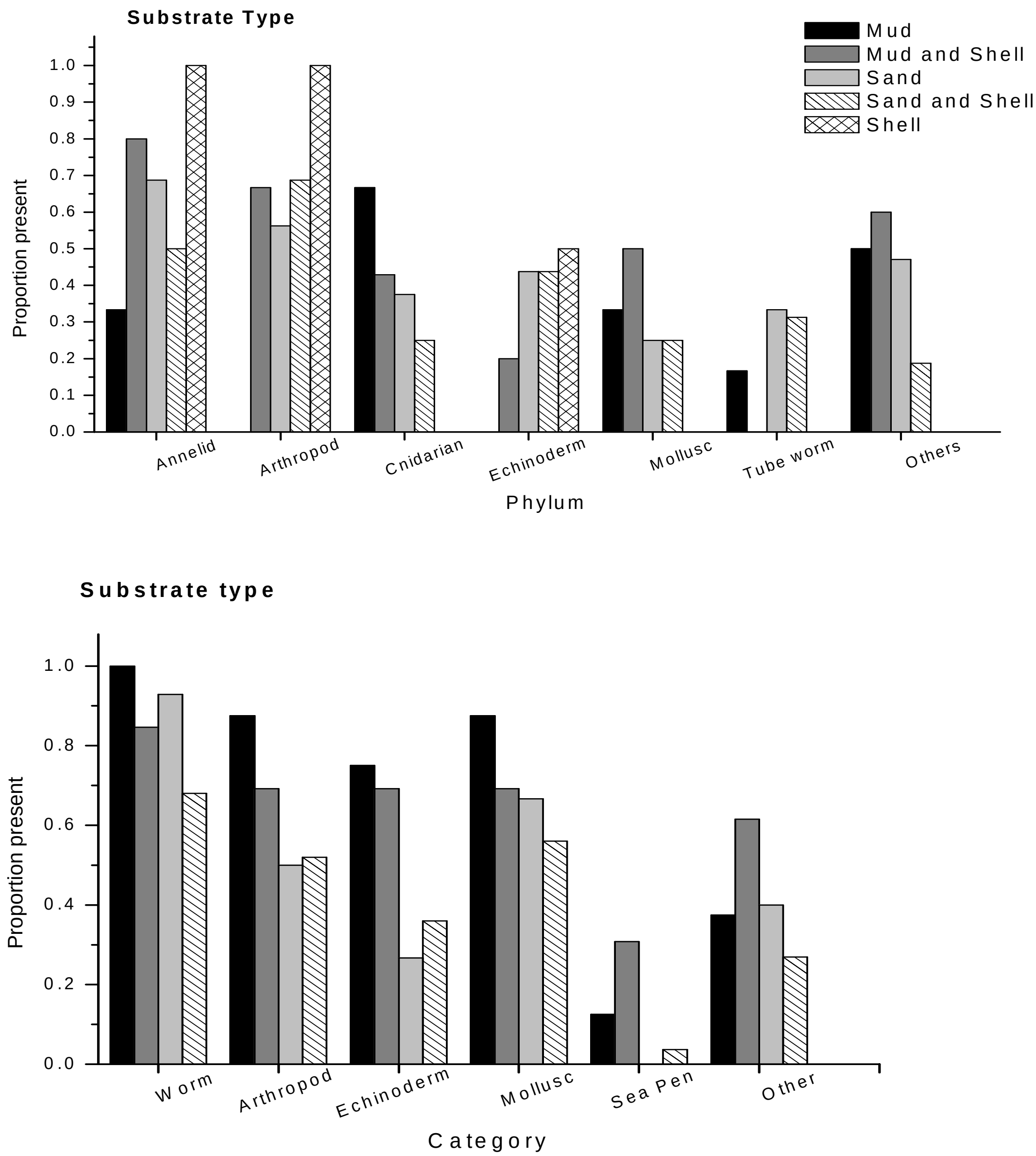

Fig. 4. The relationship between substrate type (from videos and grab samples) and the proportion of sites in which we counted at least one individual of a given taxa in 2006 (Top, N = 44) and 2007 (Bottom, N = 67).

Table 1. Pearson's bivariate correlations for physical parameters of the sampling location, epibenthic vegetation, substrate type and invertebrate densities in ponar grabs samples. "Distlag" = Distance from the north end of the lagoon. "Subtype" is the substrate type – mud, mud and shell, sand, sand and shell and shell. Top (2006) and bottom (2007). Bolded correlation coefficients are significant (α = 0.05).

