SPARS -- Sidney Pier Artificial Reef Science:

Qualitative and quantitative analyses of volunteer diver monitoring over four years

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Introduction

In November 1996, the Township of Sidney, located near Victoria on Vancouver Island, British Columbia, Canada (see Fig. 1), built a 90m long waterfront pier. The purpose was to enhance the opportunities for local residents and tourists to view the seascape, to fish recreationally and to dive for enjoyment and education. Government regulatory agencies required that the Township provide compensation for habitat lost to the pier. Two artificial reefs were constructed on either side and parallel to the pier, not only to address this requirement but also to promote economic development, marine stewardship and community involvement. The reef material chosen were preformed concrete structures called Reefballs™. The pier and its associated reefs were intended to attract interest and support from the public, schools, media, researchers, developers and tourists, partly because this was the first application of such reef technology in the temperate waters of the north-east Pacific Ocean.

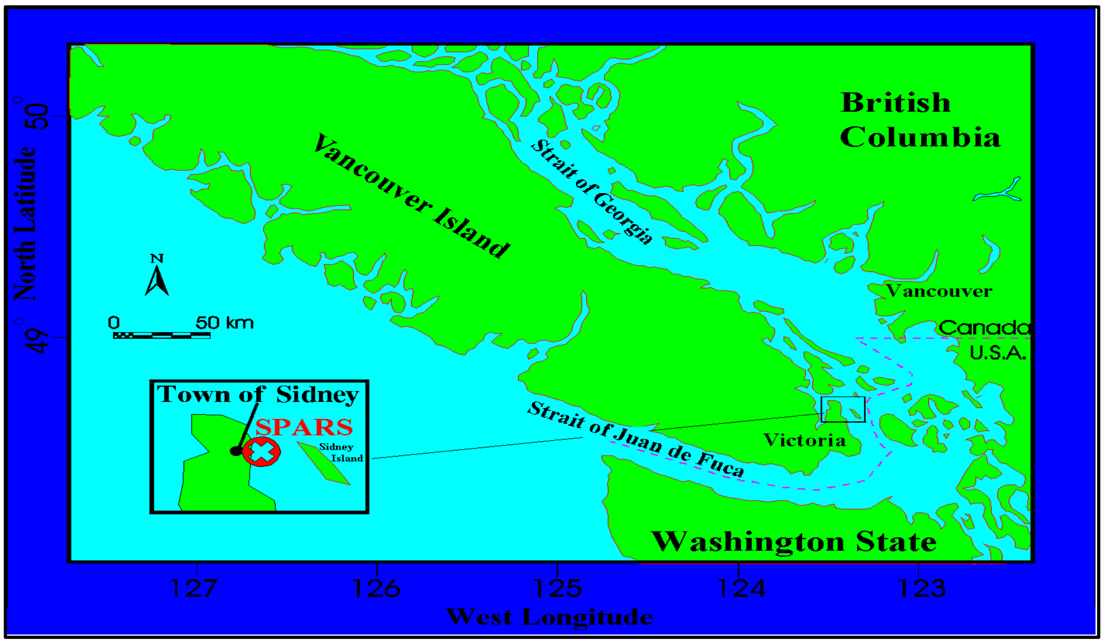

Figure 1. Location of SPARS artificial reefs on Vancouver Island, British Columbia.

There is considerable debate in the literature about whether artificial reefs act as attraction foci for fish and other organisms, or whether they truly enhance the local productivity of fish (for review see Pickering and Whitmarsh 1996).

To monitor the effectiveness of these artificial reefs, local community leaders approached scientists at the Institute of Ocean Sciences, a local research facility of federal Department of Fisheries and Oceans (DFO). Without sufficient resources for such diver-intensive projects, the Institute worked collaboratively with the Professional Association of Diving Instructors' (PADI) Project, the Royal British Columbia Museum (RBCM) and funding agencies. Together they designed and managed a project called SPARS -- Sidney Pier Artificial Reef Science -- involving considerable in-kind contributions and volunteer time especially from recreational SCUBA divers. Stemming from this small local project since 1997 is the DFO "Reefkeepers" initiative dealing with subtidal monitoring procedures, information handling system and community stewardship approach. This volunteer survey program was not designed to address the issue of regional productivity, as there was no effort to measure and compare commercial species biomass around the reefs with changes in catches for the region.

The objective of this report is the interpretation of the resulting dataset gathered by the specially-trained volunteer divers over the five year period from 1997 to 2001. Specifically, the report is intended:

- to provide an analysis of the sampling biases, quality and usability of data;
- to examine qualitative and quantitative patterns in biotic factors which can be determined from this type of survey protocol;
- to recommend protocols to make similar volunteer diver surveys more accurate and objective.

Reef construction

On 12 November 1996, the Township of Sidney constructed two adjacent artificial reefs from 270 hollow, igloo-shaped Reefballs^{TM} each about 170 kg in weight, 1 m in diameter and filled with access holes. These holes allow fish and other organsims to enter the interior, as well as create a whirlpool effect inside the ball that is intended to aid feeding invertebrates. The balls were formed by pouring concrete into a fiberglass mold that contained an internal, inflatable bladder. A dozen or so holes are made in the wall, by placing rubberized balls between the fiberglass mold and the inflatable bladder before pouring the concrete into the mold. Since ordinary concrete has high pH levels due to calcium hydroxide in the mixture, microsilica was added to reduce the pH level to about 8.3, or the average pH of sea water. Additionally, microsilica reacts with calcium hydroxide to help strengthen the balls, giving them an expected life of five hundred years or so. The surface texture was also roughened to foster colonization of sessile marine organisms; the workers sprayed the inside of the mold with sugar water before casting. Consequently the outer layer of concrete resisted hardening and was washed away when the mold was removed.

Figure 2. Reefball deployment off Sidney wharf, and diver showing landward entry point to Artificial Reef South (AS) just south of Sidney Pier.

Using a barge and crane, the construction team randomly placed the Reefballs roughly parallel to each side of the pier, in about equal numbers and mostly as a single layer (not stacked) on sea bottom (Fig. 2). The resulting
irregularly-shaped reefs called Artificial North (AN) Reef and Artificial South (AS) Reef are about 15m x 30m in areal extent, and oriented perpendicular to the shore in 8 to 10 m water depth.

Situated within 20m of the AS Reef, there is a so-called Natural South (NS) Reef, chosen in this project as an established similar habitat for comparative surveys. In fact, the NS Reef is probably also a man-made feature, the remains of a relic pier or wharf made of well-rounded boulders thought to be ballast rock from ships (see Fig. 3).

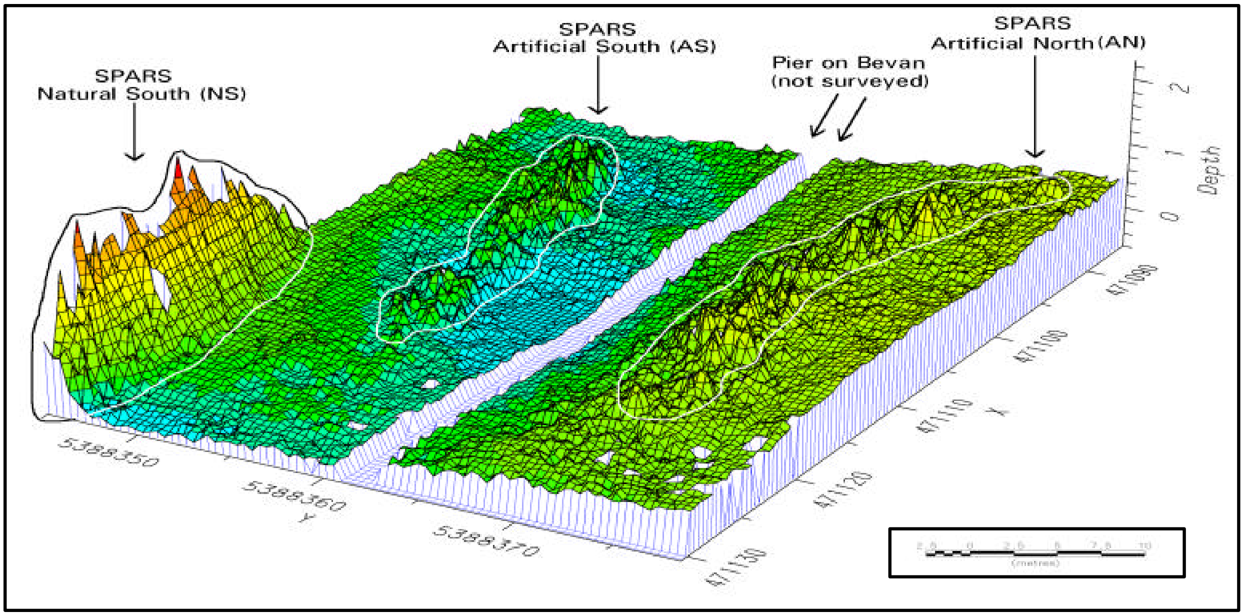

Figure 3. Three dimensional bathymetric perspective of the SPARS study area (top diagram) and Artificial South Reef surveyed by the Canadian Hydrographic Service on February 1997. (Note that the vertical scale is exaggerated by 2, making rounded features such as the Reefballs look like mountain peak).

Maintenance of artificial reefs is an issue, since eventually, their ability to trap silt and organic waste products will result in burial, and a regression of the hard substrate available to soft substrate conditions. The structure of such reefs can be important in preventing this to a greater or lesser degree (for review see Pickering and Whitmarsh 1996), as can the location (in relatively low depositional or sedimentation areas).

Volunteer support

Since DFO did not have adequate resources to monitor these artificial reefs, volunteer recreational divers were recruited, trained and supervised to conduct the SPARS surveys. Under the management and direction of DFO habitat biologists and RBCM curators, young, enthusiastic and competent biologists were hired for co-ordinating volunteers, scheduling surveys, writing reports, analysing data, educating children and informing the public. Funds were acquired for salaries and expenses from regional and national government initiatives for youth advancement such as Science and Technology Youth Internship and Eco-Education Environmental Program.

Methods

Reef monitoring protocol

The key objective of SPARS is to study and assess the development and use of new artificial reefs by marine animals that are recreationally harvested, ecologically important and/or rare and endangered species. The non-professional individual divers and dive clubs were enthusiastic but needed special training to use a scientifically-defensible yet practical survey protocol. The DFO and RBCM biologists commenced to develop the Reefkeepers Guide (Conley et al. 1999) as a published set of step-by-step modules. The Guide is intended to serve as a comprehensive, multi-purpose tool for all participants, divers and non divers alike, to their pursuit for fun, adventure, education and data when routinely surveying artificial and natural reef biota. Five modules comprise the Reefkeepers' Guide, as follows; some are still under development and testing.

Module 1: Project Set Up describes how to organize and set-up individual monitoring projects. Topics include assembling a core planning team, determining the project objectives, choosing and marking study sites, performing baseline surveys, mapping the area, selecting species for monitoring, organizing survey passes, and making time tables and rosters.

Module 2: Reef Surveying using Scuba Divers outlines how to carry out the data collection for monitoring surveys. Instructions include planning dive surveys, supervising volunteer divers, conducting survey passes, recording plants and animal observations, verifying the data and archiving them.

Module 3: Underwater Diving Safety describes and stresses the safety aspects of monitoring surveys. The Reefkeepers are instructed in assessing the safety hazards, verifying safe dive times for surveys, assembling safety equipment and notifying appropriate agencies about dive plans. They also are lead in supervising volunteer divers, safe exit from the water, and reporting to a dive safety officer.

Module 4: Managing Information describes the computerized information management system called A Reef Keepers System or ARKS. It provides guidance to using the database, customizing it for projects, entering different types of data, and producing data summary reports. The Module also provides the technical architecture of the database for those experienced with databases and data analysis. In addition, there are instructions in handling survey data sheets, videotapes, photographs and other project materials.

Module 5: Training Curriculum for Instructors provides instructors with the detailed learning outcomes expected of survey divers and other volunteers, as well as a practical course outline for training the project teams of divers and others. The instructors are assumed to already have a professional working knowledge about local marine biology with experience in SCUBA surveying and mapping.

Database software

ARKS (A Reef Keepers System) equips Project Co-ordinators with a powerful, flexible, easy-to-use PC software for managing all the Reefkeepers' monitoring data as well as the project details, participants contact information, photographs and videos. Programmed as a MicroSoft Access application, ARKS allows the recording and reporting on the observations made during dives on one or more reefs. There are over 40 forms or menus in ARKS. Some like the start-up form are menus that use descriptions to lead hierarchically to other menus. Others are data forms that allow information to entered and changed. All the menus are standardized for ease of data entry into the database. The required data fields are included in a straightforward manner, with minimal customization needed. ARKS is available as a stand-alone runtime version either on a CD-ROM or as a downloaded file from the DFO public FTP site. System requirements are : Software: Windows Operating System; Hardware: IBM compatible (minimum 486), 8MB RAM, 20 MB hard disk space, 2X CD-ROM (if using the CD-ROM version).

For an individual Reefkeepers' project, ARKS is particularly valuable in reporting project successes to volunteers, sponsors, the community, and potential funding sources. For DFO and the other projects involved in the Reefkeepers' network, this database ensures that all data are stored in a standard format, enhancing the quality of the data.

In the future, the data collected by individual projects in coastal waters will be sent routinely as updated MSAccess files to the DFO Science Branch for verification and archival in a central database. This will facilitate the analyses and interpretation of data from multiple monitoring projects, and to report about coastal trends in marine ecosystem status and trends. Although the use of the database is relatively straight forward and explained well in the Reefkeepers' Guide, there is some training required. Part of the Certified Reefkeepers training course is devoted to the use of ARKS to better ensure its best use.

Volunteer effort and surveying approach

From reef construction (November 1996) to its last survey (April 2001), twenty seven volunteer divers attended one or more training workshops and conducted at least one survey. One third of these were PADI Dive Masters or Instructors, and the others certified as PADI Open Water or Advanced divers. Three of the divers were marine biologists and professional curators. One of these biologists (who is also one of this Guide's authors) and a father and his teenage son have conducted more than 12 surveys.

During the surveying period of 1004 days XXXX, the divers surveyed a total of over 5,000 minutes on 44 XXX different dates on a biweekly or monthly schedule. On thirty three dates, they conducted one to three paired surveys for inter-diver comparisons especially those including a professional biologist. In 1997 and 1998, monitoring effort focused almost equally on the two artificial reefs, with total observation times ranging from 700 to 900 minutes annually. Largely because of poor diving conditions, monitoring effort declined in 1999 especially at the Artificial South and Natural South reefs. Declining diver interest was attributed to even fewer surveys in 2000 and 2001. In terms of individual transect passes, the most effort (ie. about 2000 minutes of total observation time) has been directed at Pass #3, looking for sessile and "slow" motile invertebrates. Detailed video surveys for conducted on eleven dates mostly on AN Reef transect.

In consultation with other project partners, three professional marine biologists who are expert in local marine biota prepared together a fixed, standard list of selected taxa to be monitored. This list included only taxa that are relevant to the project objectives, found in the habitat chosen for monitoring, and relatively easy to identify by non-professional divers. The taxa list itself was intended to be short enough to be practically used underwater, by fitting on one or two data sheets printed on waterproof paper and carried on a diver's clipboard. To deal later with estimating data precision and accuracy, the Reefkeepers approach encourages paired surveys by two divers who are buddied for safety and can independently record their concurrent observations along a fixed transect. As each taxa is observed, the divers tallied and recorded counts up to 10. If a taxa was much more abundant, the divers roughly estimated their relative abundance as "many" (11 to 100) or "abundant (>101). The divers conducted up to three different passes of the transect, each pass targetting a subset of the taxa list over a set duration (e.g. 10 minutes). Survey times were scheduled for daytime slack tides and low currents for survey ease and diver safety. A full reef survey with its different passes required about 40 minutes of dive bottom time, reserving air for other diving requirements. The duties of data collection officer was usually assigned to one of the divers, compiled and verified the data sheets immediately after the survey, and submitted them to the project manager for archive.

For the SPARS Project, divers searched for 102 selected taxa along a 30m transect fixed to both artificial reefs and adjacent natural one. The transect was clearly marked by yellow nylon rope permanently anchored along the centre, long axis of each reef (dive sheets are included in Appendix A). During the ten minute duration of Pass One, the divers both looked for and immediately recorded any of 17 listed fish species including rockfish and herring that might be swimming or schooling above the reef, and likely frightened away by the following diving activities. Next the divers resurveyed the transect for a ten-minute Pass Two, observing any of 22 species of fish and motile invertebrates such as sculpins, shrimp and crabs that are quick to hide or difficult to see. For Pass Three, the divers searched for twenty minutes, recording

48 selected taxa of slow or sessile invertebrates including sea anemones, nudibranchs, chitons, snails and seastars. Finally, the divers if still willing and able, made a ten-minute Pass Four down the transect again, to record relative abundance of up to 17 taxa of macro-algae such as filamentous algae and kelp.

Habitat mapping

The Canadian Hydrographic Service conducted bathymetric soundings with a Kongsberg-Simrad EM3000 acoustic swath sonar in February 1997 at the SPARS reefs and vicinity. The system simultaneously logged range and reflected intensity values.

In support of SPARS, a group of commercial companies donated time and equipment; using the Seabed Imaging and Mapping System (SIMS) in March 1998 to characterize the bottom substrates, vegetation and habitats on and around the Sidney Pier and reefs. Hardware included a towfish with high resolution, low light video camera positioned to DGPS standards and optimized with altimeter for shallow water applications. The software consisted of a Microsoft Access 97 database of twenty three attribute fields. A 10m and 20 m grid was surveyed with over 11,000 survey points about seabed sediments and biota. The seabed imagery was viewed and classified by a marine geologist and marine biologist following procedures outlined in Harper et al (1998a). Classification data were imported to ArcView GIS software and selected plots printed. The results are reported in Harper et al (1998b).

The SIMS findings are described below in considerable detail because of their value for SPARS data interpretation. SIMS employs a towfish carrying a high resolution, low light video camera positioned to DGPS standards and optimized with altimeter for shallow water applications. In this study, seabed imagery at over 9,000 classified data points was georeferenced with UTM coordinates. The imagery was then viewed and classified by both a marine geologist and a marine biologist, following procedures outlined in Harper *et al*. From these classification data, they produced selected plots, several included here, to provide an overview of the benthic area.

There is evidence of a wide range of man-made features on the seabed (debris). There are two highly prominent features: the artificial reef structures constructed with Reefballs along both sides of Bevan Pier, and a "reef feature" made of rubble that trends sub-parallel to the Pier (Fig. 4). Although this second feature may be a natural reef of weathered bedrock, Harper et al (1998a) believe it more likely to be the remains of an old pier made of ballast rock from ships. Most of the material in the reef appears to be well-rounded boulder or smaller cobble/pebble-sized material, typical of ballast material cast off from ships using wharves such as those in Departure Bay of Nanaimo where the train quays loaded coal to ships. This feature called the "Natural Reef" for the purposes of this study, has about l m of relief and very steep sides.

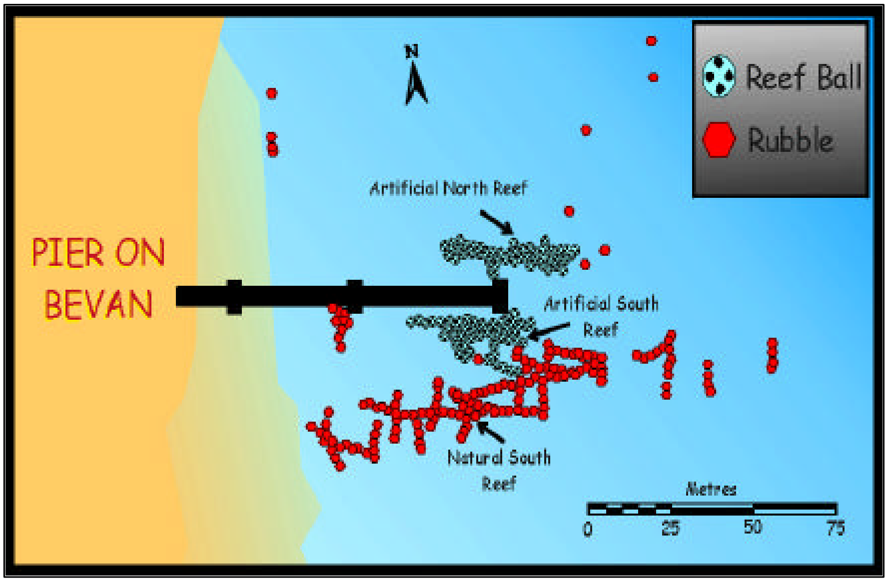

Figure 4. Map showing the relative location and size of the Bevan Pier, the artificial and natural reefs (taken from Harper et al 1998a)

Of incidental interest are other man-made features including bottles, tires, pilings, a crab trap, a traffic cone, metal grates and a coffee mug. There are a few concentrations of wood debris on the seabed, including an area just to the east of the old Sidney wharf fingers, that may represent a wreck site reported in the area.

Harper *et al* (1998b) further delineated a variety of seabed geologic units in the study area. Bedrock crops out along the shoreline and at one location offshore. On the adjacent land areas, this bedrock is overlain by a glacial marine clays that are mostly mud but contain a small amount of sand and occasional pebbles, cobbles and boulders. Offshore, however, the fine clay particles have been eroded away leaving sand and a veneer of coarser pebbles, cobbles and boulders. Locations of these coarse gravels indicate that there is only a thin cover of mud and sand overlying the glacial marine clay; that is, areas containing pebble, cobble or boulder are generally erosional and there is little sediment being deposited at the present time. There appears to be sufficient current energy, originating from both tide and wave action, to prevent deposition of the finest sediment.

The coarsest areas of the seabed occur along the shoreline (where stronger wave action removes most of the mud and sand) and along the Natural Reef. The area to the north of the Bevan Pier is generally free of gravel and is comprised of mud and sand. This "softer" sediment suggests that this area is depositional with an accumulation of sand and mud above the glacial marine clays. More evidence of infauna such siphon or burrow holes in the seabed also suggests lower energy occurs in this area.

In turn, the seabed substrate and depth influences the distribution of biota in the study area. Four major groups of vegetation occur near the Bevan Pier and the studied reefs:

- Dominant foliose red algae in waters closest to the shore, and on the artificial reefs and natural reef .
- Dominant eelgrass (*Zostera* spp) on the softer sand and mud under and south of the Pier and further offshore,
- Dominant filamentous red algae generally as a sparse cover on the softer sand and mud offshore; and
- Dominant *Agarum* vegetation covering the slightly coarser substrate in deeper areas southeast of the Pier.

The only faunal features that were mapped from the imagery were infauna holes created by animals of undetermined taxa. The distribution of the infauna holes shows relatively high densities on the north side of the Pier where softer sediments predominate.

In summary, Harper *et al* describe most of the surrounded seabed is soft sand and mud sediment, in contrast with the hard substrate of the two artificial reefs and the "natural" reef. The video examination also suggests that the artificial reefs have different associated algal assemblages than most of the area, although similar to those assemblages of the "natural" reef (Fig. 5). Algal cover was also much higher on all three reefs, generally in the >25% cover categories compared to <5% algal cover of most of the surrounding area.

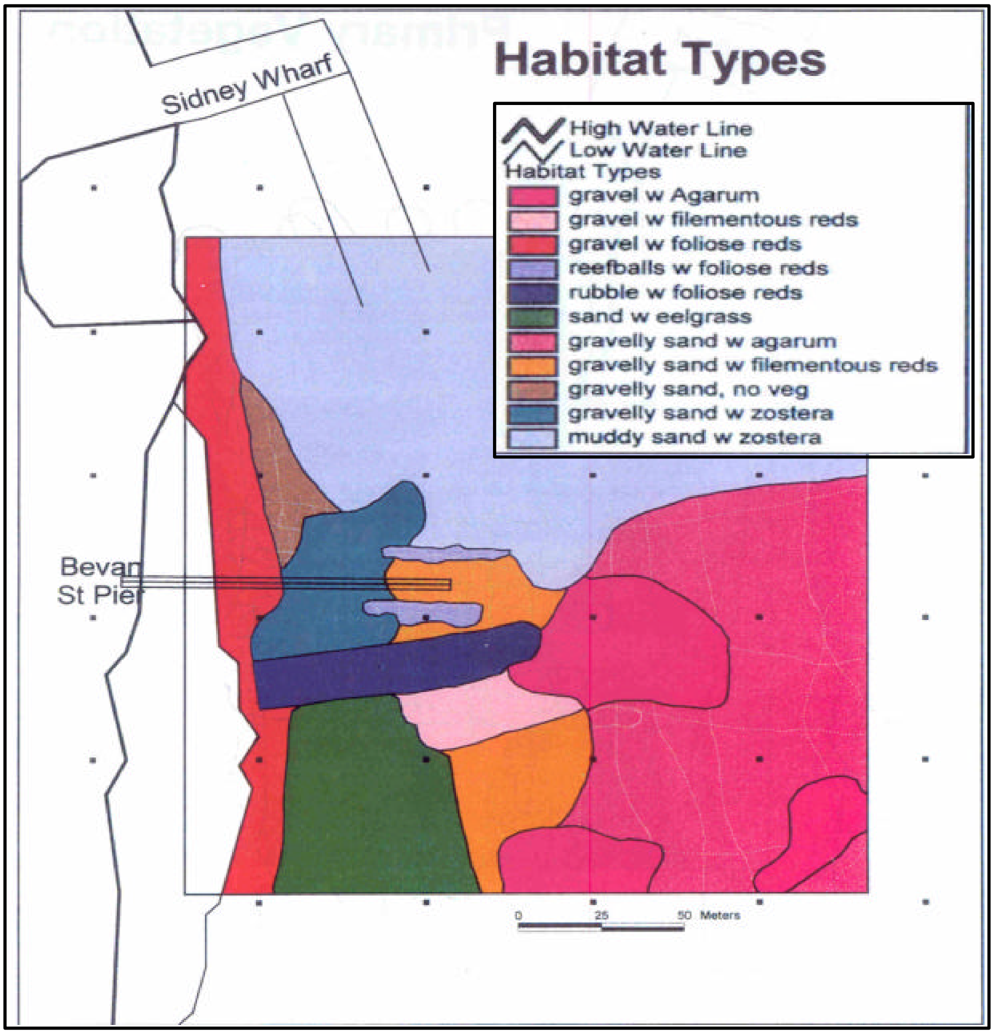

Figure 5. Map of habitat types surrounding the Reefball and rubble reefs. (taken from Harper et al *1998b)*

Coincidentally the Pier was constructed at a location that approximately divides the area into two general biophysical types (and coincidentally places the two artificial reefs in these two different environs):

- The *area to the south* with slightly coarser substrate and containing the densest portion of the eelgrass bed. The coarser nature of the seabed suggests that this south area has slightly higher currents, more mechanical wave and current energy. The southern area is generally erosional as evidenced by the widespread occurrence of gravel.

- The *area to the north* with slightly finer sediments supporting more infauna and dominated by sparsely distributed red algae; these features suggest slightly lower current energy levels and a mud-sand depositional area.

Ocean monitoring

In April 1997, divers moored an Aanderaa RCM-4 recording current meter with directional vane plate, location pinger and CTD Conductivity Temperature Depth sensor on one of the most seaward Reefballs of the AN Reef, about 2m above the sea bottom and in approximately 4 m water depth (Fig. 6). Near-surface current speed and direction, temperature and salinity (conductivity) are recorded every 30 min, almost continuously to present. However, biological fouling of the instrument's rotor and sensors is an ongoing problem of maintenance. Typically monthly, volunteer divers scrub the instrument to remove algal growth that hinders reliable records. Periodically they remove and re-deploy the instrument for professional servicing and data recovery.

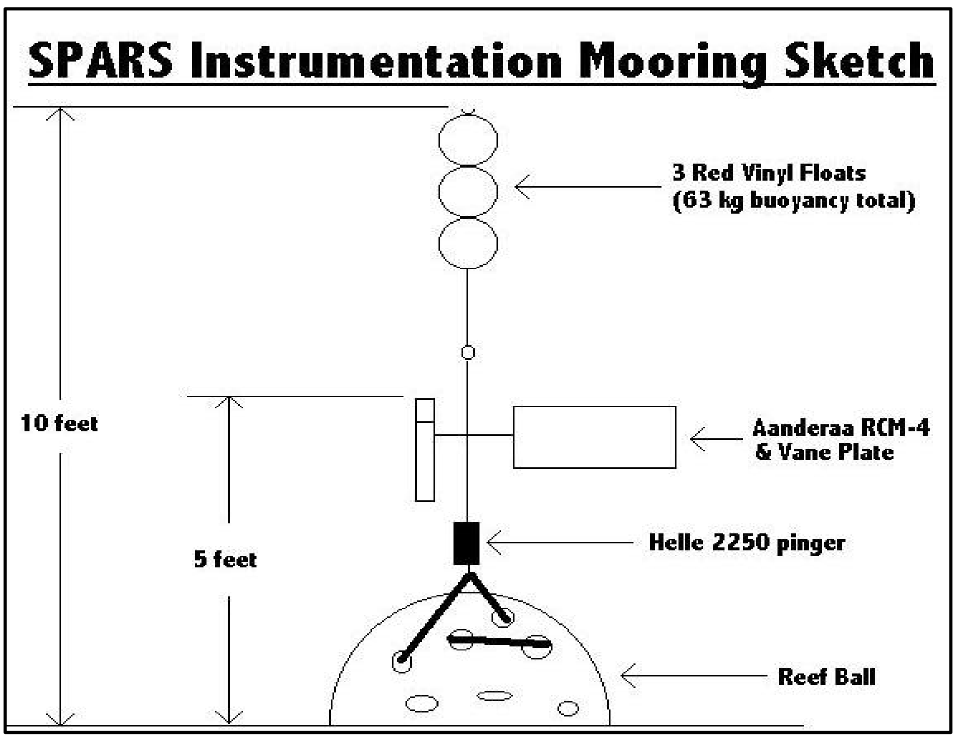

Figure 6. Schematic diagram of the SPARS current meter mooring.

Dive Surveys and Participants

The temporal duration, participants and dive conditions of surveys for each reef are outlined in the following Table 1, 2 and 3. Table 4 includes a complete species list used by divers.

Table 1. Summary of survey dates and completed surveys
(includes combinations of partial dive surveys but excludes incomplete surveys)

Reef	First survey date	Last survey date	Number of complete surveys	Longest gap between surveys
AN Reef Artificial North	3/15/97	4/14/01	61	November 1999 to April 2001
AS Reef Artificial South	3/22/97	11/25/00	53	September 1999 to November 2000
NS Reef Natural South	3/22/97	4/14/01	16	August 1998 to April 2001

Table 2. Summary of weather and water conditions for each survey date (Information is incomplete for several dives)

Survey date (yyyymmdd)	Start time	Weather conditions	Underwater visibility (m)	Video record
19980502	0800	100% overcast, breeze	5-7	Yes
19981101		clear	7	Yes
19981114		heavy rain	5	
19981201		wind to 100 k, heavy rain		
19981213		overcast, rain, wind 50-70k	5	Yes
19990105		clear, calm, overcast		
19990117		high SE wind, heavy rain		
19990130		overcast, chop, breeze	2-3	
19990307		clear, sunny, calm		
19990320		sunny, clear, calm	2-3	Yes
19990330		cool, 30 % cloud cover		
19990619		overcast, breeze, 1ft swell	10	
19990814		sunny and calm	2-3	
19990911			7	
19990925		sunny		Yes
19991009			10	
19991024			10	
20001125		overcast, wet, cool	1	Yes
19980521	1300	overcast, breeze, 1ft swell	3	
19980606	1425	hot, sunny, calm	3-5	Yes
19980718	1230	clear, windy, mild chop	7	
19980804	1430	clear, warm breeze, calm	3	

19980816	1145	cloudy (50%)	7	
19980905	1030	clear, sunny, calm	4-5	
19970306	1130	50% cloud, 10cm chop	5	Yes
19970315	0805	overcast, snow, 0.5m chop	5	
19970322	0900	overcast, calm	1	Yes
19970327	1316	overcast,windy, 9C	3	
19970426	1115	50% overcast, calm	3-5	Yes
19970501	0944	tide rising, calm	3	
19970503	1130	25% overcast, 1 ft chop	1	
19970510	1200	sunny, calm, 20C	1	
19970518	1430	calm, sunny	1	
19970522	0930	0.5 kn curr., tide falling, calm	3	
19970621	1330		1	
19970712	1000	overcast, slack tide, calm	1	
19970728	1300	sunny warm and calm	5	
19970731	1400	sunny warm and calm	3	
19970809	0830	10% overcast, calm, 25C	1	
19970913	1430		2	Yes
19971011	1330		3-5	
19971025	1300	overcast (100% clouds)	2	
19971108	1115	clear (0% cloud)	2	
19971122	1000	overcast, 0.5 m chop, rain	2	
19971206	0915	high lying fog	5-7	Yes
19971220	0900	33% overcast, chop, high tide	1	
19980207	1300	25% overcast, calm, sunny	2	Yes
19970201	1015	25% overcast, 0.5 m chop	1	Yes
19980307	1100	sunny, slight breeze	7	
19980324	1300	90% overcast , 20C	2	
19980404	0930	25% overcast, calm	7	Yes
19980421	1130	25% overcast, calm, 16C	4	
19991122		sunny, cool		
20010414	1019	strong current	4-7	Yes

Table 3. Diver affiliations, certifications and survey effort

Diver ID Number	Last name	First name	Role and affiliation	Certification Level	Total surverys AN	AS	NS
52	Barr,	Keelie	Diver	Advanced Open Water		1	
90	Biffard,	Doug	Diver, BC Parks	Open Water	1	1	
15	Campbell,	Doug	Diver		1	1	
29	Carter,	Kristine	Diver, Carter's Charters	Dive Instructor	1	3	2
3	Chapman,	Bob	Diver	Open Water		1	
27	Conley,	Kevin	SPARS Coordinator	Open Water	1		
24	Edgell,	Jon	Diver		2	1	1
11	Feldman,	Dan	Diver, Technician		4		2
19	Fitz,	Jill	Diver, Axys Group	Dive Master	1	4	1
89	Fuller,	Heidi	Diver		1		
30	Gavilan,	Manny	Diver		1	1	1
17	Green,	Gordon	Diver, Royal BC Museum		2	5	
33	Hirschbold	Markus	Diver	Dive Master		3	1
69	Howell,	Kate	Diver	Open Water	1	1	
36	Kalina,	Mike	Diver	Dive Master	6	2	5
85	Klokeid,	Adam		Open Water	5		
1	Kusch,	Adam	Diver	Advanced Open Water	5	3	1
42	Kusch,	Ron	Diver	Dive Master	9	5	2
54	Kyba,	Kim	Diver	Open Water	4	1	
39	Lambert,	Phil	Diver, Royal BC Museum	Advanced Open Water	7	7	2
25	Palmer,	Karen	Diver		5	8	
45	Robin,	Steve	Diver	Divemaster	1	3	
60	Schwann,	Samantha	Diver				1
56	Seaker,	Janice	Diver	Advanced Open Water	5		
26	Sendall,	Kelly	Diver, Royal BC Museum	Advanced Open Water		2	
48	Soley,	Tish	Diver, Ocean Sports	Dive Master	2	1	
70	Taylor,	Steve	Diver, Forest ecologist	Advanced Open Water	2		
58	Utterson,	Jim	Diver	Advanced Open Water		1	
14	Zaharychuk,	Dave	Diver, Videographer	Dive Master	5	7	

Note: Jim Cosgrove, a PADI Dive Master with the Royal B.C. Museum, is not included in the list because he did not conduct or record any survey dives. Instead he took videos of the reefs, and kept detailed logs of personal observations. Jim was one of the experts who verified species identifications and abundances.

Table 4. Taxa included for 4 passes on SPARS identification list

ID #	Species Name: Common Name	FormGroup	Pass Number
1	Sebastes caurinus: Copper Rockfish	rockfish	1
2	Sebastes maliger: Quillback Rockfish	rockfish	1
3	Sebastes nebulosus: China Rockfish	rockfish	1
4	Sebastes melanops: Black Rockfish	rockfish	1
5	Sebastes flavidus: Yellowtail Rockfish	rockfish	1
6	Sebastes spp. (adult):Other Adult Rockfish	rockfish	1
7	Sebastes spp. (juvenile): Juvenile Rockfish	rockfish	1
8	Cymatogaster aggregata: Shiner Perch	surfperch	1
9	Damalichthys vacca: Pile Perch	surfperch	1
10	Embiotoca lateralis: Striped Perch	surfperch	1
11	Brachyistius frenatus: Kelp Perch	surfperch	1
12	Ophiodon elongatus: Lingcod	hexagrammids	1
13	Oxylebius pictus: Painted Greenling	hexagrammids	1
14	Hexagrammos decagrammus: Kelp Greenling	hexagrammids	1
15	Gasterosteus aculeatus: 3-Spine Stickleback	sticklebacks and tubesnouts	1
16	Aulorhynchus flavidus: Tubesnout	sticklebacks and tubesnouts	1
17	Engraulis mordax: Northern Anchovy	schooling fishes	1
18	Clupea pallasii: Pacific Herring	schooling fishes	1
19	Family Osmeridae: Smelt	schooling fishes	1
20	Syngnathus leptorhynchus:Bay Pipefish	pipefish	2
21	Scorpaenichthys marmoratus:Cabezon	sculpins	2
22	Jordania zonope:Longfin Sculpin	sculpins	2
23	Enophrys bison:Buffalo Sculpin	sculpins	2
24	Rhamphocottus richardsonii:Grunt Sculpin	Sculpins	2
25	Myoxocephalus polyacanthocephalus:Great Sculpin	sculpins	2
26	Hemilepidotus spp.:Irish Lords	irish lords	2
27	Eumicrotremus orbis:Spiny Lumpsucker	lumpsuckers and clingfish	2
28	Gobiesox maeandricus:Northern Clingfish	lumpsuckers and clingfish	2
29	Pholidae/Stichaeidae:Gunnels & Pricklebacks	gunnels and prickleback	2
30	Pleuronichthys coenosus:C-O Sole	sole	2
31	Coryphopterus nicholsi:Blackeye Goby	gobies	2
32	Pandalus danae:Coonstripe Shrimp	shrimp	2
33	Cancer magister:Dungeness Crab	crabs	2
34	Cancer productus:Red Rock Crab	CRABS	2
35	Cancer gracilis:Slender Crab	CRABS	2
36	Pugettia producta:Northern Kelp Crab	CRABS	2
37	Pugettia gracilis:Kelp Crab	CRABS	2
38	Telmessus cheiragonus:Helmet Crab	CRABS	2
39	Scyra acutifrons:Sharp-Nosed Crab	CRABS	2
40	Pagarus spp.:Hermit Crab	CRABS	2
41	Oregonia gracilis:Decorator Crab	CRABS	2
42	Porifera:Sponges	SPONGES	3
43	Metridium senile:Plumose Anemone	SEA ANEMONES	3

44	Epiactis prolifera:Brooding Anemone	SEA ANEMONES	3
45	Serpula vermicularis:Calcareous Tube Worm	PLUME WORMS	3
46	Eudistylia:Feather Duster Tube Worm	PLUME WORMS	3
47	Dirona albolineata:Alabaster Nudibranch	NUDIBRANCHS	3
48	Anisodoris nobilis:Sea Lemon Nudibranch	NUDIBRANCHS	3
49	Archidoris montereyensis:Sea Lemon Nudibranch	NUDIBRANCHS	3
50	Cadlina luteomarginata:Com. Yellow-Margin Nudibranch	NUDIBRANCHS	3
51	Acanthodoris hudsoni:Hudson's Dorid Nudibranch	NUDIBRANCHS	3
52	Acanthodoris nanaimoensis	NUDIBRANCHS	3
53	Flabellina verrucosa	NUDIBRANCHS	3
54	Flabellina trilineata	NUDIBRANCHS	3
55	Diaulula sandiegensis:Brown Spotted Nudibranch	NUDIBRANCHS	3
56	Triopha catalinae:Common Orange Spotted Nudibranch	NUDIBRANCHS	3
57	Phyllaplysia taylori	NUDIBRANCHS	3
58	Aeolidia papillosa	NUDIBRANCHS	3
59	Melibe leonina:Hooded Nudibranch	NUDIBRANCHS	3
60	Geitodoris (Discodoris) heathi	NUDIBRANCHS	3
61	Onchidoris bilamellata:Brown Barnacle Nudibranch	NUDIBRANCHS	3
62	Tonicella lineata:Lined Chiton	CHITON	3
63	Tonicella insignis	CHITON	3
64	Mopalia hindsi	CHITON	3
65	Cryptochiton stelleri:Gumboot Chiton	CHITON	3
66	Hinnites giganteus:Purple-hinged Scallop	BIVALVES	3
67	Pododesmus macrochisma:Jingle Shell or Rock Oyster	BIVALVES	3
68	Diodora aspera:Rough Keyhole Limpet	SNAILS	3
69	Lacuna sp.	SNAILS	3
70	Nucella lamellosa:Wrinkled Whelk	SNAILS	3
71	Fusitriton oregonensis:Hairy Triton	SNAILS	3
72	Henricia leviuscula:Blood Seastar	SEASTARS	3
73	Pycnopodia helianthoides:Sunflower Seastar	SEASTARS	3
74	Evasterias troschelli:Mottled Seastar	SEASTARS	3
75	Pisaster ochraceus:Purple or Ochre Seastar	SEASTARS	3
76	Pisaster brevispinus:Pink Short-Spined Seastar	SEASTARS	3
77	Leptasterias:Six-Ray Seastar	SEASTARS	3
78	Ophiopholis aculeata:Daisy or Painted Brittlestar	BRITTLESTARS	3
79	Amphiodia sp.	BRITTLESTARS	3
80	Psolus chitonoides:Creeping Pedal Sea Cucumber	SEA CUCUMBERS	3
81	Cucumaria miniata:Orange Sea Cucumber	SEA CUCUMBERS	3
82	Eupentacta quinquesemita:White Sea Cucumber	SEA CUCUMBERS	3
83	Parastichopus californicus:California Sea Cucumber	SEA CUCUMBERS	3
84	Cnemidocarpa finmarkiensis:Broad Base Tunicate	SEA SQUIRTS	3
85	Metandrocarpa taylori:Orange Social Tunicate	SEA SQUIRTS	3
86	Pyura haustor:Wrinkled Tunicate	SEA SQUIRTS	3
87	Didemnum albidum	SEA SQUIRTS	3
88	Balanus crenatus:Acorn Barnacle	BARNACLES	3
89	Balanus nubilis:Giant Barnacle	BARNACLES	3
90	Enteromorpha	GREEN ALGAE	4
91	Ulva:Sea Lettuce	GREEN ALGAE	4

92	Agarum	GREEN ALGAE	4
93	Alaria	BROWN ALGAE	4
94	Laminaria	BROWN ALGAE	4
95	Nereocystis:Bull Kelp	BROWN ALGAE	4
96	Sargassum	BROWN ALGAE	4
97	Costaria	BROWN ALGAE	4
98	Gigartina:Turkish Towel	RED ALGAE	4
99	Iridaea	RED ALGAE	4
100	Porphyra	RED ALGAE	4
101	Gracilaria	RED ALGAE	4
102	Zostera spp.:Eel Grass	ROOTED PLANTS	4

Data Management

Output files from ARKS ACCESS database

A series of data output tables were designed in the ARKS database, for the analyses included in this report. The names and output protocols for these tables are included in Appendix B.