		Salinity	Distlag	Depth	Algae	Seagrass	Subtype	Annelid	Arthropod	Cnidarian	Echinoderm	Mollusc	Others
Salinity	R	1.00	-0.57	-0.18	0.27	0.27	-0.11	-0.03	-0.02	0.10	0.05	0.24	-0.02
	P	.	0.000	0.272	0.095	0.097	0.505	0.860	0.889	0.557	0.762	0.144	0.929
Distlag	R		1.00	0.12	-0.15	-0.42	0.17	-0.13	-0.12	-0.11	-0.24	-0.38	-0.15
	P		.	0.446	0.348	0.006	0.292	0.417	0.457	0.488	0.132	0.016	0.363
Depth	R			1.00	0.25	-0.20	0.23	0.27	0.28	0.20	0.22	-0.17	0.27
	P			.	0.098	0.187	0.140	0.078	0.067	0.199	0.157	0.290	0.076
Algae	R				1.00	-0.06	-0.05	-0.15	-0.12	-0.07	-0.18	0.04	-0.13
	P				.	0.696	0.754	0.344	0.428	0.639	0.256	0.804	0.407
Seagrass	R					1.00	0.06	0.11	-0.05	-0.10	-0.06	0.65	-0.05
	P					.	0.713	0.502	0.734	0.528	0.716	0.000	0.742
Subtype	R						1.00	0.10	0.04	-0.09	0.11	-0.12	-0.07
	P						.	0.522	0.790	0.563	0.493	0.452	0.666
Annelid	R							1.00	0.92	0.78	0.84	0.10	0.90
	P							.	0.000	0.000	0.000	0.519	0.000
Arthropod	R								1.00	0.84	0.91	-0.05	0.95
	P								.	0.000	0.000	0.771	0.000
Cnidarian	R									1.00	0.72	-0.13	0.83
	P									.	0.000	0.424	0.000
Echinoderm	R										1.00	0.02	0.89
	P										.	0.885	0.000
Mollusc	R											1.00	0.05
	P											.	0.770
Other	R												1.00
	P												

		Longitude	Latitude	Salinity	Depth	Algae	Seagrass	Subtype	Worm	Arthropod	Echinoderm	Mollusc	Seapen	Other
Longitude	R	1.00	0.85	0.54	-0.38	-0.23	0.21	-0.08	0.07	-0.09	-0.04	0.22	0.00	-0.15
	P	.	0.000	0.000	0.003	0.065	0.104	0.505	0.554	0.473	0.732	0.078	0.978	0.235
Latitude	R		1.00	0.50	-0.36	-0.19	0.31	-0.23	0.06	-0.13	-0.14	0.41	0.04	-0.13
	P		.	0.000	0.004	0.137	0.012	0.057	0.624	0.316	0.275	0.001	0.715	0.281
Salinity	R			1.00	-0.18	-0.23	0.15	-0.22	-0.03	-0.22	-0.21	0.24	-0.01	-0.03
	P			.	0.162	0.069	0.235	0.068	0.836	0.071	0.091	0.051	0.935	0.833
Depth	R				1.00	0.37	-0.22	0.12	0.11	-0.02	-0.12	-0.07	0.13	-0.07
	P				.	0.005	0.104	0.339	0.418	0.912	0.385	0.611	0.308	0.581
Algae	R					1.00	-0.23	0.00	0.15	0.40	0.33	0.00	0.34	0.24
	P					.	0.070	0.990	0.248	0.002	0.010	0.990	0.006	0.061
Seagrass	R						1.00	-0.24	0.16	0.00	-0.08	0.50	-0.10	-0.06
	P						.	0.054	0.211	0.984	0.565	0.000	0.427	0.668
Subtype	R							1.00	-0.01	-0.03	-0.12	-0.28	0.01	-0.04
	P							.	0.954	0.811	0.319	0.022	0.958	0.763
Worm	R								1.00	0.43	0.38	0.25	0.09	0.41
	P								.	0.000	0.002	0.041	0.457	0.001
Arthropod	R									1.00	0.81	0.09	0.18	0.35
	P									.	0.000	0.456	0.157	0.004
Echinoderm	R										1.00	-0.01	0.01	0.34
	P										.	0.926	0.926	0.005
Mollusc	R											1.00	0.13	0.03
	P											.	0.281	0.790
Seapen	R												1.00	0.04
	P												.	0.775
Other	R													1.00
	P													.

In 2006, mollusc density was higher in areas with seagrass (Mann-Whitney U, $P = 0.001$, Fig. 5). The density of other invertebrate groups did not appear to be affected by the presence or absence of algae or seagrass.