Data Corrections and Combinations

Because of the subjective and non-rigorous nature of this type of survey procedure, it was necessary to harmonize the resulting data as much as possible. This required a re-examination of every data sheet and database entry. This was done as objectively as possible, but in certain cases, the opinion of the most expert divers had to take precedence when there were conflicting identifications. The inherent variability of counts of highly mobile taxa, colonial forms and/or extremely small and abundant forms had to be dealt with. A great deal of time and effort was taken to retroactively interview divers to provide more accurate ranges in abundance of some of these forms. Incidental forms such as pelagic herring, anchovies and smelt, and non-reef species such as mud-dwelling ophiuroids, although included in the database, were excluded from analyses because they were deemed inappropriate to analyses related to the reef. In addition, data on percent coverage of algal forms was not included, because this information was collected only in the latter surveys. Thus, the analyses to follow included data only from passes 1-3.

Appendix C contains a complete listing of changes and corrections made to the database and the rationale for the changes. Appendix 3 lists the complete revised database, including divers, pass times, reef, dates, total taxa, total abundance and revised estimated abundances for each survey date and dive. The following analyses and graphics were done using the corrected and revised data abundances and taxa.

Prior to data analyses, Ms. Gaye Sihin went through the data sheets thoroughly and made a series of corrections. Throughout the course of the data analyses, Dr. Burd also found errors or ommissions, and corrected them in the database.

Changes to the data (see Appendix C) included;

1. Examination of outliers - sightings of rare taxa once by one diver which are not normally found in this habitat
2. Data eliminations – data which was not reliable due to diver inexperience, incomplete survey passes, etc.
3. Data Combinations - data for which different divers did different passes for the same reef (initial dives only) were combined to produce complete surveys

4. Converting log-ranked abundances to estimated abundances - using the expert divers (particularly Phil Lambert and Jim Cosgrove), probable high estimates of certain forms and possible mid-identifications were examined. In some cases, clear and consistent diver biases were noted (see below: Sources of Sampling Bias). This process included analysis of "unusual" (single or double sightings per reef over the entire study period). Some of these identifications are probably incorrect, but could not be modified without further information.
5. Oversights – several ubiquitous and common taxa were consistently not "seen" by certain divers.
6. Missed data sheets and new input to database – a few survey events were missed in the entry process and had to be incorporated.

Sources of sampling bias

The most important sources of sampling bias are inherent in the logistics of conducting opportunistic volunteer- diver surveys. Dive schedules had to be based on the willingness and availability of sufficient numbers of volunteer divers, on the weather, currents and visibility of the dive site. Therefore, the timing of surveys was opportunistic rather than rigorous. Because the program was voluntary and designed for public participation and education, a number of divers involved had limited or no experience with dive surveys or benthic ecology. As a result, each diver brings a unique set of biases to the project. The intent is that there are sufficient divers and replication to allow strong or dominant biotic patterns to be measured.

In addition, because of the limited pool of divers available at any given sampling time, the coverage on the reefs is somewhat uneven spatially and temporally, particularly in the last 2 years of the project. For example, the natural reef, which was intended as a baseline for comparison with the developing artificial reefs, was not surveyed as often as the articificial reefs, and was not surveyed at all from August 1998 until April 2001.

Finally, the counting method used was most accurate for those taxa which were large and easily visible, with less than 20 individuals per reef. For colonial or abundant forms, the method of counting was a logarithmic ranking, so that counts of "Many" (10-100) and "Abundant" (>1000) were highly inaccurate and subjective. The diver inevitably stopped counting after about 20, and started estimating.

There are several specific sources of error inherent in each dive survey. These include errors related to:

- Visibility on the day of the dive
- Algal and other encrustation (can be seasonal)
- Diver equipment: hand-lights, comfort and effectiveness of dive gear (such as flotation, air consumption, etc.)
- Diver effort (pushing aside algae, searching inside balls, swimming distance from reef etc.)
- Current
- Taxonomic experience and search-image of divers
- Diver bias (how each diver counts and separates individuals)

These errors cannot be quantitatively assessed for this type of study. They can be described graphically, with the reasons for their occurrence discussed.

The dive logs include a description of the visibility on the day of sampling. This information can be helpful in determining why some dives had considerably higher counts and species identified than others. The visibility is related to season and the presence of algal blooms in the water, bottom disturbance (from the divers or other sources), current conditions and freshwater runoff. Macro and micro-algal encrustation was noted for only a portion of the study period, so that complete records are not available. Also, the method of counting was not suitable to determining algal cover. Certainly, the more extensive algal cover in summer can affect the visibility of certain organisms, particularly those that hide. From talking to divers, it was also clear that not all divers had hand-lights, which would be essential to this type of survey, particularly under conditions of poor visibility.

In order to explore the possible taxonomic sampling bias inherent in the experience of various divers, a comparison of number of taxa observed (Fig. 7) relative to the most experienced diver (Phil Lambert), was conducted. There is no evident pattern in bias over time. In a number of cases, other divers had similar taxa counts. Observed species number was considerably lower than reference on at least 4 dives.

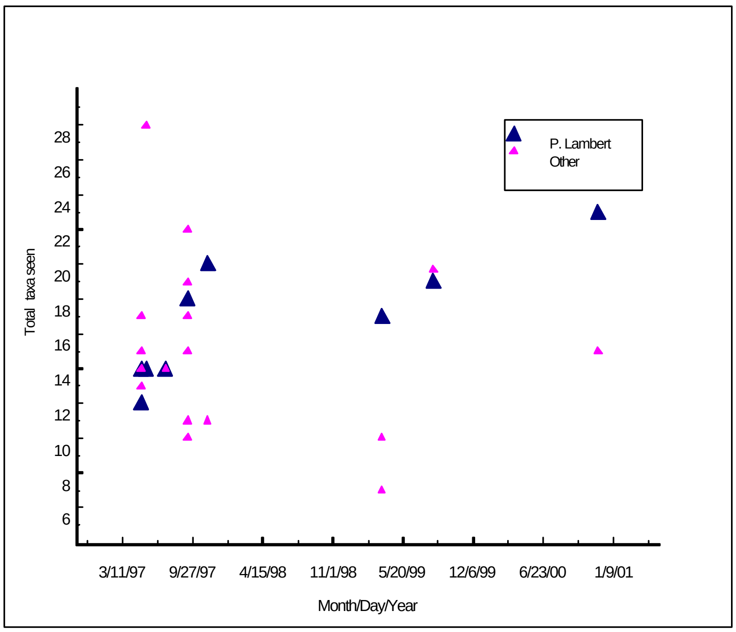

Figure 7. Relative number of taxa seen by dive buddies of Phil Lambert. Note the extremely high value for the one buddy was later re-assigned to a different reef (see Appendix C).

There were several instances where the two most abundant taxa (shrimp and acorn barnacles) were marked as abundant by 1 or 2 divers for a reef and date, and missed entirely by another diver. These were considered situations in which a) one diver did not have a light and was not seeing "hiding" animals (shrimp); or b) the species was so ubiquitous that is was overlooked as "background noise" by less experienced divers. In consultation with the expert divers and their personal dive logs, this oversight was corrected for the barnacles, which are sessile for life and cannot "disappear" when at least 1 "experienced" diver saw "Many" (see Appendix C for corrections). Shrimp numbers were more problematic. Obvious errors in two dives were corrected based on Phil Lambert's dive logs, but it was decided that because the shrimp can "swim" out of the way, changes to these numbers could not be done with confidence. Therefore, for the multivariate community analyses, the shrimp were taken out of all surveys because the numbers were considered unreliable.

To illustrate the "human" element (search image, differences in estimated counts, etc.) in diver bias, the number of taxa seen by each diver for each survey event, and the mean taxa seen per reef over the entire sampling period, are shown in Figure 3. Based on the results of the most experienced biologists and divers (see Table 3), and on dive logs from Jim Cosgrove (the videographer), it appears that a taxa richness ranging from about 14 to 25 would be expected for all reefs after the initial dives on the developing artificial reefs. Standard deviations suggest that a reasonable statistical range of expected taxa based on the expert divers might be more like 11 to 24. Certain divers had unusually low taxa counts, particularly those diving only once during the program (persons 33, 54 and 85). These divers presumably have less developed taxonomic ability or search images than the expert divers. One diver (person 11) always had unusually high taxa counts, suggesting that he tends to "split" taxa or identify more species than are present.

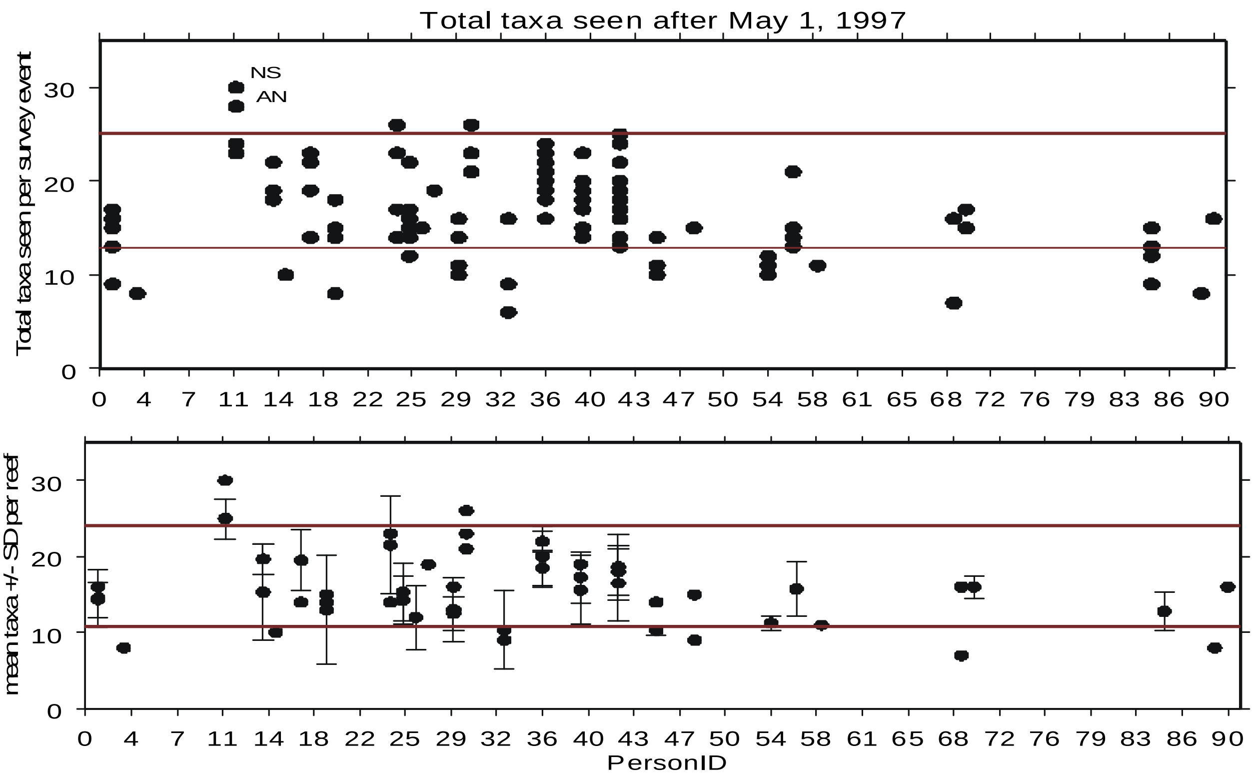

Figure 8. Diver bias in total taxa counts. For reference, the experienced divers are considered to be 1,17,26,36,39,42,48 and 56 (see Table 3).

Data Analyses

Because the data were not collected rigorously enoughly to test statistical hypotheses or answer specific questions amenable to statistical testing, data analyses were mostly exploratory in nature. Once final corrections to the data were complete (see Appendix D), it was possible to proceed with data analyses. Because it is recognized that certain aspects of the dive surveys were likely to be more precise than others, the data were analysed in several ways based on the potential sources of error and diver bias described above. Formats included;

1. All data untransformed
2. Data from selected expert divers untransformed
3. All data log (x+1) transformed
4. Invertebrate data only
5. Fish data only

Not all subsets of data were analysed using the full suite of methods outlined below. In addition, when results were not appreciably different for subsets of toe total data, they were not included.

The selection of “expert” divers was based on taxonomic experience, biological survey experience, proficiency at diving, and the number of total dives made on the reefs. Although this is possible to do, it is somewhat arbitrary, except in the most obvious cases. The arbitrary subset of divers used included 1, 17, 25, 26, 36, 39, 42 and 48 (see Table 3). Multivariate analyses described for the total data (untransformed) were repeated using an extreme data transformation (log x+1), which downgrades the contribution of the most abundant species and increases the importance of the rare species. This was considered appropriate since;

- The abundance counts were originally recorded on a log-ranked scale before they were converted to more accurate counts
- The weighting bias of a Bray-Curtis similarity measure is heavily in favour of the most abundant taxa, whereas counts were more accurate for the rare forms.

The analyses were repeated for invertebrate data only, on the assumption that the seasonality of fish occurrences might have been creating a confounding influence. Finally, the analyses were repeated for fish data only, since some of the dominant fish were obviously more evident on the artificial reefs than on the natural reef, and to see how seasonal signals may bias results.

Summary statistics

1. Comparison of mean and variance of abundance estimates for all survey dates and reefs.

2. Mean and standard deviations of abundance and taxa, as well as total taxa numbers for each survey date and reef, and sampling precision based on replication (see Downing 1979).

3. Relative abundances (percentage) of major taxonomic groups for each reef and date.

4. Dominant species distributions for each reef over time

Multivariate Analyses

A dissimilarity measure (Bray-Curtis 1957) was used to assess the pair-wise similarity in overall faunal composition (Diver passes 1-3) between reefs and times. This index weights the most abundant species most strongly.

Hypothesis Testing

The primary hypothesis of interest was:

Ho: There was no difference in overall faunal composition between the reefs (AN, AS, NS)

The Bray Curtis Similarity measure and an unweighted pari group mean average sort was used for clustering the species abundance data from all dives. This included non-parametric significance testing (Nemec and Brinkhurst 1988). The null hypothesis was tested at each linkage in the dedrogram, to determine if groups of surveys can be objectively separated at a certain probability (Type I error or alpha=10%). The significance testing in effect asks the question, are the mean faunal compositions of reefs AS and AN significantly different from each other or from the natural reef? Because there was insufficient replication for each survey location and date, replication in the data was artificially created by grouping all the surveys for each reef together. Thus, the analysis simply compares the average faunal compositions for each reef (regardless of changes over time). If the null hypothesis is rejected, it cannot be said that the reefs are the same. However, this does not mean that they are different. The within-reef variability could be too high to have a powerful enough test. To determine power, the alternate simple hypothesis was tested, with a Type II error (beta) set at 10%[1]:

Ha: There was a difference in overall faunal composition between the reefs.

A simple bootstrap simulation method for testing the alternate hypothesis (and thus power) of each linkage in the dendrogram was used (Nemec 2000). Power is tested for each linkage, or for pre-selected groupings of samples. The output files for these analyses are shown using similarities (1-dissimilarities) for the cluster dendrogram. Note that it is not appropriate to test power for linkages for which the null hypothesis cannot be rejected.

Probability Distributions

A method for examining the overlap in probability distributions of total faunal composition between each of the artificial reefs and the natural reef was used to examine the relative temporal variability of the natural or "reference" reef, and relate that to the proportion of surveys in which the composition of the artificial reefs overlapped the "reference" distribution. This method is described in detail in Burd (2002). The cumulative frequency distributions of pair-wise dissimilarities from the Bray-Curtis matrix is used. Because these are pair-wise values, a reference composition is required, with which to compare each reef and survey composition. The "average" NS composition for the entire survey period was used for this "reference" point. The degree of overlap in the frequency distributions indicates the relative probability that the artificial reefs have the same composition over time as the natural reef. This method is particularly useful in cases where long time-series data have not been collected in an appropriate way to meet the assumptions of standard hypothesis and power testing protocols (see Lenth 2001, and Burd 2002).

[1] The setting of type I and type II errors at 10% follows the Environment Canada Environmental Effects Monitoring Program technical guidance for Cycle II Pulp and Paper and Cycle I Metal Mining industries (EC 1998).

Results

Habitat Conditions and Evolution

Detailed current meter, temperature and salinity data are not included but can be examined through the Institute of Ocean Sciences data management program (contact: Andrew Lee, Institute of Ocean Sciences, PO Box 6000, Sidney, B.C. Canada V8L 4B2). Fouling problems with the current meter rotor resulted in limited time-series data, however, results show that with the tidal cycle removed the predominant current direction is to the southeast (see Figure 9). This can be related to several features, including wind, estuarine circulation and/or the relative strength of ebb/flood tides. Because of the location and temperature/salinity profiles, it is likely that the currents are mainly affected by rectified tidal flow, and less by estuarine flow (see Thomson 1981). Sea-temperatures at 9 m depth are relatively uniform, ranging from about 7-9^{o}C in winter, and 10-12 ^{o}C in summer. Fall and spring temperatures are intermediate, but show some variation from year to year, and were generally about 1-2^{o}C lower in spring 1997and 1999 than in spring 1998 (end of El Nino). This type of difference can have an effect on the productivity of shallow coastal waters, particularly for plant production. Salinity values ranged from 26.5 to 30 ppt, with clear surficial freshwater signals in October, and late winter/early spring, related to peak rainfall and run-off from land sources and the Fraser River. Salinity values were highest in late fall and early winter (November through January) in 1997 and lowest in late March 1998. In 1999, a dramatic drop in salinity occurred (to 20 ppt) in September, and remained until the end of the year (end of recording).

Over the 5 year period, there was little burial of the reef structures by natural siltation. Environmental dynamics were not studied in detail, but observational and video recordings over time provide a means to qualitatively describe the development of the reef habitat and settlement patterns. The first dives at the three reefs took place about 4 months after deployment, towards the end of March 1997. Only the artificial reefs were videoed. The videos provide limited information on general coverage and major groups. The diver data provides more detailed information on fish and invertebrates, but algal cover was not systematically recorded until relatively late in the study. The report on habitat mapping by Harper et al. (1998b) notes that both the reefballs and the artificial reef were covered by foliose red algae in March 1998, and that this was in contrast to the surrounding substrate, which had lighter cover of filamentous red algae between the reefs and zostera beds to the north of the reefs in muddier substrates.