For 2007, we used the percent cover of algae and seagrass from videos and used a backward stepwise logistic regression with an initial model that included latitude, substrate type, algae and seagrass percent cover to predict the presence or absence of arthropod, mollusc and echinoderm densities. We selected the initial variables to fit into the model based on the bivariate correlation and included variables that appeared to be important and were not substantially correlated to each other. In 2007, the only significant relationships between physical parameters and invertebrate presence were between latitude and the presence of molluscs (Binary Logistic Regression, $B = 14.9$, Wald = 8.8, $P = 0.003$, 79 % of cases categorized correction, Fig. 6), substrate type and echinoderm presence (Wald = 8.10, $P = 0.044$, 69 % of cases categorized correctly).

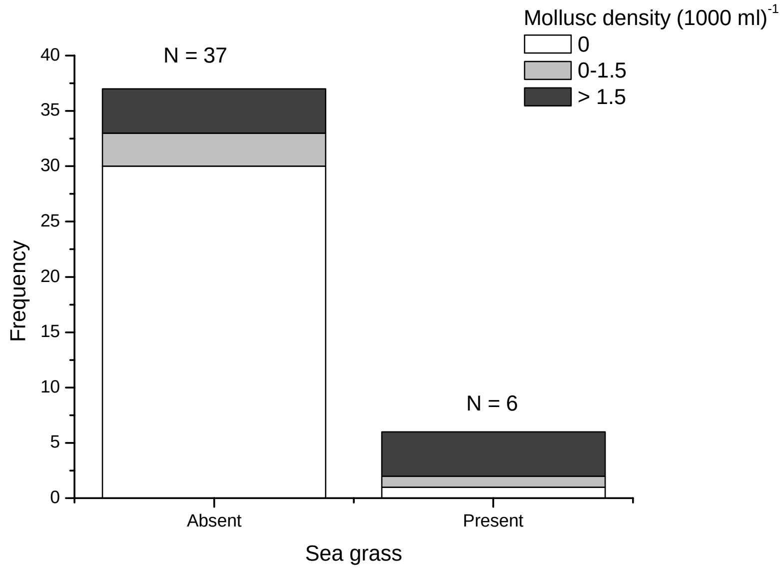

Fig. 5 The effect of seagrass presence or absence on the frequency of high, medium and low mollusc density categories in 2006.

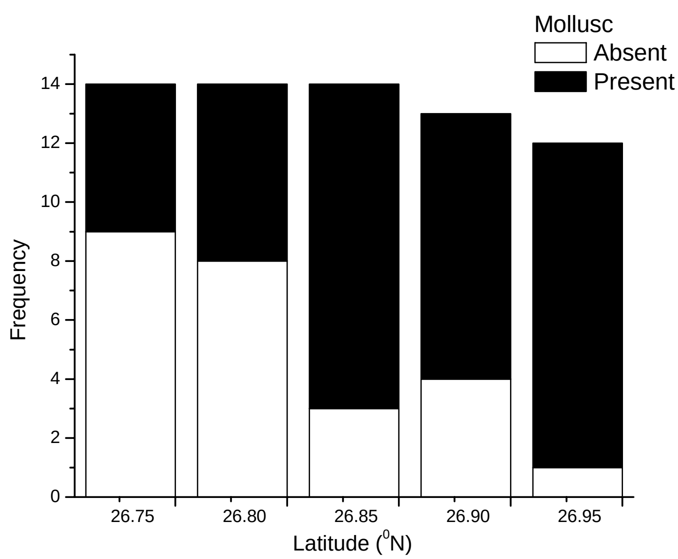

Fig. 6. The effect latitude on the frequency of sampling sites, where at least one mollusc was observed at a sampling site. For reference: 26.75 corresponds to the area infront of Isla Abroa; 26.80 is between O'Freidera and Punta Piedra; 26.85 is between O'Freidera and Isla Pelicana; 26.90 is at the centre of Isla Pelicana; 26.95 is between Isla Garzas and the north end of the lagoon

Principal Components Analysis

Our principal components analysis showed that three orthogonal components accounted for 38, 24, and 11 % and 26, 20 and 12 % of the total variation in the data in 2006 and 2007, respectively.

For 2006 the first principal component represents sites that have a high density of all types of invertebrates other than molluscs. These sites are moderately deep with a low percentage cover of algae. The second principal component are in highly saline, north western sections of the lagoon, which are shallow with high percent cover of seagrass and molluscs. The third principal component represents deep areas with a high percent cover of algae that are located towards the eastern sections of the lagoon.

The first component in 2007 characterized sites which had a high number of worms, arthropods, echinoderms and “other” taxa, as well as a high percent cover of algae. The second component reflected shallow sites that were located in the north western section of the lagoon, which contained molluscs and seagrass and had a low percent cover of algae. The third component characterized sites that were deep, with high percent cover of algae, moderately low percent cover of seagrass and a high percent cover of sea pens.

Table 2. Rotated components matrix (Varimax) for 2006 and 2007 showing the correlations coefficients between the component variables and each of the three principal components.

Variables	2006			2007		
	1	2	3	1	2	3
Longitude	0.00	0.76	-0.20	-0.01	0.92	-0.08
Latitude	0.13	0.89	0.03	-0.07	0.88	-0.02
Salinity	0.00	0.64	0.11	-0.19	0.70	0.01
Depth	0.28	-0.22	0.75	-0.19	-0.47	0.60
Algae	-0.18	0.17	0.86	0.36	-0.17	0.70
Seagrass	-0.04	0.71	0.06	-0.02	0.11	-0.29
Worm				0.60	0.00	0.14
Annelid	0.94	0.04	0.03			
Arthropod	0.98	-0.04	0.03	0.88	-0.06	0.15
Echinoderm	0.93	0.08	-0.05	0.89	-0.03	-0.02
Mollusc	0.00	0.68	-0.07	0.06	0.26	0.18
Sea pen				0.06	0.15	0.76
Cnidarian	0.87	-0.03	0.05			
Other	0.97	0.01	0.02	0.61	-0.10	0.02

2006 Taxonomic composition of invertebrate samples.

A total of 11 different phyla were collected in the lagoon during the sampling period. All of the annelids sampled were polychaetes and the vast majority of arthropods belonged to the subphylum of crustaceans, with the only exception of two sea spiders.

There were 8 and 6 different families of echinoderms cnidarians. All phyla that were pooled into the 'other' section only included one or two families only.

Table 3. Invertebrate taxa identified in this study. Numbers in parenthesis indicate identified taxa on a higher level than species.

Phylum	Class	Order	Family	Species
Annelida	Polychaeta	Aciculata	Eunicidae	*Eunice valens*
			Glyceridae	*Glycera spp.*
				Hemipodus borealis
			Lumbrineridae	*Lumbrineris zonata*
			Nephtyidae	*Nephtys caecoides*
				Nephtys californiensis
			Nephtyidae (3)	
			Nereididae	*Cheilonereis cyclurus*
				Nereis procera
				Nereis spp.
				Plathynereis bicanaliculata
			Nereididae (3)	
			Oenonidae	*Arabella iricolor*
			Onuphidae	*Nothria elegans*
			Pholoidae	*Pholoe tuberculata*
			Phyllodocidae	
			Pilargidae	*Pilargis berkeleyi*
			Polynoidae	*Arctonoe fragilis*
				Arctonoe vittata
				Halosydna brevisetosa
				Hermathoe hirsuta
Annelida	Polychaeta	Canalipalpata	Ampharetidae	*Amage*
			Chaetopteridae	
			Cirratulidae (2)	
			Pectinariidae	*Pectinaria californiensis*
			Poecilochaetidae	
			Sabellidae	
			Spionidae	
			Terebellidae (3)	
Annelida	Polychaeta		Maldanidae	
			Opheliidae	*Armandia brevis*
				Ophelia spp.
			Orbiniidae	
			Paraonidae	*Levinsenia gracilis*
			Paraonidae	
	Polychaeta (14)			
Annelida (10)				
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca*
			Ampeliscidae	
			Ampithoidae	*Cymadusa spp.*

			Calliopiidae	*Oligochinus lighti*
			Caprellidae	*Caprella equilibra*
			Corophiidae	*Corophium spp.*
			Dexaminidae	*Atylus*
				Polycheria osborni
			Eusiridae	*Accedomoera*
			Hyalidae	*Hyale spp.*
			Hyalidae	
			Isaeidae	*Photis spp.*
			Leucothoidae	*Anamixis linsleyi*
			Leucothoidae (2)	
			Lysianassidae	*Allogaussia*
				Allogaussia recondita
			Lysianassidae	
			Melitidae	*Elasmopus*
			Oedicerotidae	*Synchelidium*
			Talitridae	*Orchestoidea californiana*

Table 5. (continued)