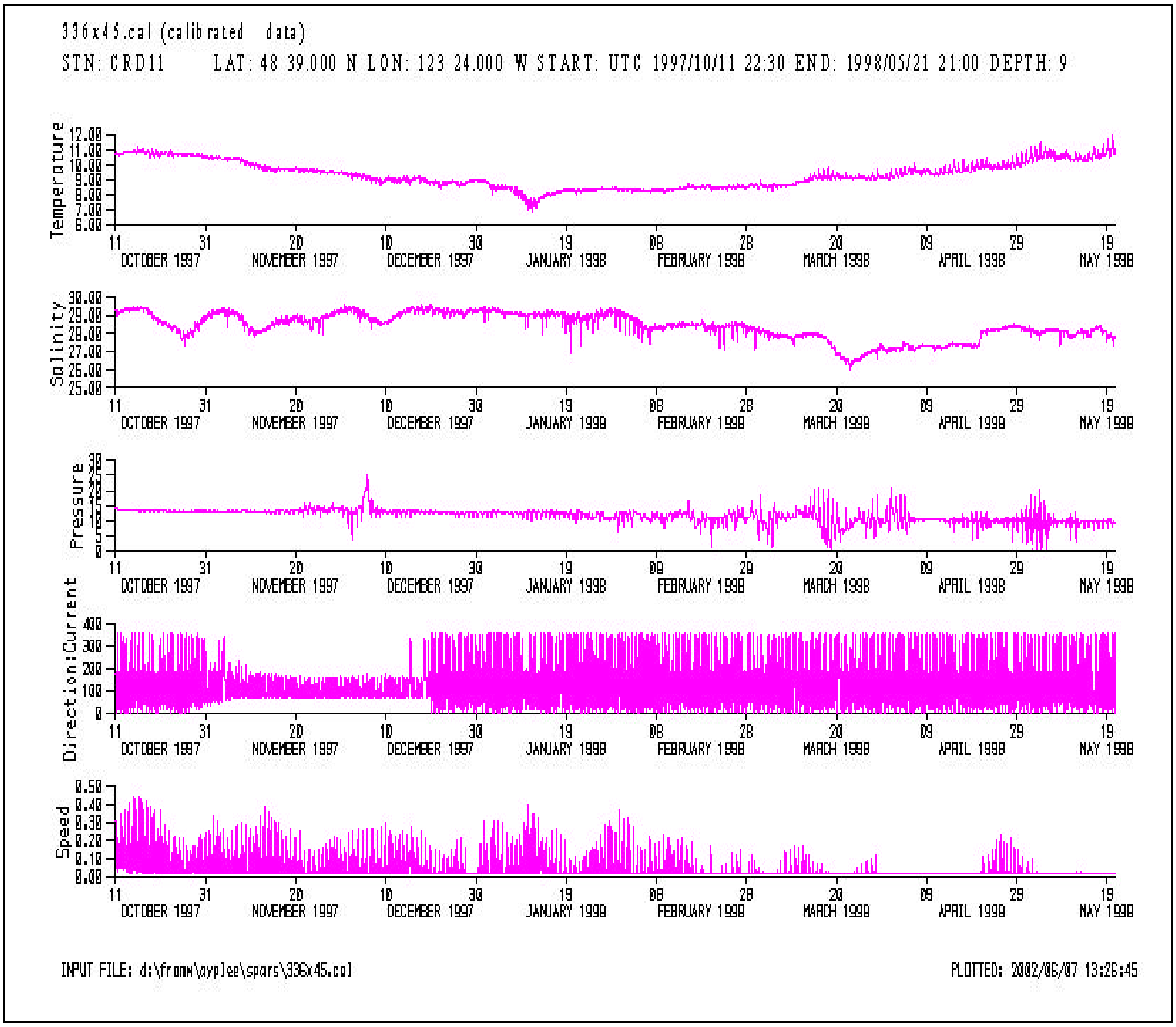

Figure 9. Sample plot of temperature, salinity and current meter data for the period from October 11/97 to April 21/98.

Artificial South Reef (AS):

At this time, filamentous red algae appeared to be the first plant colonizer, with >50% coverage on the upper side of the balls. The shaded or undersides of the balls were uncolonized by macroalgae, barnacles or any other visible forms. One month later, the filamentous reds appeared to be dying (turning white), with more greens and foliose reds growing on the topside and attachment ropes. At this time, a few mature crabs, starfish and anemones were evident. By September of 1997, the algal coverage was very high, with *Ulva* evident on the undersides of the balls. More encrusting invertebrates were evident, including bryozoans, with associated predaceous nudibranchs. More invertebrate grazers were evident, particularly kelp crabs. By early December 1997 most of the macroalgae had died back (<5% cover), with only the stipes remaining, along with a few small forms or portions of foliose red algae. Some barnacles had appeared on the inside edges of the balls. In the video a school of tubesnout were swimming around the reef.

By February of 1998, conditions were similar to December, except that the foliose red algal coverage had again increased to 30-50%. A few young *Laminaria* were beginning to grow on the balls. The insides of the balls still appeared to be clean, with considerably more barnacles evident. By the next April, algal cover (larger reds) was 100% on the upper half of the balls, with patches of sponges or tunicates growing on the underside. Lots of algal debris was evident in the spaces between the balls. At the deep end of the transect, a few *Laminaria* were evident. By May 1998 the red foliose algae had covered the lighted sides of the balls, and grown to larger than 2 ft in length, with little Laminaria evident except at the deep end (about 25% coverage). By June of 1998, the large reds had been replaced in areas by patches of sponge. Lots of juvenile rockfish were evident. By December of 1998 many perch were evident, and the balls were almost devoide of macroalgae, except for a few *Gigartina* and a few *Laminaria* at the deeper ends. Notably, the balls were much more bare than the same time the previous year. Sponge patches covered 50-70% of the undersides of the ball. Shrimp were abundant inside the balls, and lots of barnacles had settled.

By March of 1999 there were more *Gigartina*, about 50% coverage on the light sides by foliose reds, with some *Laminaria* at the deep end. There were now lots of small anemones and a few larger forms, barnacles and shrimp. However, no tubicolous polychaetes were evident. The final video was taken at the end of November 2000. Some *Gigartina* were vident, along with some large foliose reds, about 30% sponge cover, and more anemones. A nesting greenling was observed.

Artificial North Reef (AN)

The first video on AN was taken on Feb 8, 1998. There was low algal coverage and visibility was good. A few small red plumose algae were evident both on and between the reefs. Lots of encrusting algae were evident. There was a markedly greater algal growth on the south side of the reef. A few sunstars and crabs and lots of barnacles were present. By May 1998 there was a high coverage of plumose red algae and plumose green algae, especially on the south side of the balls. Starfish and crabs were on the algae, with lots of bryozoans on the attaching ropes. Smaller attached organisms such as barnacles were difficult to see for the algae.

By March 1999 the algae were much reduced, but greater than the year before. Lots of encrusting hydroids tunicates and sponges evident, along with many anemones, shrimp inside balls. In September 1999 the balls were covered with huge brown algae, greens, and others, with very little else visible. The final dive at the end of November in 2000 showed losts of crabs and small anemones, more barnacles than the previous years, large patches of orange sea squirts, sponges and bryozoans. Several nesting greenlings were noted.

Summary Statistics using all data

The log/log plot (Figure 10) illustrates that the variance was independent of the mean for all the surveys and reefs. In other words, there was a wide range in variance within the abundance range of the majority of samples (100-300 animals per survey event). In a more quantitative and spatially diverse sampling design, such as a gradient of infaunal grab samples, spatial patchiness or aggregation in the benthos would be clearly evident as a power relationship between mean abundance and variance (Downing 1979, Vezina 1988), with the degree of aggregation in communities indicated by the slope and elevation of the power regression. However, the abundance estimates for the SPARS data are simply total counts for the entire reef, therefore, the values are for a single, frequently repeated sample for each reef. Therefore, patchiness or changes in aggregation between samples would be temporal, rather than spatial. Depending on the reliability of the data, it appears that there was no clear temporal patchiness indicated. Rather, the variance of abundance estimates would be driven by the other sources of error and diver bias.

The summary data showing mean and standard deviations of abundance and taxa, as well as total taxa numbers for each survey date and reef is shown in Table 5. Precision is the standard error as a proportion of the mean abundance. This measure has been used to indicate how representative the count of organisms is for a given sample location and time (Downing 1979). For benthic infaunal samples, 20% is generally considered acceptable (Downing 1979). In the SPARS data set, which is much less quantitative, the sampling precision was greater than 20% in 4 cases, but never over 30%. For this type of sampling design, this is probably reasonable. Three of the 4 precision values >20% were for the natural reef. This is probably because the natural density of growth was highest on this reef, making accurate counts of organisms more difficult.

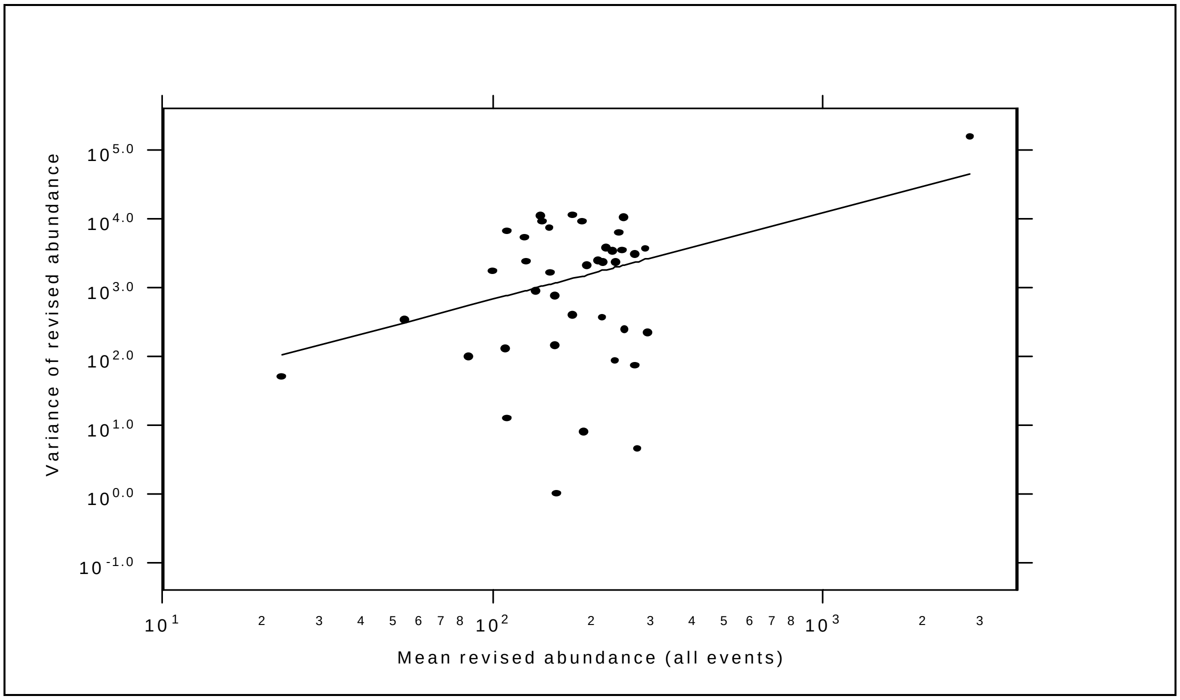

Figure 10. Mean and Variance log/log relationship for all reefs and dates.

The mean abundance with standard deviations was plotted along a time scale for the three reefs (Figure 11). Fluctuations were considerable, but there were no discernable differences between reefs, except that the lowest abundance values occurred on the two artificial reefs in the first few surveys. This type of abundance fluctuation is not unexpected, with seasonal changes related to species life-cycles, visibility and algal cover on reefs. A gradual increase in abundance seems evident in AS, with considerably higher values in the final survey in November 2000 than any other survey for the natural or artificial reefs. The high abundances in the last survey are attributed to a few opportunistic taxa (acorn barnacles, rock oyster) and colonial animals (orange social tunicate). What is surprising is that such a considerable overshoot of opportunists was not evident on the artificial reefs until 3 ½ years after deployment of the reef balls. This suggests that AS is still developing, and has not yet reached a stable community composition.

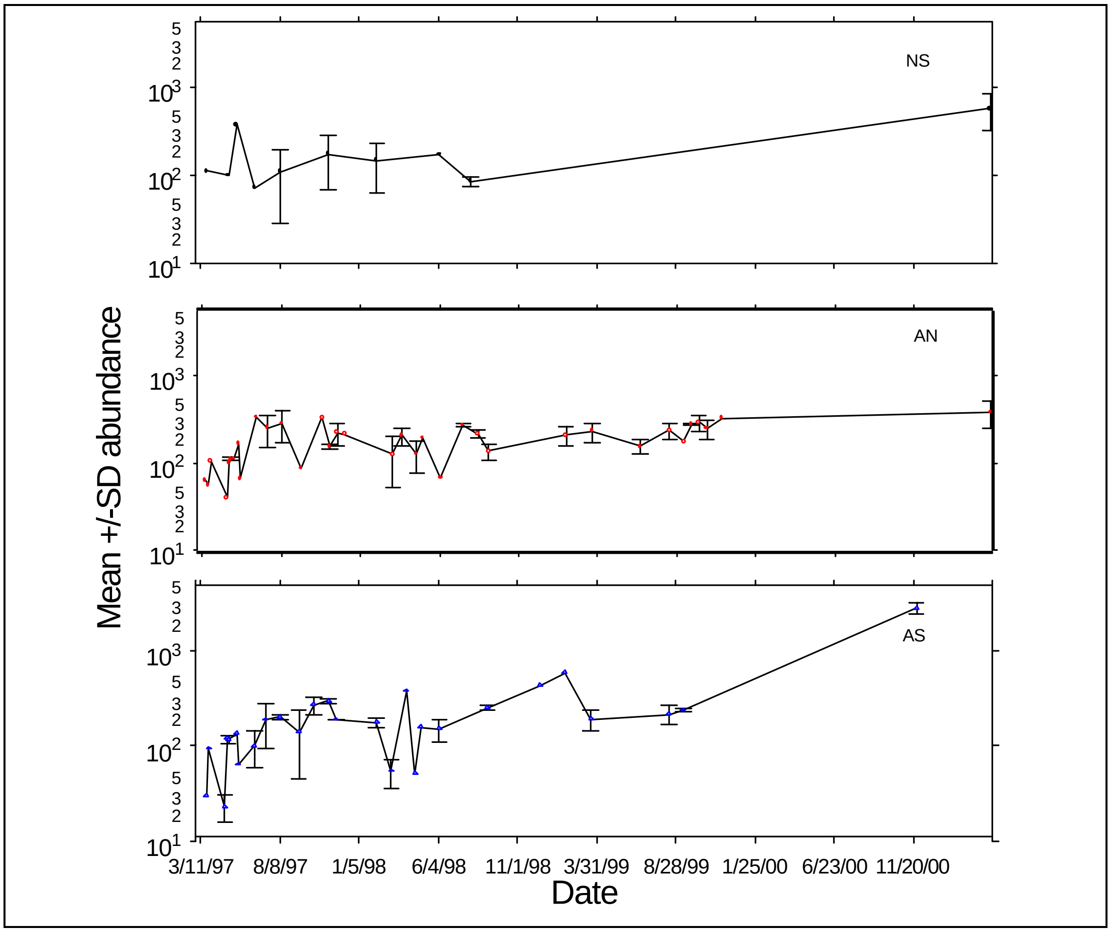

Figure 11. Mean total abundance fluctuations for the three reefs over time.

Table 5. Summary of abundance data for each reef and survey date.								
Reef	Date	# of Replicates	Total # of taxa	Mean # of taxa	S.D. taxa	Mean abundance	S.D. abundance	Precision (%)
AN	3/15/97	1	14	14	0	64		
AN	3/22/97	1	9	9	0	56		
AN	3/27/97	1	12	12	0	104		
AN	4/26/97	1	9	9	0	40		
AN	5/1/97	1	14	14	0	99		
AN	5/3/97	2	19	16	1.41	110		2
AN	5/10/97	1	14	14	0	111		
AN	5/18/97	1	17	16	0	165		
AN	5/22/97	1	19	19	0	66		
AN	6/21/97	1	27	27	0	332		
AN	7/12/97	2	27	19.50	4.95	250	102.53	20
AN	8/9/97	2	30	21	4.24	282	108.90	19
AN	9/13/97	1	16	16	0	87		
AN	10/25/97	1	21	21	0	329		
AN	11/8/97	2	19	15.50	2.12	154	12.02	4
AN	11/22/97	2	30	21	7.07	220	61.52	14
AN	12/6/97	1	19	19	0	214		
AN	3/7/98	4	24	13	2.16	125	72.75	15
AN	3/24/98	3	22	14	1	206	47.80	9
AN	4/21/98	2	17	14	2.12	126	48.79	19
AN	5/2/98	1	19	19	0	192		
AN	6/6/98	1	17	17	0	67		
AN	7/18/98	2	30	23	2.12	271	8.49	2
AN	8/16/98	2	25	21	5.66	214	19.09	4
AN	9/5/98	2	22	16	0.71	135	29.70	11
AN	1/30/99	3	16	11	2.89	208	49.52	8
AN	3/20/99	3	19	12	4.58	231	57.94	8
AN	6/19/99	2	21	17	2.83	154	27.58	9
AN	8/14/99	2	23	19	0	237	48.08	10
AN	9/11/99	1	13	13	0	176		
AN	9/25/99	2	16	16	0.71	274	2.12	0
AN	10/9/99	2	20	16	5.66	290	60.81	10
AN	10/24/99	3	22	17	1.53	247	59.14	8
AN	11/22/99	1	22	22	0	324		
AN	04/14/01	3	29	17	2.65	380	130.93	17
AS	3/22/97	1	10	10	0	30		
AS	3/27/97	1	12	13	0	93		
AS	4/26/97	2	14	9	0	23	7.07	15
AS	5/1/97	1	14	14	0	118		
AS	5/3/97	2	20	14	0.58	117	11.50	5
AS	5/18/97	1	14	14	0	135		
AS	5/22/97	1	17	18	0	63		

AS	6/21/97	3	15	9	3.06	100	41.58	14
AS	7/12/97	2	17	14	0	187	94.75	25
AS	8/9/97	2	23	18	2.12	201	9.90	3
AS	9/13/97	7	32	16	4.57	141	95.93	10
AS	10/11/97	2	25	20	4.95	269	55.15	10
AS	11/8/97	2	21	17	1.41	296	14.85	3
AS	11/22/97	2	26	22	0	188	2.83	1
AS	2/7/98	2	17	13	2.12	175	19.80	6
AS	3/7/98	2	14	11	0.71	54	18.38	17
AS	4/4/98	1	23	23	0	375		
AS	4/21/98	1	10	10	0	51		
AS	5/2/98	2	26	18	4.24	157		0
AS	6/6/98	3	22	11	5.80	162	45.44	9
AS	9/5/98	2	21	17	4.95	251	15.56	3
AS	12/13/98	1	20	20	0	428		
AS	1/30/99	1	15	15	0	581		
AS	3/20/99	2	17	15	2.83	193	45.96	12
AS	8/14/99	2	29	21	1.41	265	7.80	2
AS	9/11/99	2	22	20	3.54	235	9.19	2
AS	11/25/00	2	25	20	4.95	2788	395.27	7
NS	3/22/97	1	21	21	0	112		
NS	5/3/97	1	19	20	0	100		
NS	5/18/97	1	30	30	0	376		
NS	6/21/97	1	16	16	0	73		
NS	8/9/97	3	19	12	3.06	110	84.92	25
NS	11/8/97	2	25	15	5.66	175	106.07	30
NS	2/7/98	2	27	20	8.49	149	85.56	29
NS	6/6/98	1	23	23	0	171		
NS	8/4/98	1	22	18	2.83	85	9.90	6
NS	04/14/01	2	30	23	2.15	570	252.40	22