Phylum	Class	Order	Family	Species
		Amphipoda (21)		
		Cumacea	Nannastacidae	*Cumella vulgaris*
		Decapoda	Diogenidae	*Isocheles pilosus*
				Paguristes (anahuacus)
			Inachoididae	*Pyromaia tuberculata (mexicana)*
			Penaeidae	*Penaeus*
			Pisidae	*Loxorhynchus grandis*
			Portunidae	*Callinectes arcuatus*
		Decapoda (3)		
		Isopoda	Anthuridae	*Cyathura munda*
			Idoteidae	*Synidotea bicuspida*
			Paranthuridae	*Paranthura elegans*
		Isopoda (3)		
	Pygnogonida	Pantopoda	Callipallenidae	*Decachela discata*
			Nymphonidae	*Nymphon spp.*
Chordata	Ascidiacea	Pleurogona	Molgulidae	*Molgula manhattensis*
Cnidaria	Hydrozoa	Hydroida	Campanulariida	*Phialidium spp.*
	Anthozoa	Pennatulacea	Pennatulidae	
			Renillidae	*Renilla koellikeri*
	Anthozoa (3)			
Cnidaria				
Echinodermata	Echinoidea	Clypeasteroida	Dendrasteridae	*Dendraster excentricus*
	Holothuroidea	Dendrochirotida	Cucumariidae	*Cucumaria spp.*
	Ophiuroidea	Ophiurida	Amphiuridae	*Amphiodia riisei*
				Amphiodia urtica
			Ophiactidae	*Ophiactis savignyi*
				Ophiactis simplex
			Ophiocomidae	*Ophiopsila californica*
			Ophionereididae	*Ophionereis annulata*
			Ophiotricidae	*Ophiothrix spiculata*
	Ophiuroidea	Ophiurida (2)		
	Ophiuroidea			
	Asteroidea			
Entoprocta			Loxosomatidae	*Loxosoma spp.*
Gastrotricha				

Mollusca	Scaphopoda	Dentaliida	Dentaliidae	*Dentalium pretiosum* shells (8)
Nematoda				
Nemertea	Anopla	Heteronemertea	Baseodiscidae	*Baseodiscus delineatus*
	Enopla	Hoplonemertea	Amphiporidae	*Amphiporus spp.*
Sipuncula			Golfingiidae	*Golfingia margaritacea californiensis*
				Themiste spp.

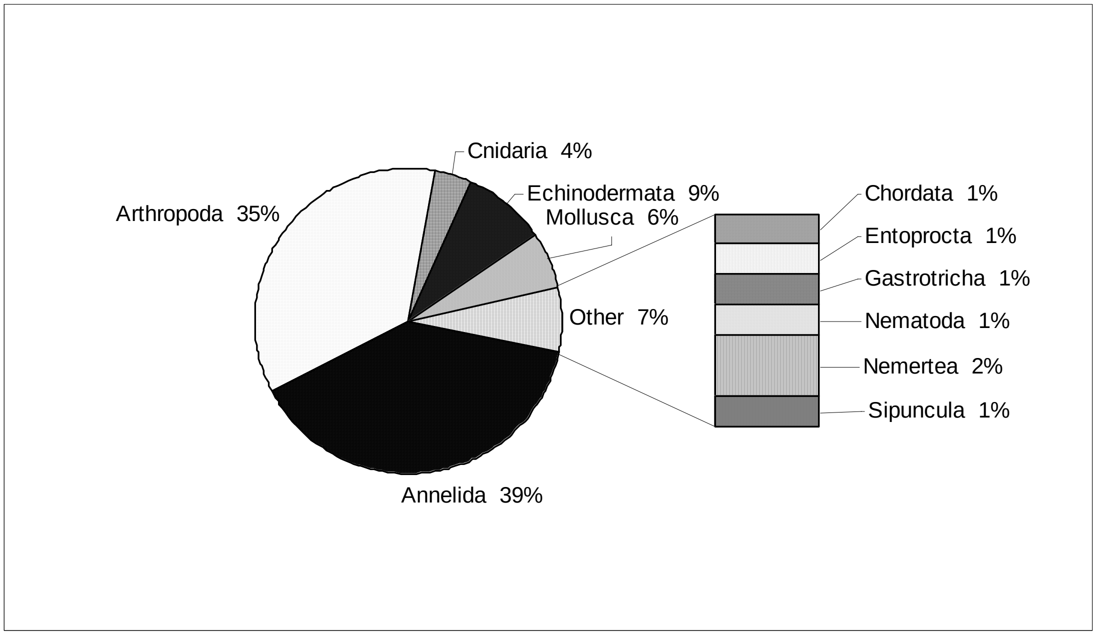

Figure 7. The number of families of eleven different phyla found in the lagoon in 2006 (total identified N=168 individual taxa).

Echinoderms were the most abundant with 459 individuals, followed by arthropods with 329 individuals (Fig 8). Annelids and cnidarians were present with 124 and 144 individuals respectively. High abundance of polychaete worms have been demonstrated in San Quintin Bay in Baja California (Diaz-Castaneda et al., 2005).

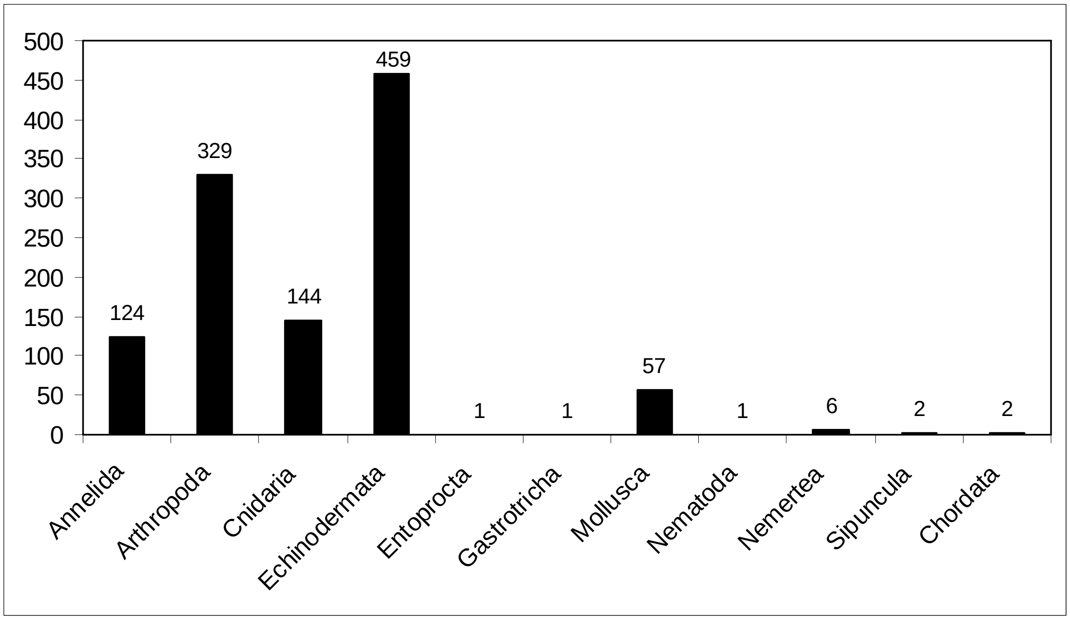

Fig. 8. Numbers of individuals of all phyla found in the lagoon (N=1126 individuals in 11 phyla).

Rarity

The majority of families (56%) were found in only 1 station (Fig. 9).

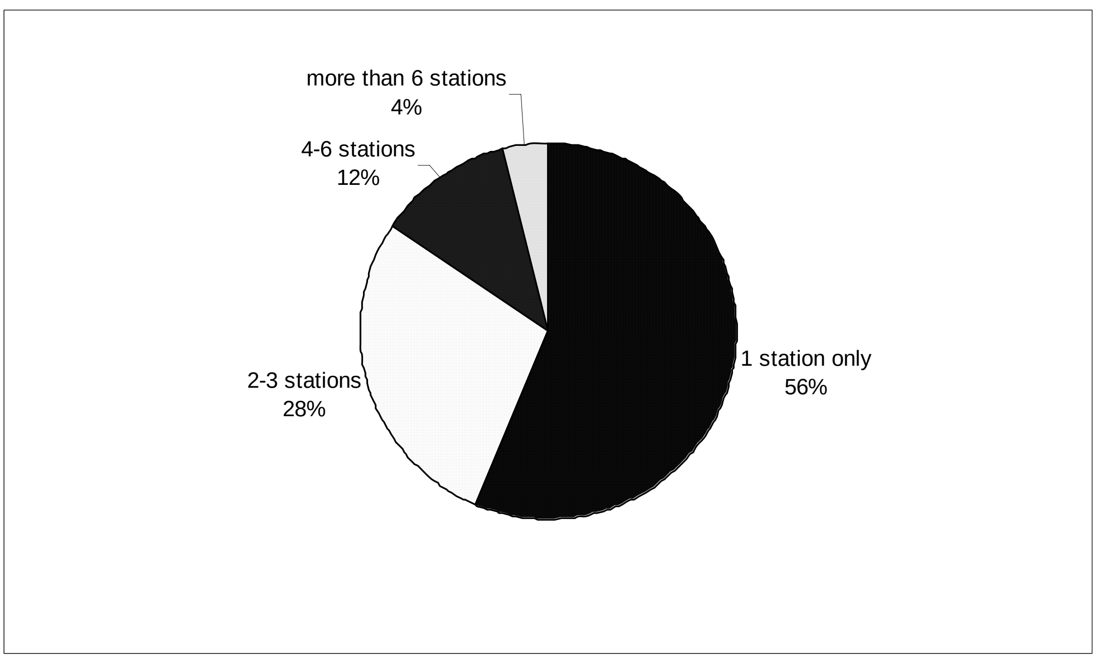

Fig. 9. Ecological Rarity: frequencies at which families were found in stations (N=73 families).