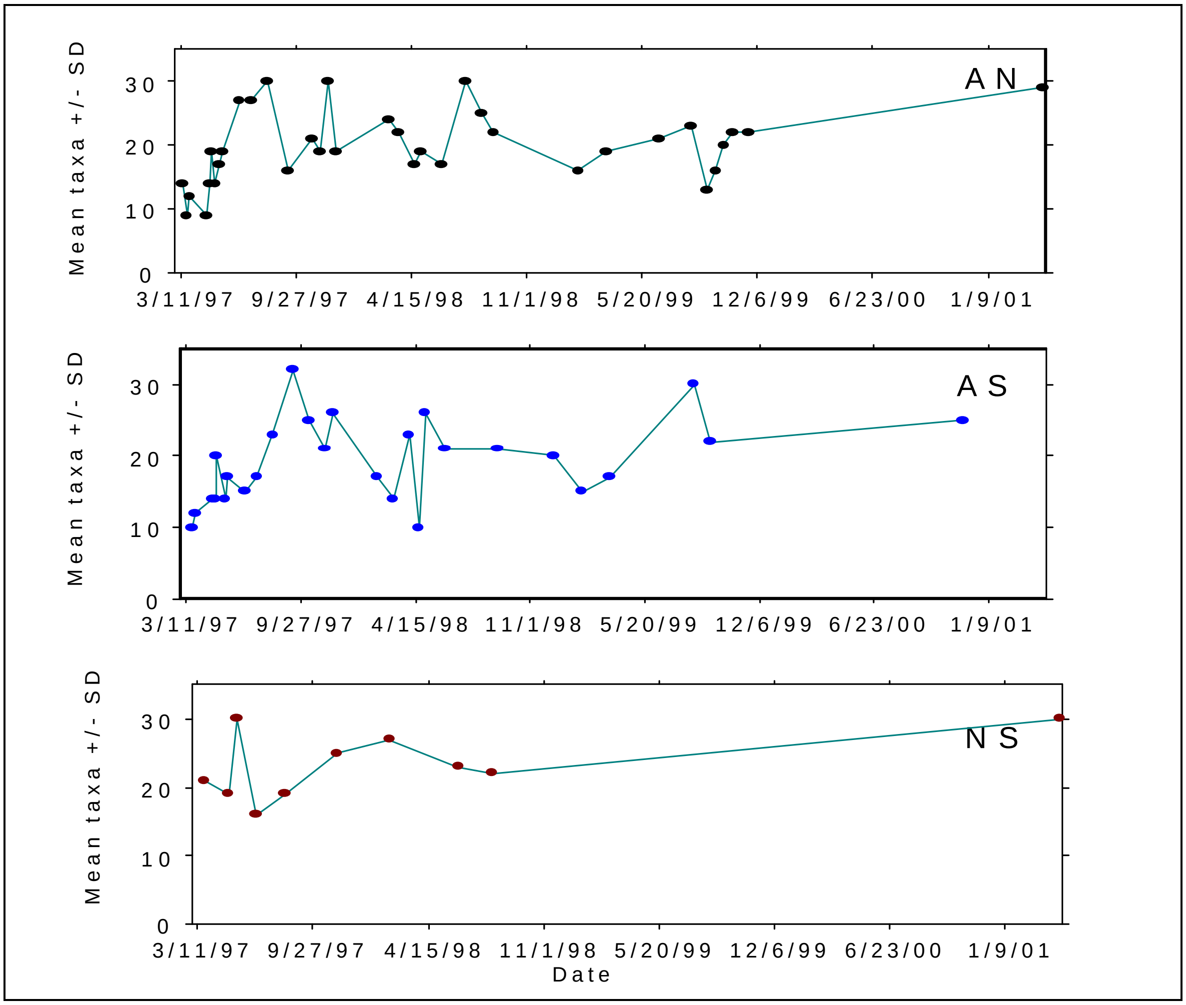

Figure 12. Total taxa (for all replicate dives) seen on each reef and each survey date.

Total taxa per reef were also plotted over time, and show reasonable fluctuations (Figure 12). Total taxa number is affected not only by diver bias, but by the number of replicate dives for each reef and date (Figure 13). For example, only single replicate dives had less than 14 total taxa per survey event. The unusually high taxa number (Figure 12) in NS is related to diver bias (see Diver 11, Figure 8 above) and is less believable than the highest values in AN and AS, which occurred on days when 2 or more divers traversed the reef. The highest taxa value of all dives occurred on AS when 7 divers surveyed the one reef. Depending on the number of replicates, it appeared that a maximum of 32 taxa (from the list used for the surveys) are likely to be identified on any reef. The values from NS suggest that anything above 16 taxa per reef (from the list provided to divers) is probably "normal" for this type of mature habitat and location. Total taxa numbers were consistently lower (10-14) than this until the first of May in AS and AN, regardless of the number of divers per survey event, and show an initial "overshoot" which is often characteristic of benthic recolonization (Pearson and Rosenberg 1978, Burd et al. 2000).

Mean taxa numbers for each reef and date show a reasonable standard deviation (Figure 14), and illustrate that the number of taxa likely to be seen by any one diver on any particular dive ranged between about 10-20 for the artifical reefs, and slightly higher (about 12-22) for the natural reef. The average number of taxa seen on AS was slightly lower than on AN, although the deviations usually overlapped. Notably, the species number did not change appreciably in any reef for the final surveys (Nov 2000 for AS, April 2001 for AN and NS), even though abundance increased somewhat in NS and an order of magnitude in AS.

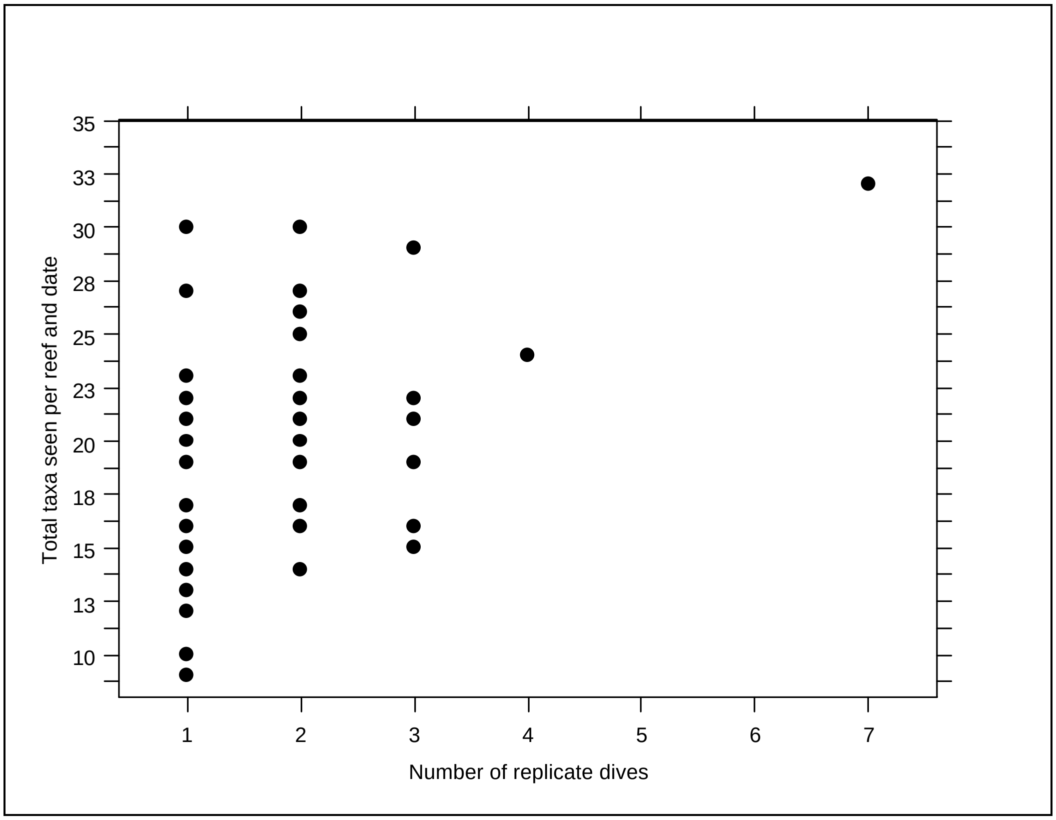

Figure 13. General increase in tota taxa seen with increased replication (number of divers per reef).

Table 6 shows the relative abundances of major taxonomic groups. Some of the seasonal patterns and temporal patchiness in abundances are evident from this table. Table 7 shows the most abundant taxa, and their relative distributions amongst the three reefs. The most abundant taxon, the acorn barnacle, is clearly a colonizer, and was rare on the natural reef. The orange social tunicate was only common on the south reefs. Sunflower starfish and red rock crab were ubiquitous, striped perch and rock oysters were not found on the natural reef, and orange sea cucumber was only found on the natural reef. The remaining taxa were fairly evenly distributed amongst the reefs. The following Figures 15 to 26 show the temporal distribution of several of these dominant taxa on the three reefs.

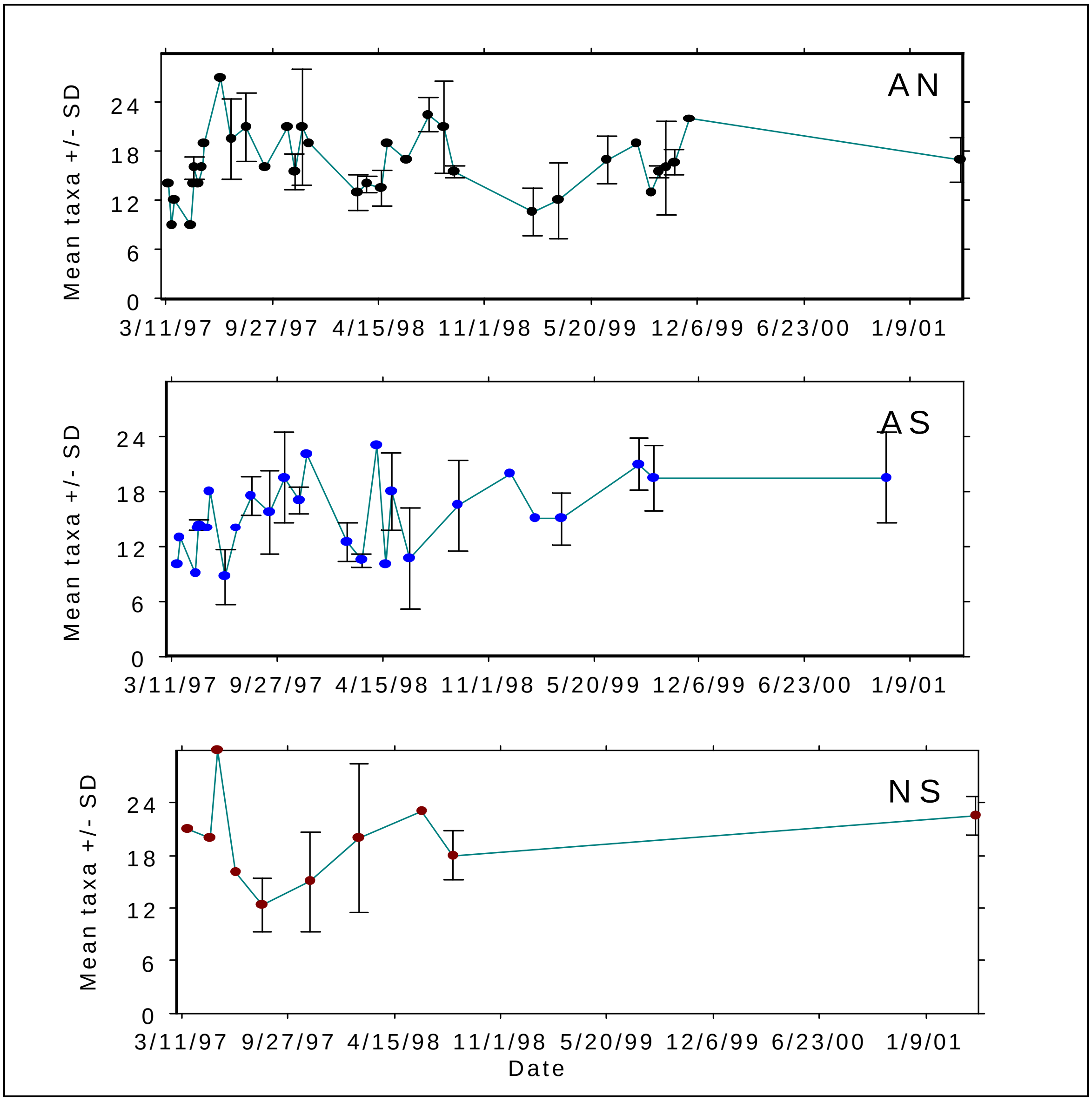

Figure 14. Mean taxa number +/- standard deviation for each reef and date.

Table 6. Relative percent abundance of major taxonomic groups for each reef and survey date. ("Total abundance" represents the mean total numerical abundance of animals in that survey)

Reef	Date	Fish	Crabs	Sponges	Antho-zoa	Nudi-branchs	Other molluscs	Seastars	Sea cu-cumber	Tunicate	Barnacle
NS	3/22/97	3.9	36.3	24.5	3.9	9.3	0.0	22.1	0.0	0.0	0.0
NS	5/3/97	42.2	24.8	0.0	7.5	5.6	0.0	19.9	0.0	0.0	0.0
NS	5/18/97	18.0	26.0	0.0	7.2	2.8	3.6	16.8	1.2	20.0	4.4
NS	6/21/97	12.9	41.4	0.0	1.4	1.4	2.9	8.6	31.4	0.0	0.0
NS	8/9/97	17.2	21.6	10.0	1.2	0.0	0.4	31.2	18.4	0.0	0.0
NS	11/8/97	2.0	7.6	0.0	0.8	1.2	0.4	21.6	5.2	60.8	0.4
NS	2/7/98	0.7	23.1	17.0	3.7	19.7	6.8	24.1	0.0	4.8	0.0
NS	6/6/98	19.4	38.2	0.6	8.8	4.7	0.0	21.2	7.1	0.0	0.0
NS	8/4/98	19.3	11.2	0.0	1.2	3.7	0.0	39.8	24.8	0.0	0.0
NS	4/14/01	0.3	2.5	21.0	0.8	2.0	0.6	2.0	54.9	21.3	0
AS	3/22/97	1.8	48.2	0.0	1.8	2.7	0.9	44.6	0.0	0.0	0.0
AS	3/27/97	5.4	18.9	0.0	4.1	6.8	0.0	64.9	0.0	0.0	0.0
AS	4/26/97	3.9	35.3	2.0	3.9	1.0	0.0	53.9	0.0	0.0	0.0
AS	5/1/97	7.0	55.7	0.0	5.2	3.5	0.0	28.7	0.0	0.0	0.0
AS	5/3/97	11.4	38.7	0.0	3.7	3.2	0.0	40.4	0.0	0.0	2.5
AS	5/18/97	14.1	37.6	0.0	0.0	0.0	0.0	30.6	0.0	0.0	17.6
AS	5/22/97	18.0	40.4	0.0	1.1	1.1	0.0	39.3	0.0	0.0	0.0
AS	6/21/97	4.8	23.2	0.0	0.0	0.0	0.0	32.0	0.0	0.0	40.0
AS	7/12/97	15.0	29.4	0.0	0.0	0.0	0.8	13.4	0.0	0.0	41.4
AS	8/9/97	32.1	15.3	0.0	0.6	0.9	0.0	17.6	0.0	5.1	28.4
AS	9/13/97	24.7	23.4	0.0	0.0	1.7	0.1	20.1	0.0	0.0	29.9
AS	10/11/97	19.5	15.8	8.1	0.0	1.6	2.2	11.8	0.0	0.4	40.6
AS	11/8/97	21.2	8.6	8.1	0.6	1.0	0.0	19.8	0.0	0.0	40.7
AS	11/22/97	35.5	18.1	1.1	3.3	7.6	0.4	27.9	0.0	0.0	6.2
AS	2/7/98	19.7	8.0	0.6	0.0	0.6	0.0	14.0	0.0	0.0	57.1
AS	3/7/98	3.7	49.5	0.0	3.7	10.3	0.0	32.7	0.0	0.0	0.0
AS	4/4/98	4.9	21.5	1.6	1.1	1.4	0.3	10.9	0.0	31.3	27.2
AS	4/21/98	8.0	36.0	0.0	2.0	2.0	0.0	52.0	0.0	0.0	0.0
AS	5/2/98	6.7	17.8	12.7	0.3	1.3	1.0	10.8	0.0	12.7	36.6
AS	6/6/98	2.9	9.3	3.2	0.2	0.4	0.2	20.2	0.2	0.2	63.2
AS	9/5/98	30.8	4.4	0.0	1.6	6.0	0.0	16.7	0.0	0.0	40.3
AS	12/13/98	11.3	9.6	0.0	4.2	2.5	1.1	8.5	0.0	31.4	31.2
AS	1/30/99	0.0	4.3	0.0	0.9	0.4	0.0	5.8	0.0	60.3	28.2
AS	3/20/99	2.1	15.8	0.0	1.8	11.6	0.7	22.5	0.0	5.3	40.4
AS	8/14/99	12.6	11.3	7.8	3.3	2.1	2.5	13.8	0.0	7.8	38.8
AS	9/11/99	31.5	5.2	0.0	3.4	2.8	0.0	12.5	0.0	1.5	43.1
AS	11/25/00	1.2	0.6	0.7	2.2	0.1	21.6	0.2	0.0	37.4	36.0

AN	3/15/97	2.1	27.1	0.0	12.5	25.0	0.0	33.3	0.0	0.0	0.0
AN	3/22/97	2.5	20.0	0.0	13.8	16.3	0.0	47.5	0.0	0.0	0.0
AN	3/27/97	15.2	19.0	0.0	10.5	8.6	0.0	46.7	0.0	0.0	0.0
AN	4/26/97	5.6	11.1	0.0	13.9	13.9	2.8	52.8	0.0	0.0	0.0
AN	5/1/97	11.7	43.3	0.0	11.1	8.2	0.0	25.7	0.0	0.0	0.0

Table 6 . Continued

Reef	Date	Fish	Crabs	Sponges	Antho-zoa	Nudi-branchs	Other molluscs	Seastars	Seacu-cumber	Tunicate	Barnacle
AN	5/3/97	10.7	36.8	0.0	11.1	5.1	0.0	35.2	0.0	0.0	1.2
AN	5/10/97	9.2	40.4	0.0	12.8	0.9	0.0	36.7	0.0	0.0	0.0
AN	5/18/97	36.9	40.4	0.0	5.0	0.0	0.0	17.7	0.0	0.0	0.0
AN	5/22/97	25.6	31.1	0.0	6.1	0.6	0.0	36.7	0.0	0.0	0.0
AN	6/21/97	11.5	31.3	0.0	0.7	0.0	1.8	11.5	1.8	5.4	36.0
AN	7/12/97	21.5	15.7	0.0	0.7	0.0	0.4	16.9	0.0	0.4	44.3
AN	8/9/97	33.7	10.3	0.0	0.6	0.4	1.4	14.2	0.0	0.0	39.4
AN	9/13/97	50.6	26.4	0.0	0.0	1.1	1.1	20.7	0.0	0.0	0.0
AN	10/25/97	49.5	26.9	0.0	3.2	0.4	0.0	20.1	0.0	0.0	0.0
AN	11/8/97	68.0	14.2	0.0	2.9	1.6	0.3	12.9	0.0	0.0	0.0
AN	11/22/97	53.7	12.0	6.6	6.1	2.9	0.3	17.6	0.0	0.8	0.0
AN	12/6/97	29.6	20.7	14.8	4.1	1.8	1.2	18.9	0.0	0.0	8.9
AN	3/7/98	1.4	15.6	1.4	10.4	0.0	0.9	22.9	0.0	2.3	45.2
AN	3/24/98	1.1	13.4	4.4	8.6	0.5	0.4	15.5	0.0	3.2	52.9
AN	4/21/98	8.5	54.9	0.0	11.8	0.7	0.0	20.9	0.0	3.3	0.0
AN	5/2/98	2.1	12.6	13.2	4.2	1.1	0.5	11.1	0.0	15.8	39.5
AN	6/6/98	34.3	34.3	3.0	10.4	1.5	0.0	16.4	0.0	0.0	0.0
AN	7/18/98	9.5	22.4	0.0	6.1	1.8	0.2	14.3	0.0	0.5	45.2
AN	8/16/98	23.5	6.8	0.0	3.5	7.3	0.0	12.0	0.0	0.0	46.9
AN	9/5/98	61.5	5.6	9.3	4.8	4.1	0.0	8.5	0.0	6.3	0.0
AN	1/30/99	1.3	8.2	0.6	1.5	1.1	0.0	13.7	0.0	0.0	73.7
AN	3/20/99	0.7	8.8	3.5	7.0	0.0	0.5	13.4	0.0	4.4	61.6
AN	6/19/99	13.1	20.3	0.0	10.8	2.0	0.7	15.4	0.0	0.0	37.7
AN	8/14/99	8.6	7.0	8.4	4.9	0.8	0.4	6.5	0.0	10.5	52.7
AN	9/11/99	66.7	15.9	0.0	1.6	4.8	0.8	10.3	0.0	0.0	0.0
AN	9/25/99	29.0	4.7	0.0	5.3	2.2	0.0	13.1	0.0	1.1	44.5
AN	10/9/99	32.9	5.0	0.0	5.6	6.3	0.0	8.1	0.0	0.4	41.7
AN	10/24/99	14.8	7.3	0.0	6.6	2.7	0.0	9.6	0.0	0.0	59.0
AN	11/22/99	30.3	15.7	0.0	5.5	1.5	0.0	10.6	0.0	0.0	36.5
AN	4/14/01	4.8	9.4	0.0	8.0	3.7	0.0	16.3	0.0	6.8	22.0

Table 7. Overall mean abundance of dominant taxa at each reef (total abundance per reef divided by total surveys per reef)

Taxa	Artificial North	Artificial South	Natural South
Barnacles	49.2	88.8	1.2
Sunflower Starfish	18.0	19.6	18.0
Tubesnout	10.9	6.0	1.1
Plumose Anemone	8.0	4.5	4.5
Striped Perch	6.2	5.8	0.0
Red Rock Crab	6.1	6.0	6.1
Northern Kelp Crab	5.0	7.8	4.4
Decorator Crab	4.1	2.9	6.1
Sponges	3.3	4.2	15.9
Sharp-nosed Crab	2.9	1.6	6.6
orange social Tunicate	0.4	62.8	20.0
Rock Oyster	0.1	22.5	0.0
Kelp Crab	3.8	5.0	2.9
Purple of Ochre Seastar	3.6	2.9	3.9
Copper Rockfish	3.4	3.3	2.9
Gunnels and Pricklebacks	2.9	1.5	5.0
Orange Sea Cucumber	0.0	0.0	39.8

The four dominant fish species (Figures 15 to 18) have clear seasonal differences in distribution. Copper rockfish appear to be primarily a late summer/early fall visitor to all the reefs, with higher numbers evident on the artificial reefs than the natural reef. The shiner perch was more clearly evident in quantity in the fall, and may be an opportunist, because it was seen only once on the natural reef. The less developed or crowded artificial reefs may attract these species because of available hiding spaces, or because of specific food items present on the developing reefs. The striped perch also appears to be a late fall/winter visitor, and was again conspicuously absent on the natural reef. The tubesnout also was a predominantly late fall visitor to the artificial reefs, with only periodic sightings on the natural reef.