Evenness

We calculated an index of family diversity and evenness rather than the standard index which is based on species because most families were comprised of only one individual. In general, diversity is high in the upper lagoon with all values of evenness below 0.5. Closer to the mouth of the lagoon, more stations with only one or no invertebrates were found (Fig. 10). This is likely due to the more uniform habitats, deeper and faster water flow in this area. This creates a more turbid, hostile environment with less solar input, leading to lower levels of diversity (Menge & Sutherland, 1976; Roy et al., 1998). In addition, within the lagoon and at higher latitudes some of the sampling sites were less than 2 m deep and would have included diverse inter-tidal communities. Salinity appeared to be greater further in the lagoon and high diversity has also been demonstrated in hypersaline environments (Gordon, 2000; Masero & Perez-Hurtado, 2001).

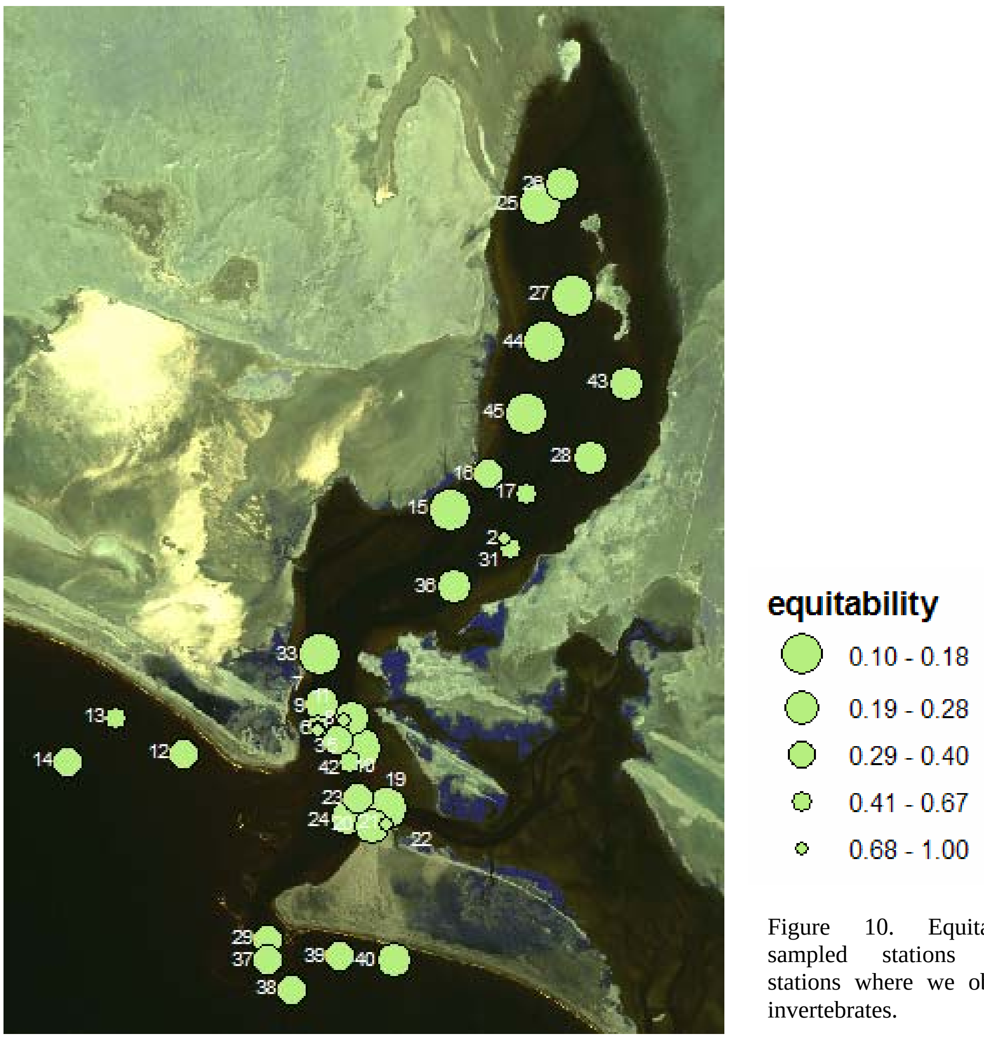

Figure 10. Equitability at sampled stations (excluding stations where we observed no invertebrates.