The distribution of shrimp (Figure 19) was included to illustrate why shrimp could safely be taken out of analyses. As indicated in Appendix C, some divers saw shrimp when their dive partners did not. This was related to the use of hand lights, and careful examination of the inside of the balls where the shrimp typically hid. In addition, Jim Cosgrove indicated that clouds of shrimp would rise and swim away as he passed with the video camera. Thus, if one diver passed first, he or she might see shrimp whereas the dive partner might not. The distribution of shrimp noted in dives suggests that they were probably ubiquitous as well as numerous on all reefs right from the beginning. Shrimp will very quickly colonize a fresh, heterogeneous habitat which offers hiding locations.

The crabs, in general, seem to be most evident in the summer months. Dungeness crab (Figure 20) seemed to be most abundant on the artificial reefs, with a high number evident only once on the natural reef. The latter occurrence was identified in notes in the dive log indicating that these were 2 cm or newly settled juveniles. They were subsequently seen only twice on the natural reef, in very low numbers. The red rock crab (Figure 21) was the most abundant of the crabs, and was common on all reefs. It also shows a general increase in abundance in the summer months. The northern kelp crab (Figure 22) was also common on all reefs, and did not show any particular seasonal distribution.

The orange social tunicate (Figure 23), a late-colonizing colonial form, was definitely predominant on AS. It did not occur on either artificial reef until a year after deployment, and was evident only a few times on the natural reef in the first year of the study.

The anemone *Metridium senile* (Figure 24) was obviously a rapid colonizer and tended to be colonial. It was fairly ubiquitous on all reefs, and is obviously a natural dominant sessile form in this type of habiatat. The abundance of this taxa did seem to increase on AS over time. However, many of these may have drifted in with the currents.

The acorn barnacles (Figure 25) have abundance values which are not accurate because the high numbers were not always reflected in the ranking method used by divers. These are clearly opportunistic colonizers, and were rare on the natural reef. They were evident fairly early on after deployment on AS, and increased rapidly in abundance. They were not evident on AN until several months later. However, some divers seem to have ignored this taxa, since it tends to be regarded as “background noise” or be hidden under algal cover in summer (see Appendix C). Despite this, the barnacles clearly increased to their highest abundance on reef AS 3 ½ years after deployment.

Finally, the sunflower starfish (Figure 26), a large predator on a variety of invertebrate species, was ubiquitous over all reefs and times, although its abundance fluctuated. It was highest in abundance on AN on the final survey in April, 2001.

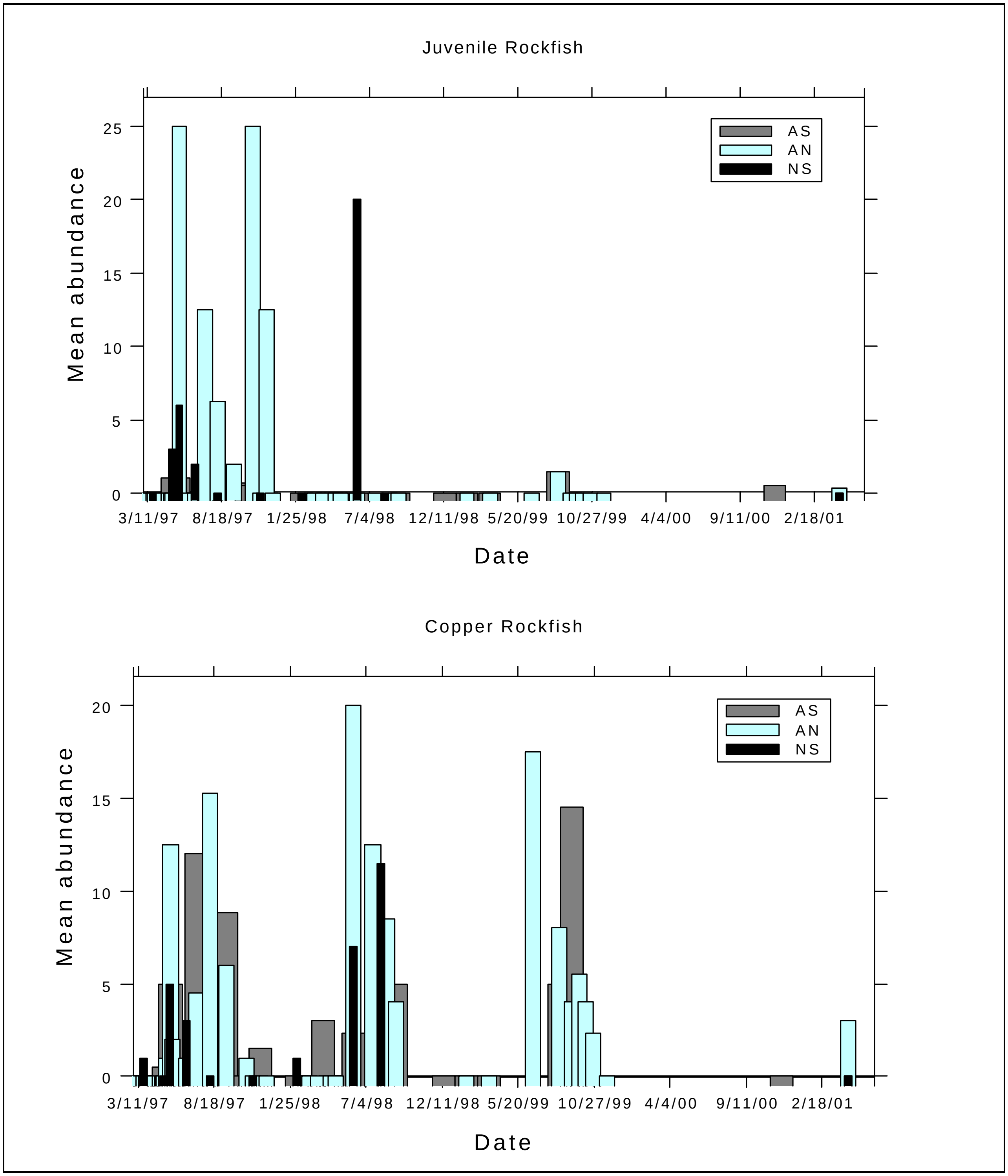

Figure 15. Temporal distribution of juvenile and adult copper rockfish on the three reefs. Note the bars below the 0 x-axis indicate dates that surveys were done but no sightings occurred.

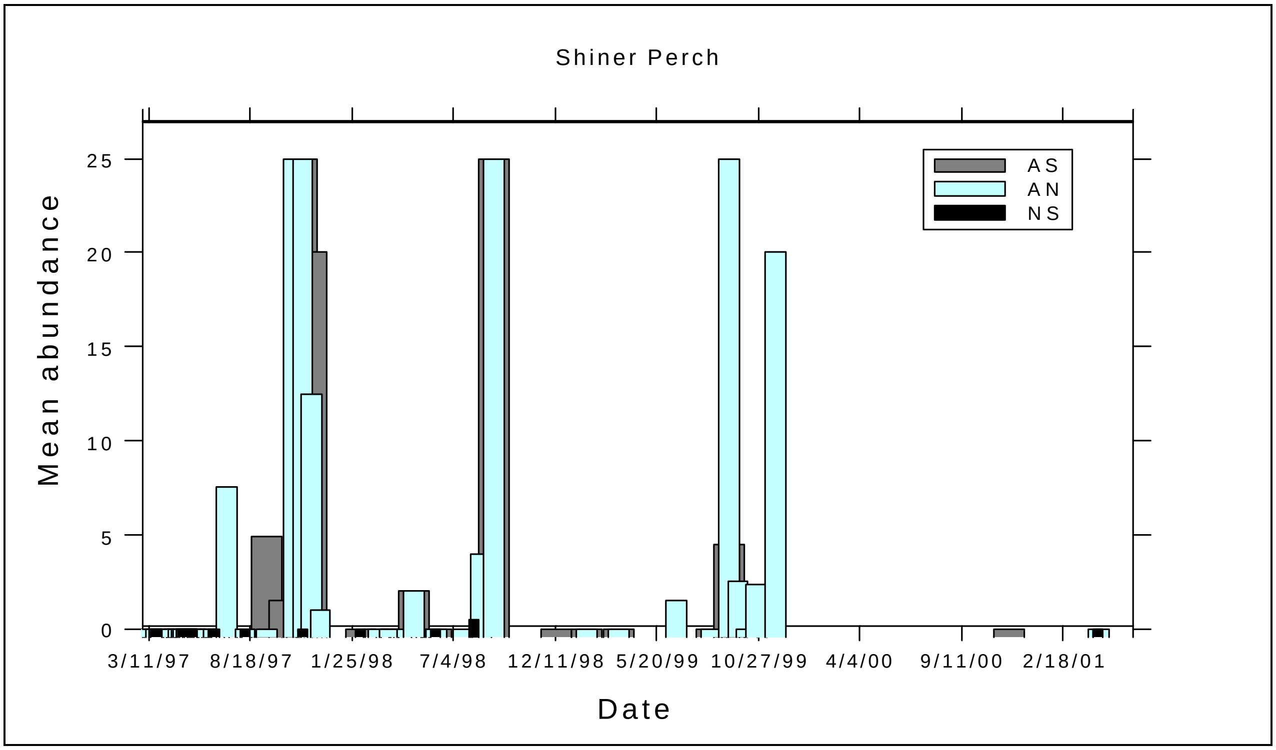

Figure 16. Temporal distribution of shiner perch on the three reefs.

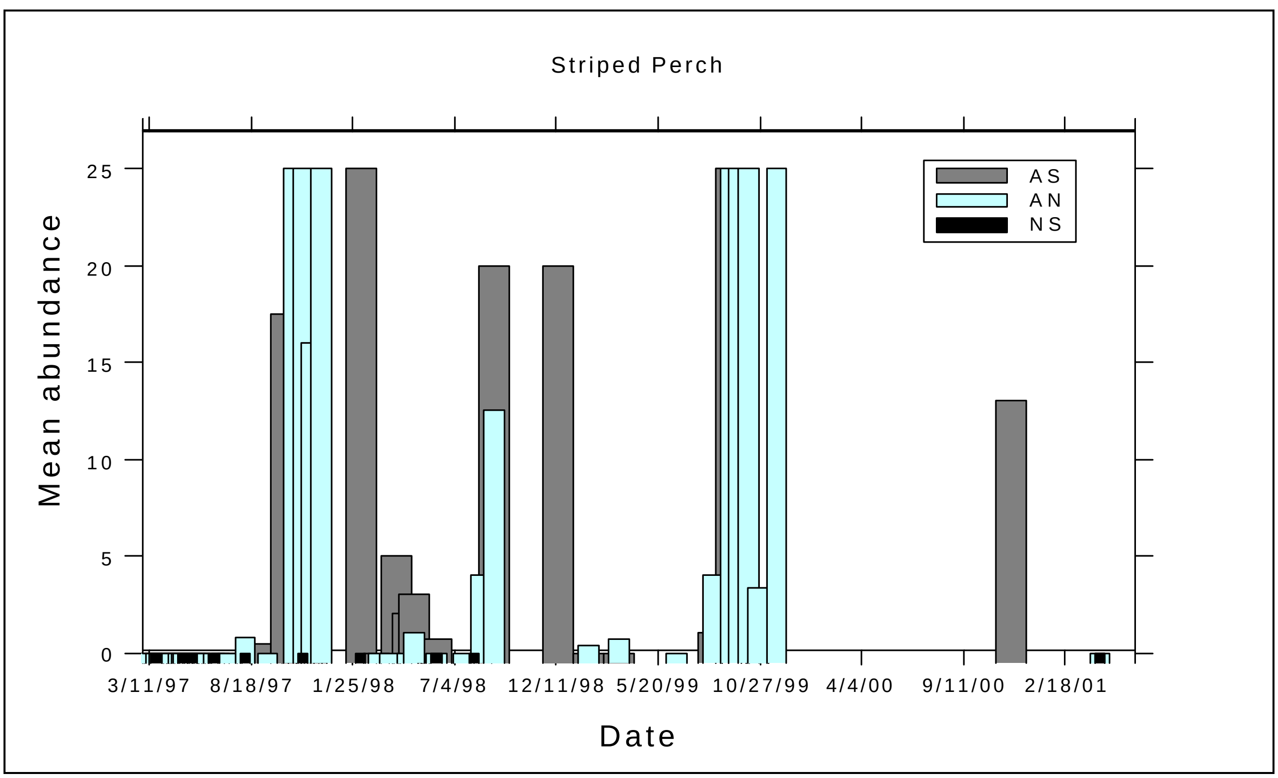

Figure 17. Temporal distribution of striped perch on the three reefs.

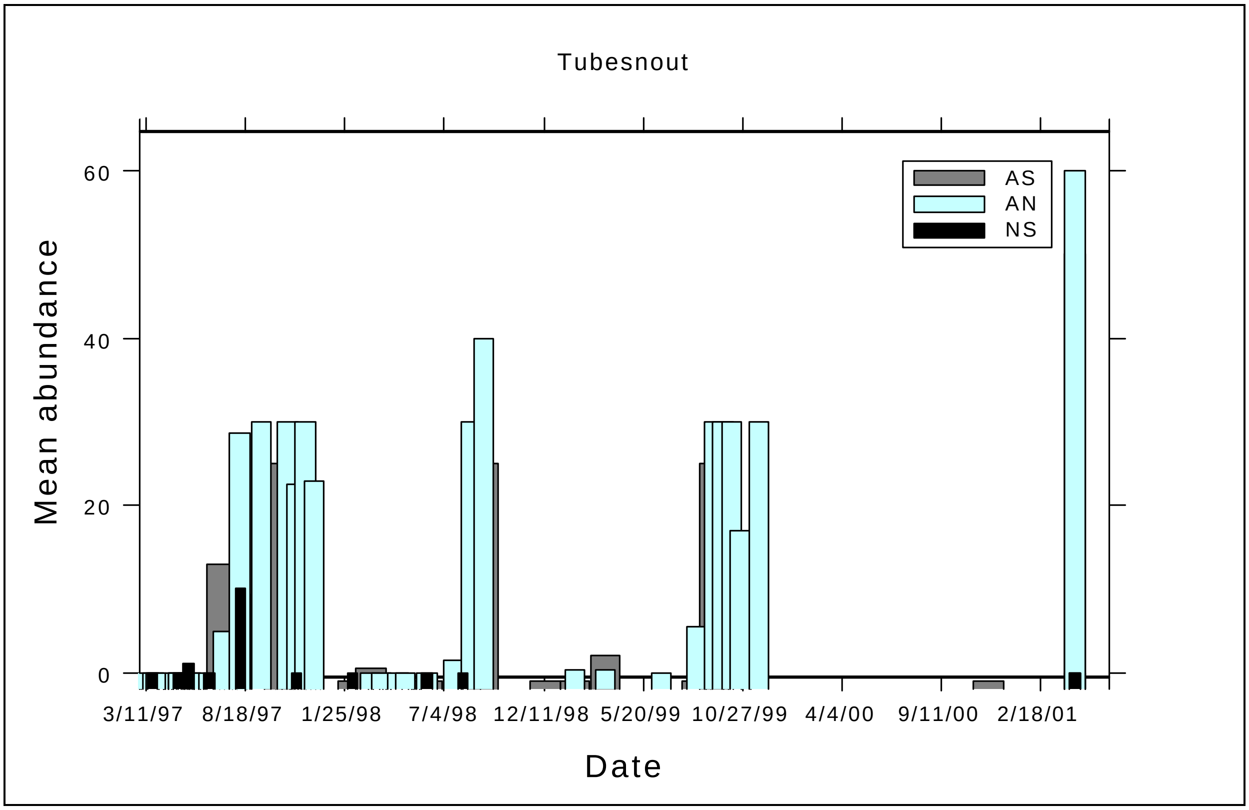

Figure 18. Temporal distribution of tubesnout on the three reefs.

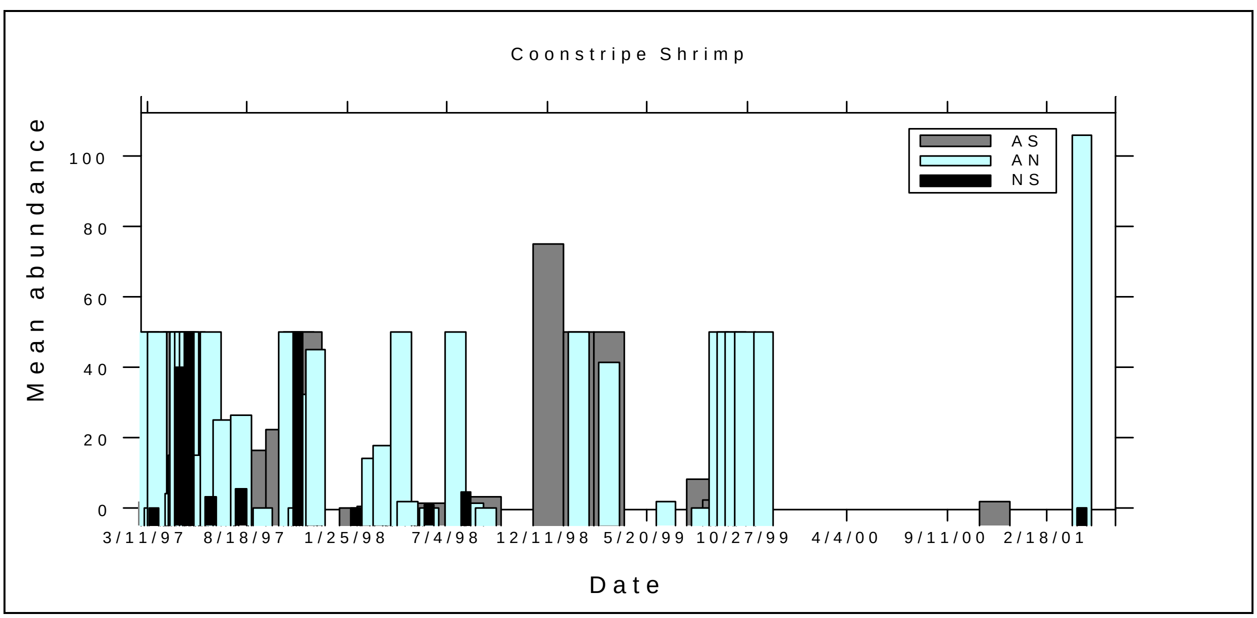

Figure 19. Temporal distribution of shrimp on the three reefs.

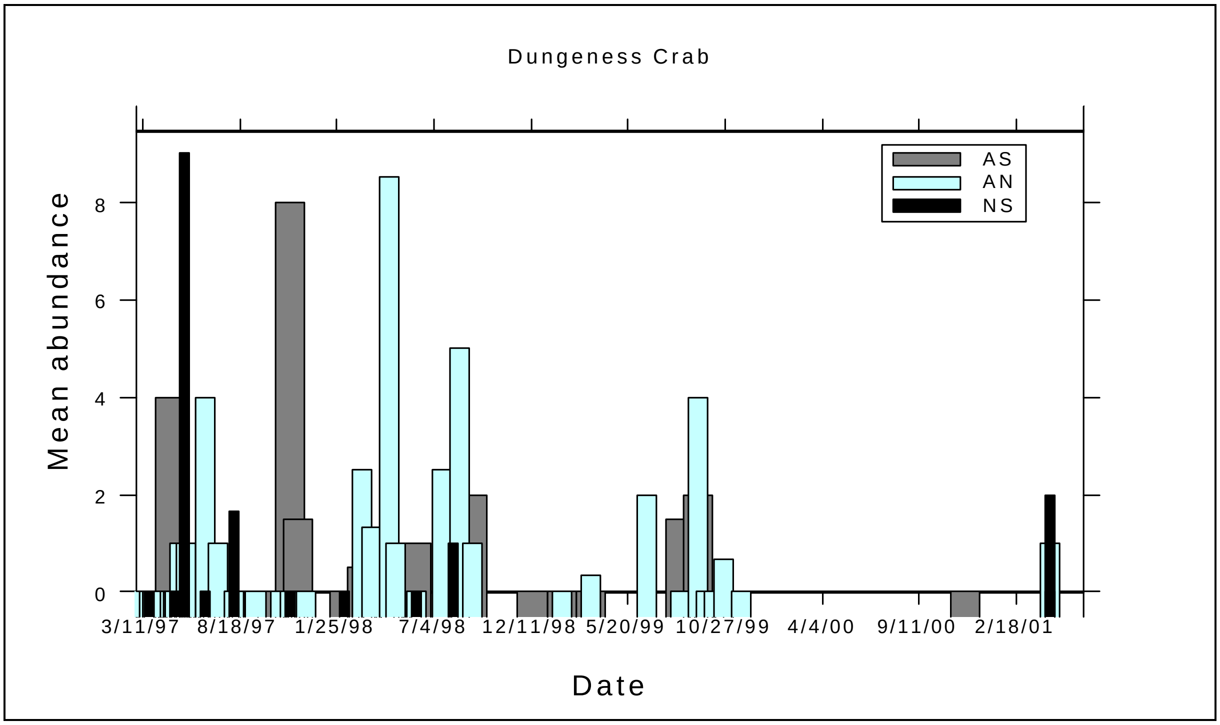

Figure 20. Temporal distribution of Dungeness crab on the three reefs.

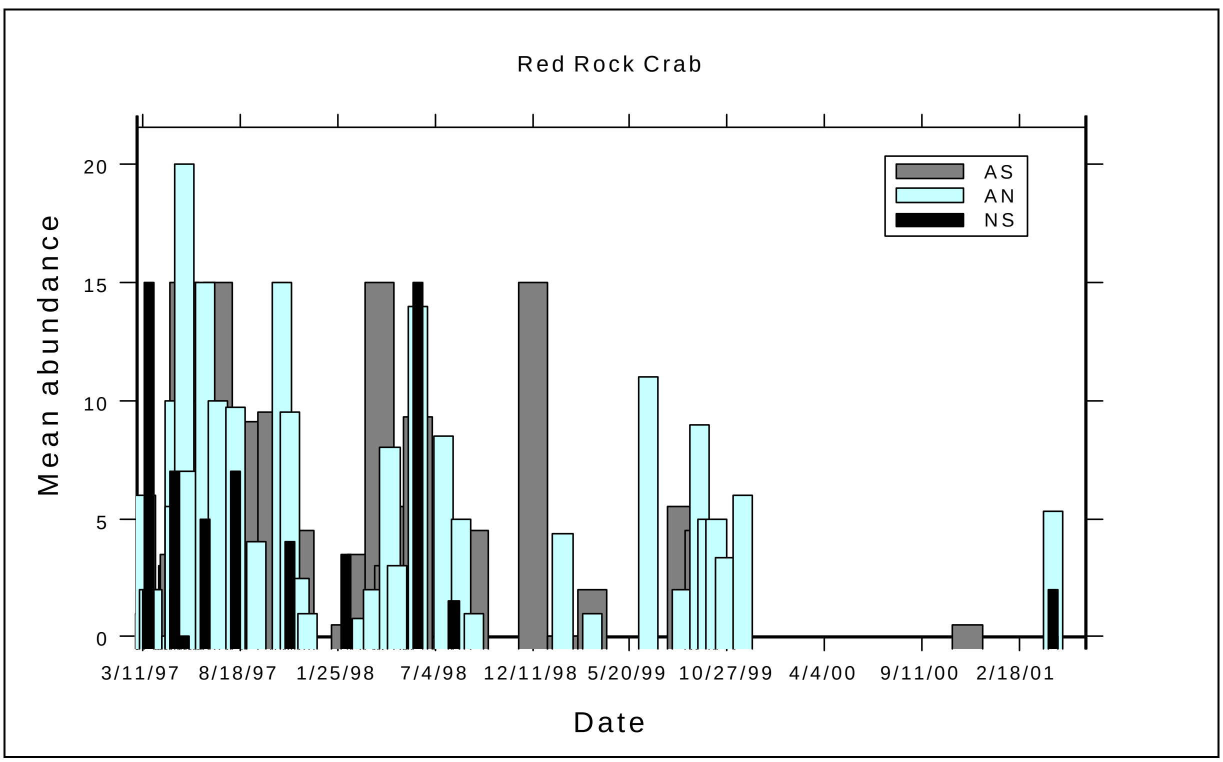

Figure 21. Temporal distribution of red rock crab on the three reefs.

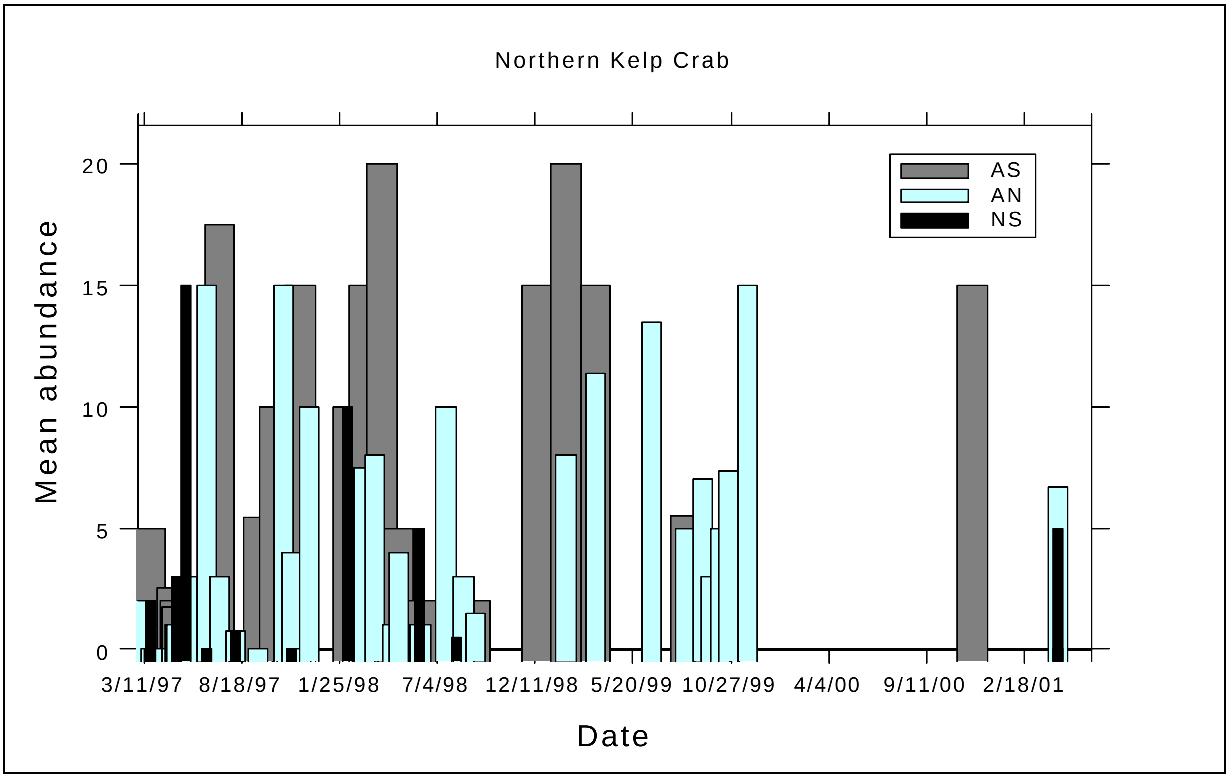

Figure 22. Temporal distribution of northern kelp crabs on the three reefs.

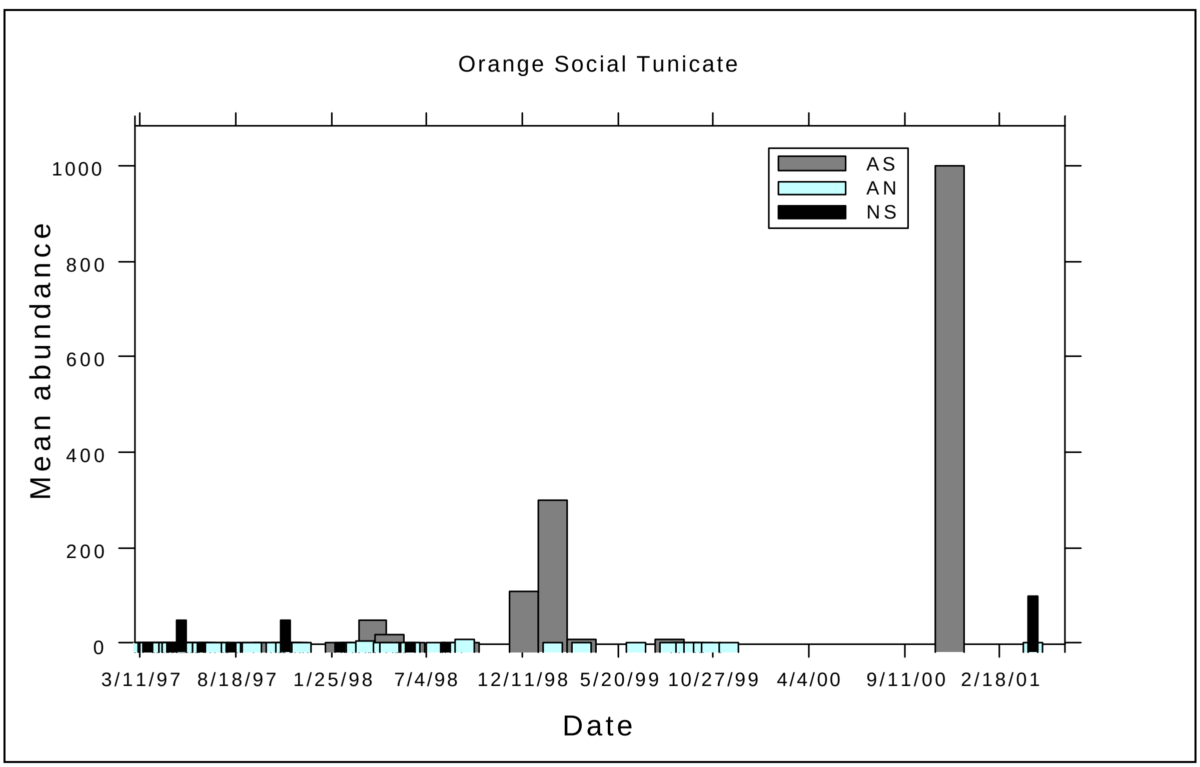

Figure 23. Temporal distribution of the colonial orange social tunicate on the three reefs.

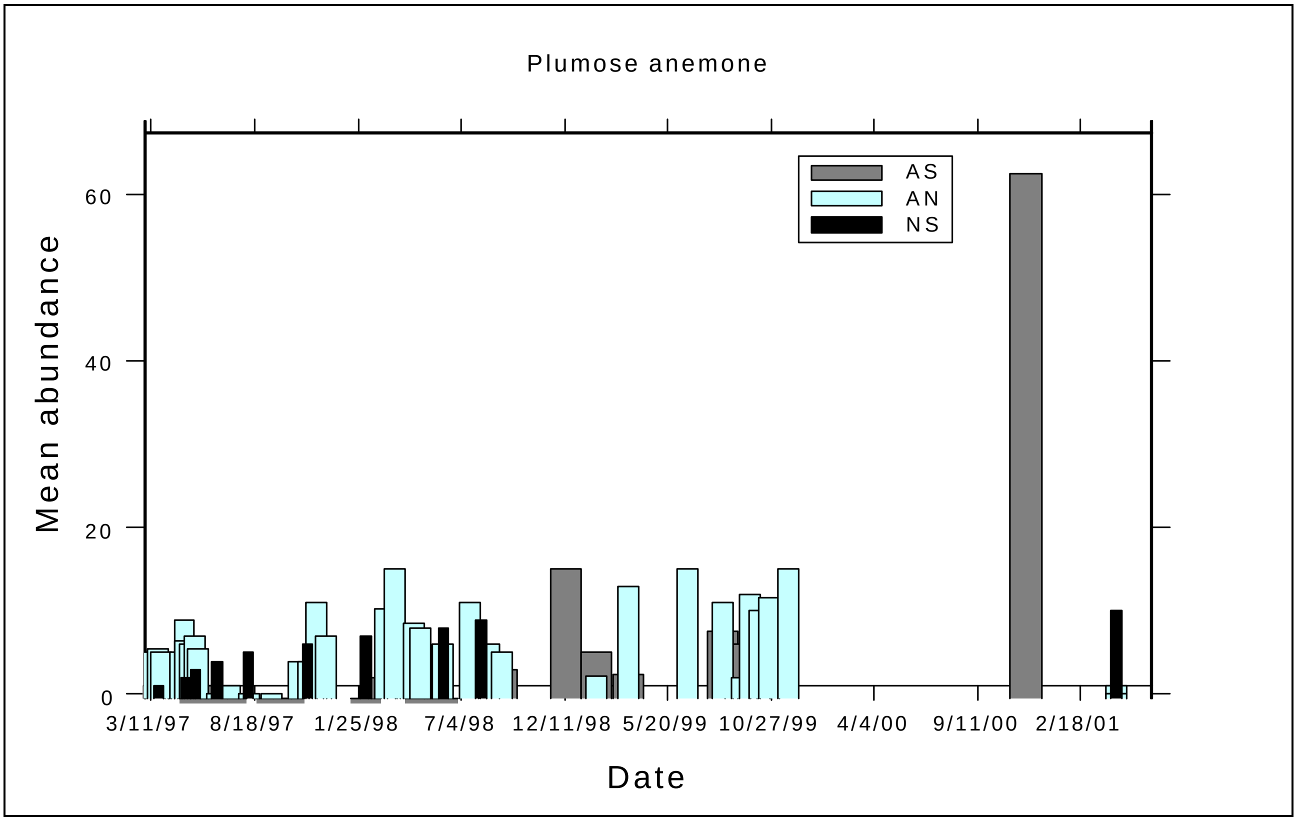

Figure 24. Temporal distribution of Metridium senile *(anemone) on the three reefs.*

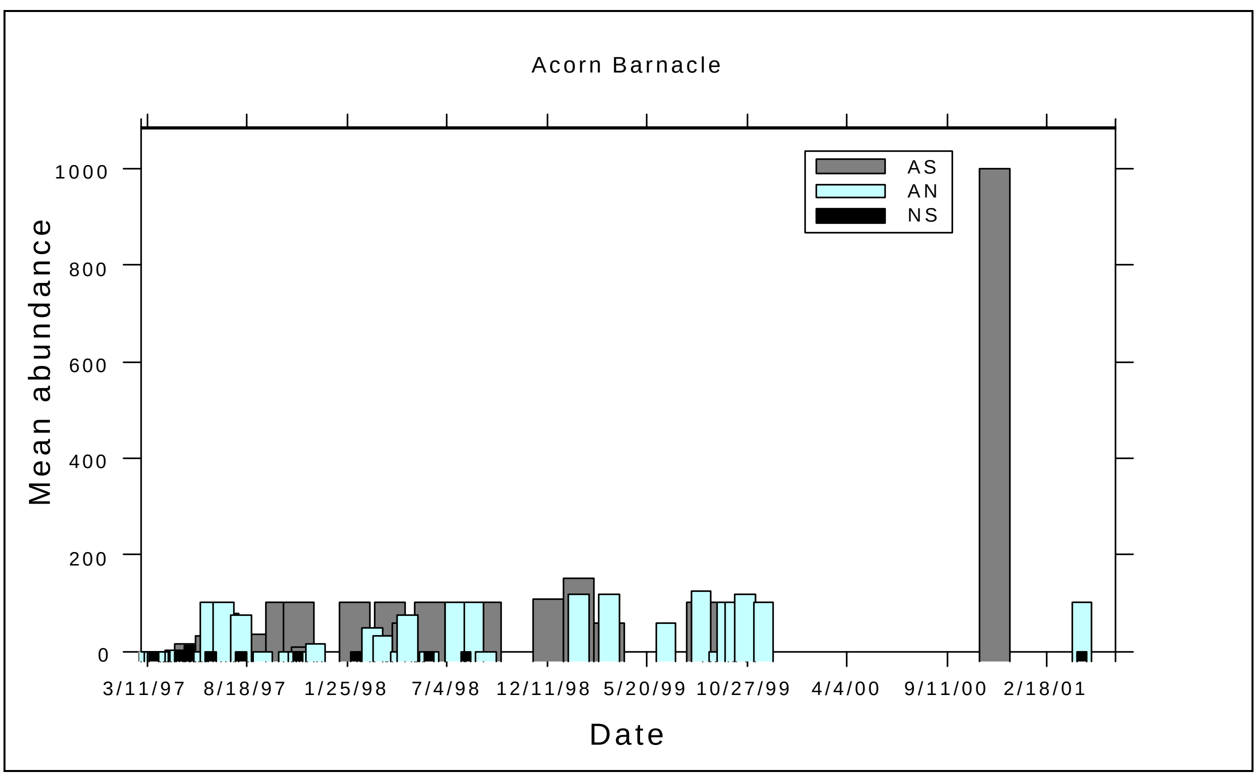

Figure 25. Temporal distribution of acorn barnacles on the three reefs.

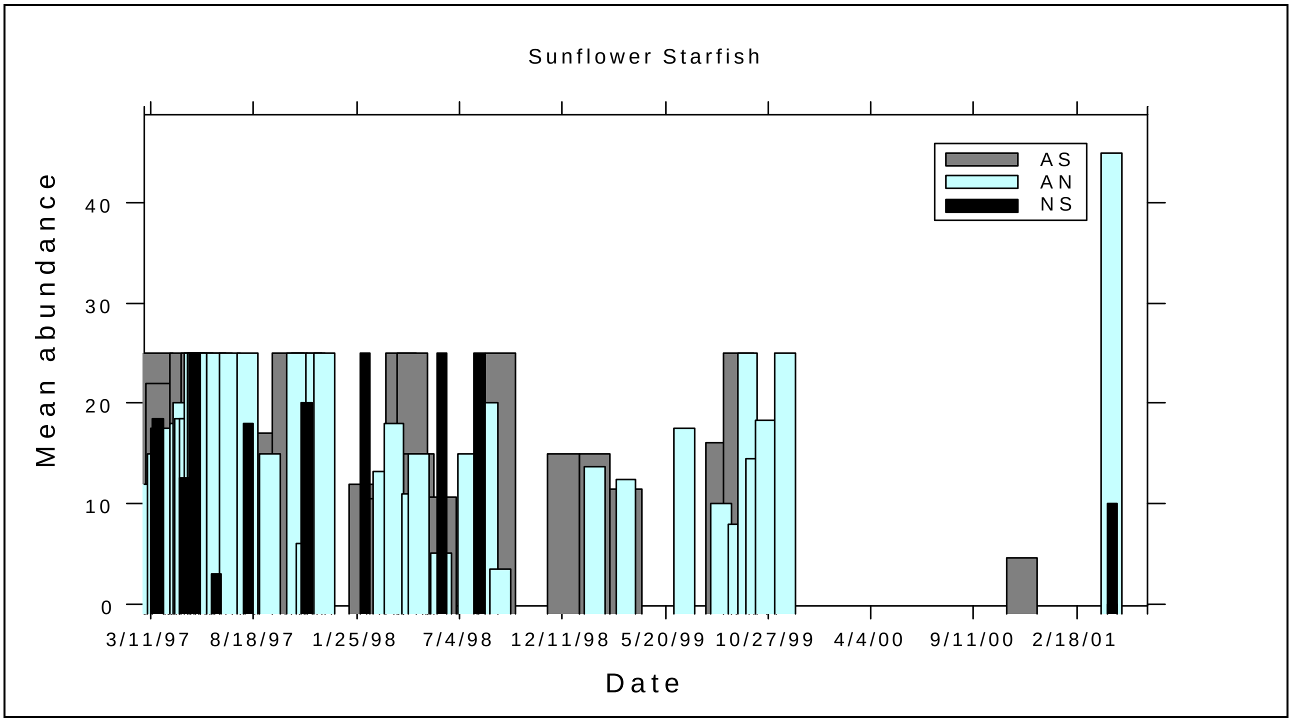

Figure 26. Temporal distribution of sunflower starfish on the three reefs.