Future Research

In future years we will sample a smaller number of sites, in much greater detail in order to obtain a better estimate of total biodiversity. These sites will be stratified according to different habitat types and possibly based on the principal components that we identified in this analysis. For each sample we will conduct analysis of the sediment size, chemical composition of sediments, and the extent of organic material in substrate. In addition we will conduct a more complete biodiversity assessment of the benthic invertebrates by bagging the entire contents of the sample in the field and sorting through the samples under a microscope in order to include specimens smaller than 1 mm and obtain a more reliable assessment of species or family abundance. A more complete biodiversity assessment of the site would allow us to better account for rare species, or families, or taxa that are particularly vulnerable to anthropogenic change that have yet to be documented in this region (Diaz-Castaneda et al., 2005). The extent of organic material may be particularly important to detect anthropogenic stresses on the environment such as pollution (Díaz-Castañeda & Harris, 2004). In future analysis we would use this data to divide the taxa into meaningful functional guilds or trophic groups so that our analyses can better reflect interactions between composite species and the environment (Brown, 2004).

In addition to selecting sampling sites for a complete biodiversity assessment, we would also monitor a number of key indicator species that may be the best sentinel species to detect the impacts of specific types of anthropogenic activities in the lagoon. Unlike relatively well-studied terrestrial environment such as old-growth forests (Canterbury et al., 2000), or rivers (Vlek et al., 2004; Tullos et al., 2006), there has been less consensus on ecological indicators of habitat quality in marine benthic environments (Hansson et al., 2000). This is largely due to the tremendous natural variability in invertebrate communities that depend on factors such as substrate type, distance to shore, salinity, temperature, latitude or depth (Ricketts et al., 1985). At present there have not been a sufficient number of comparable studies along the coast of Baja California in order to be able to identify the best indicator species or an indicator index of different species to assess the health of different benthic ecosystems (Borja et al., 2000). Our sampling method will include control areas and sampling design will be targeted towards assessing the impacts of human activities. For example we may focus on monitoring specific species of molluscs in areas of the lagoon which experience different levels of benthic fisheries (Hansson et al., 2000), or polychaetes worms in intertidal or nearshore areas at varying distances from communities or aquaculture operations in order to examine the effects of land-based pollution. Without information on the historic “pristine” state of the invertebrate community, it is not possible to assess how fisheries or other types of human activities might have affected the benthic invertebrates in the lagoon. However our data can help to detect the effects of development that may occur around the lagoon in the future.

The limited number of significant relationships between the variables, or the percentage of the overall variability in our data reflected in the principal components for the two years may be partly attributed to the omission of these types of variables that are key drivers of macrofaunal assemblages in marine sediments (Bergen et al., 2001). In addition, we believe that we would have been able to detect strong relationships between our variables by reducing some of the measurement error caused by our estimates in percentage cover of epibenthic flora, researcher ability to consistently detect invertebrates from benthic substrates in the field, variability in the depth of the ponar grab between sites as well as differences in salinity or temperature measurements at the surface of the ocean (where we sampled) and at the sea floor. To address part of these limitations, the Submersibles Group at the University of Bath is currently attempting to engineer a robotic submersible to sample marine sediments at a consistent depth and collect video samples at the sea floor.

It would also be important to extend our sampling season into the fall because oceanic productivity and the extent of disturbances caused by benthic fisheries and whales are also likely to differ seasonally. We will establish a small number of permanent research sampling sites throughout the lagoon and measure the same location repeatedly throughout the lagoon. Longitudinal data in the exact same location may be especially important to understand the impacts of the benthic fisheries or feeding gray whales on floral and faunal communities as well as the recolonisation process in epibenthic or benthic environments (Pech et al., 2002; Tillin et al., 2006).

By coupling more detailed analysis of biodiversity and sediment physio-chemistry in a small number of sites to underwater videos over the entire lagoon, we will create a GIS generated map of the area and then compare this information to spatial patterns of epibenthic flora or marine sediment infaunal assembles, demonstrated in previous research at San Ignacio and adjacent bays (Ward et al., 2003). This ecological data will then be coupled to spatial socioeconomic data of fishing and tourism activities within the lagoons.

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