Selected divers only

The sub-set of data using only the selected “expert” divers shows abundance distributions very similar to those for the entire data set (Figure 27).

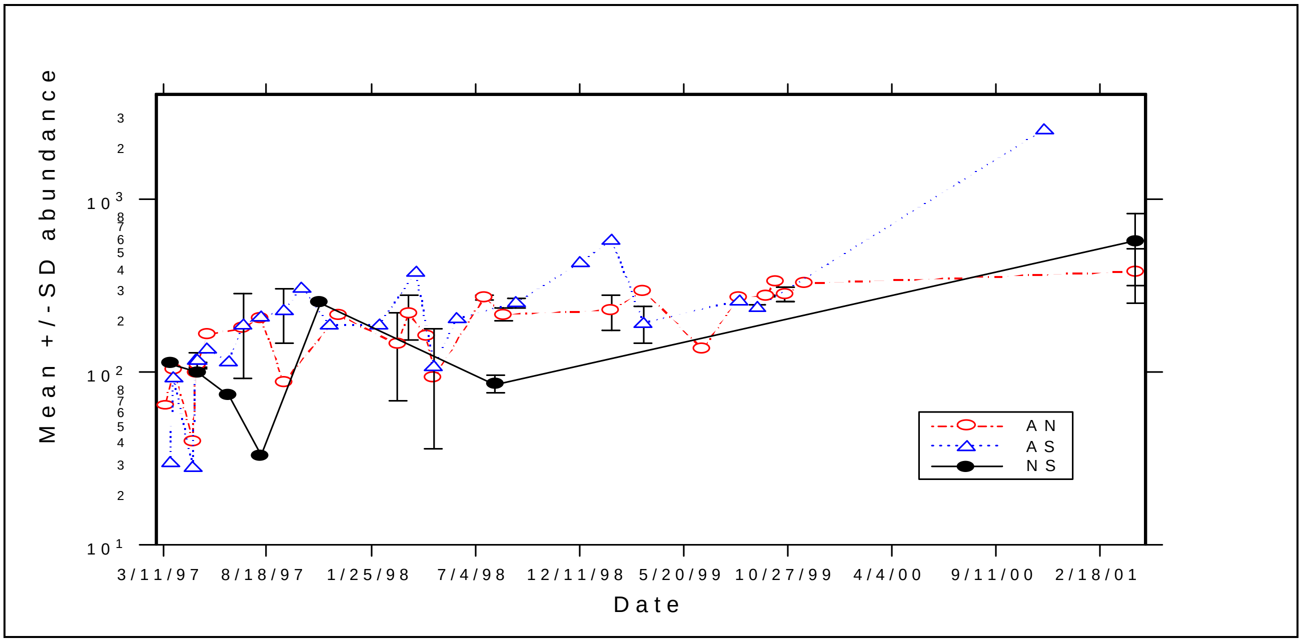

Figure 27. Mean distributions of abundance for selected divers over time.

The mean taxa seen per reef and dive event (Figure 28) showed somewhat less extreme fluctuations than the overall data, but similar mean values ranging from 12-22 for all reefs

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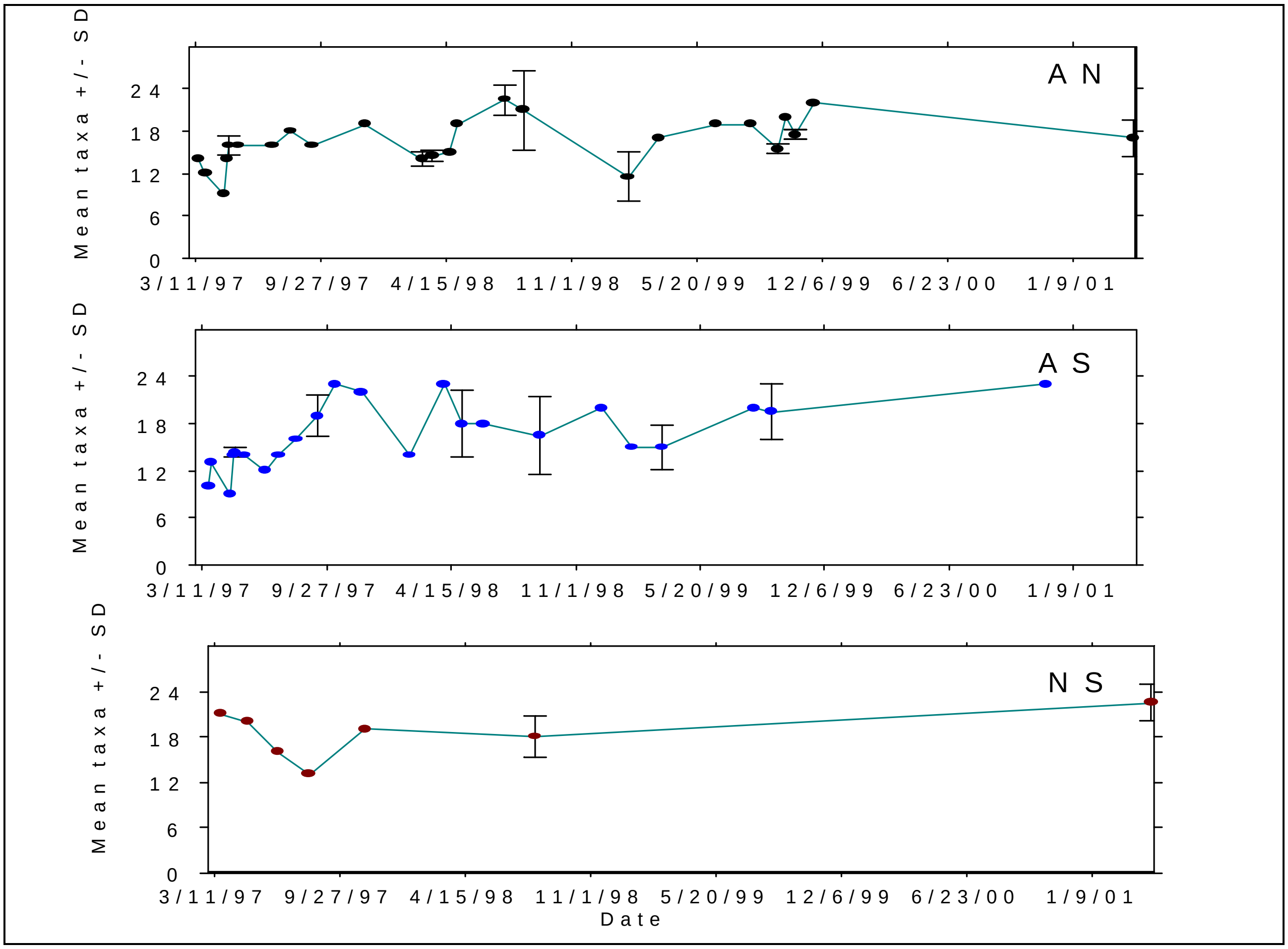

Figure 28. Mean taxa for each reef over time using selected diver data.

Multivariate analyses

Total Data (untransformed)

The pair-wise dissimilarity matrix for community composition for all surveys based on passes 1-3 is included in Appendix E1. Figure 29 shows a time-series similarity gradient illustrating how the overall community changes over time from the first survey at each reef. As expected in AN and AS reefs, the first few surveys were quite similar to each other, since there were few taxa to identify and enumerate. However, by mid-May to mid-June, the community had changed considerably. The range in dissimilarities at the natural reef over time was between 50-70%. On AN Reef, the community appeared to have reached a relatively stable level of dissimilarity to the first survey (about 60-80% dissimilar by survey #9). It is also evident that by summer 1997 surveys from each of the artificial reefs had pair-wise dissimilarities in the same range as expected from the natural reef. Note that the AS and AN surveys on April 21, 1998 showed a somewhat similar composition to the initial one for both AS and AN. This suggests that some natural defaunation event occurred which produced an effect similar to that of the initial recolonization phase of the reefs. AS Reef had a 99% dissimilar composition 3 ½ years after the first survey, suggesting that the changes in this reef were more dramatic and progressive over time than in the AN Reef.

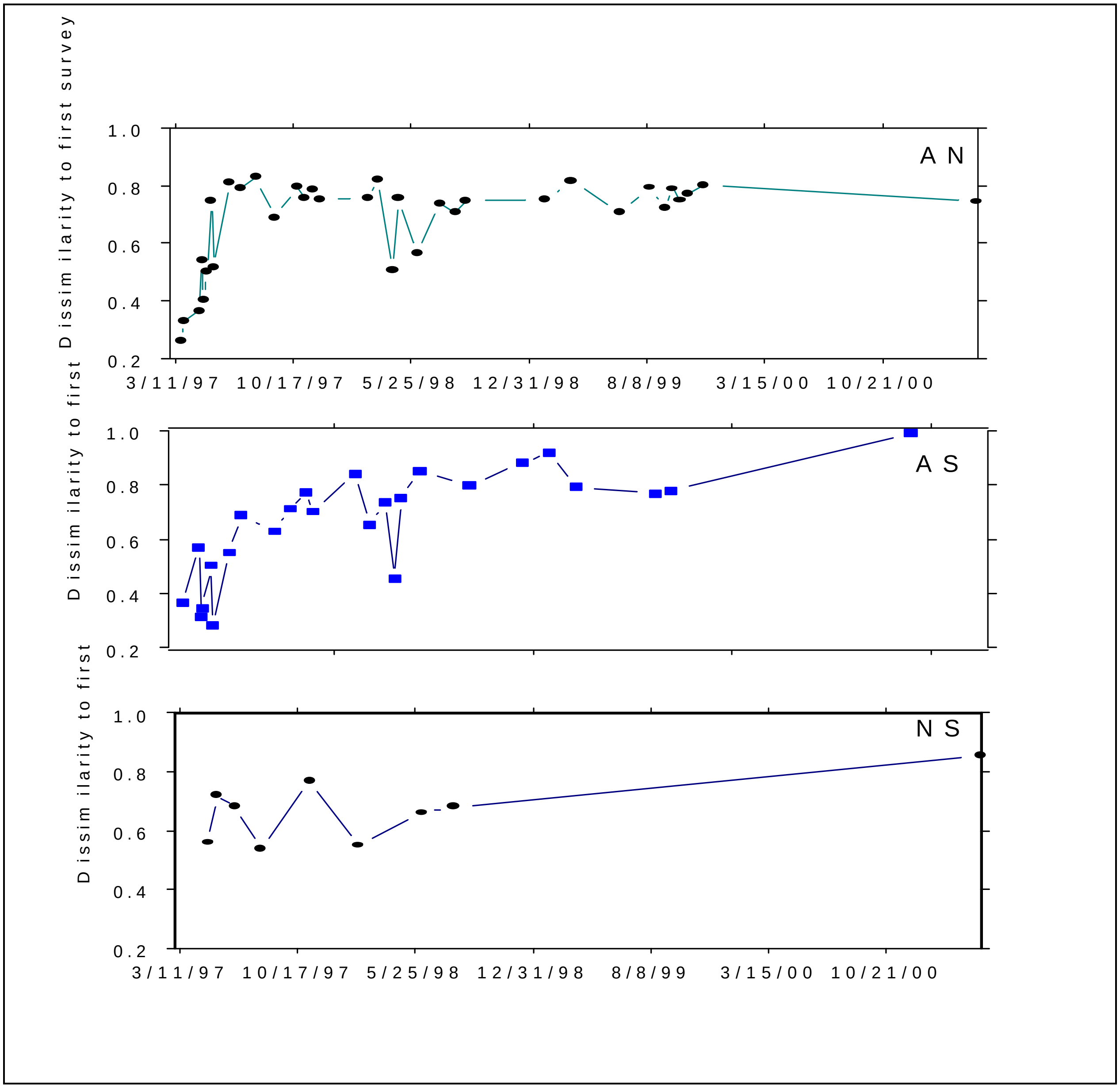

Figure 29. Dissimilarity/time gradient for all reefs, showing how the relative community composition changed from the first survey on that reef.

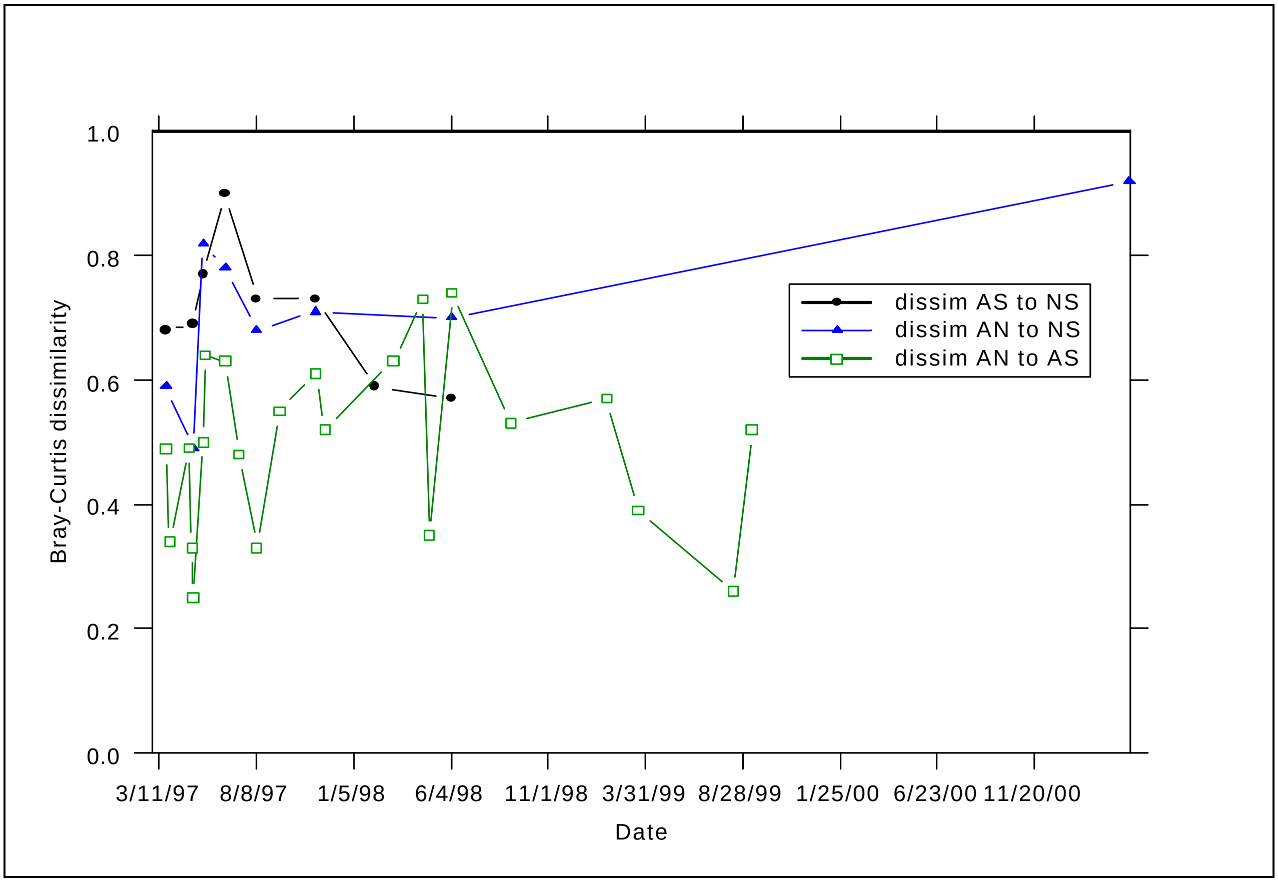

Figure 30. Pair-wise dissimilarities between reefs for concurrent dates.

Figure 30 shows the pair-wise dissimilarities between the reefs over time for those surveys in which both reefs were sampled. In general, the artificial reefs seemed to be more similar to each other over time than to the natural reef. There is an early spike (high dissimilarity) between each of the artificial reefs and the natural reef, corresponding to the time that there was an "overshoot" in total taxa numbers as the reefs were developing (see Figure 12). Unfortunately, the natural reef was surveyed with the least frequency. The highest dissimilarity measured was between AS and NS on the final survey in April 2001.

Hypothesis Testing

The primary hypothesis of interest was:

Ho: There was no difference in overall faunal composition between the artificial reefs (AN, AS) and the natural reef.

There were no significant linkages in the dendrogram for the combined species abundance data from all surveys for each reef. For combined data up to November 2000, the two artificial reefs were 62% similar, whereas AN and AS reefs were 55% and 42% similar to the natural reef, respectively (results not shown). When the final survey was added, AN and AS were 86% similar, with the two artificial reefs 77 and 72% similar respectively to the natural reef (Appendix E2). Since the null hypothesis could not be rejected, it is not appropriate to test the alternate hypothesis.

The analysis was repeated for the full data set using presence/absence data only and Sorensen's Index of similarity. Results are shown in Appendix E3. In terms of taxa only, the two artificial reefs were 87% similar to each other, but were still significantly distinct at $p<2\%$, with a power of 98%. The natural reef was less similar (81-82%) to each of the artificial reefs. Thus we can conclude in terms of species presence/absence only, all three reefs were distinct.

The significance testing in effect asks the question, are the mean faunal compositions of reefs AS and AN significantly different from the natural reef? So, with all the seasonal and developmental variation within and between the artificial reefs, it can be concluded that there was simply too much variation over time to be able to reject the null hypothesis. However, does this mean that we can conclude that all the reefs were the same? In order to do this, we need to examine the cumulative frequency distributions for all three reefs.

Probability Distributions

Figure 31A shows that 90% of the NS Reef surveys had a faunal composition <55% dissimilar to the "average" NS Reef composition for data up to the end of the year 2000. However, less than 10% of the AN and AS reef faunal compositions were less than 55% dissimilar to the NS Reef average. Therefore, 90% of the artificial reef compositions were outside the variability found for the natural reef.

However, when the final surveys for NS and AN reefs for April 2001 were added to the analysis, a major shift had occurred (Fig. 31B). The clear distinction between artificial and natural reefs had declined, mainly because there had been a dramatic change in fauna at the natural reef, greatly increasing the overall variability in faunal composition of the natural reef (90% of values with dissimilarity < 70%).

Selected divers only

To examine whether the faunal compositions of the artificial and natural reefs were different, a comparison of the frequency distributions relative to a "reference" or average NS community composition was done (Figure 32). This shows that the faunal composition of 30% of the artificial reef surveys was within the 90% reference range. Thus, based on the arbitrary sub-set of "expert" divers, it cannot be concluded that there is a difference between the artificial and natural reefs. It is somewhat reassuring that the analysis for selected diver data produced a very similar pattern and range of pair-wise dissimilarities between the two artificial reefs as for the data from the entire SPARS set (Figure 33).

Log-transformed (total) data – all dives

The multivariate analyses were repeated using a log x+1 transformation for total data. The results of these analyses are not shown because they did not differ appreciably from those using raw data.

Invertebrate Data Only - all dives

The multivariate analyses for invertebrate data only, did not produce results appreciably different in pattern from that for the overall community (see Appendix E4), suggesting that the invertebrate data dominated the pattern.

Fish data only – all dives

The above analyses were repeated for fish data only (Appendix E5), since some of the dominant taxa were obviously more evident on the artificial reefs than the natural reef. AN and AS were 85% similar, with both artificial reefs about 65% similar to the natural reef. There were no significant linkages at $p<10\%$.

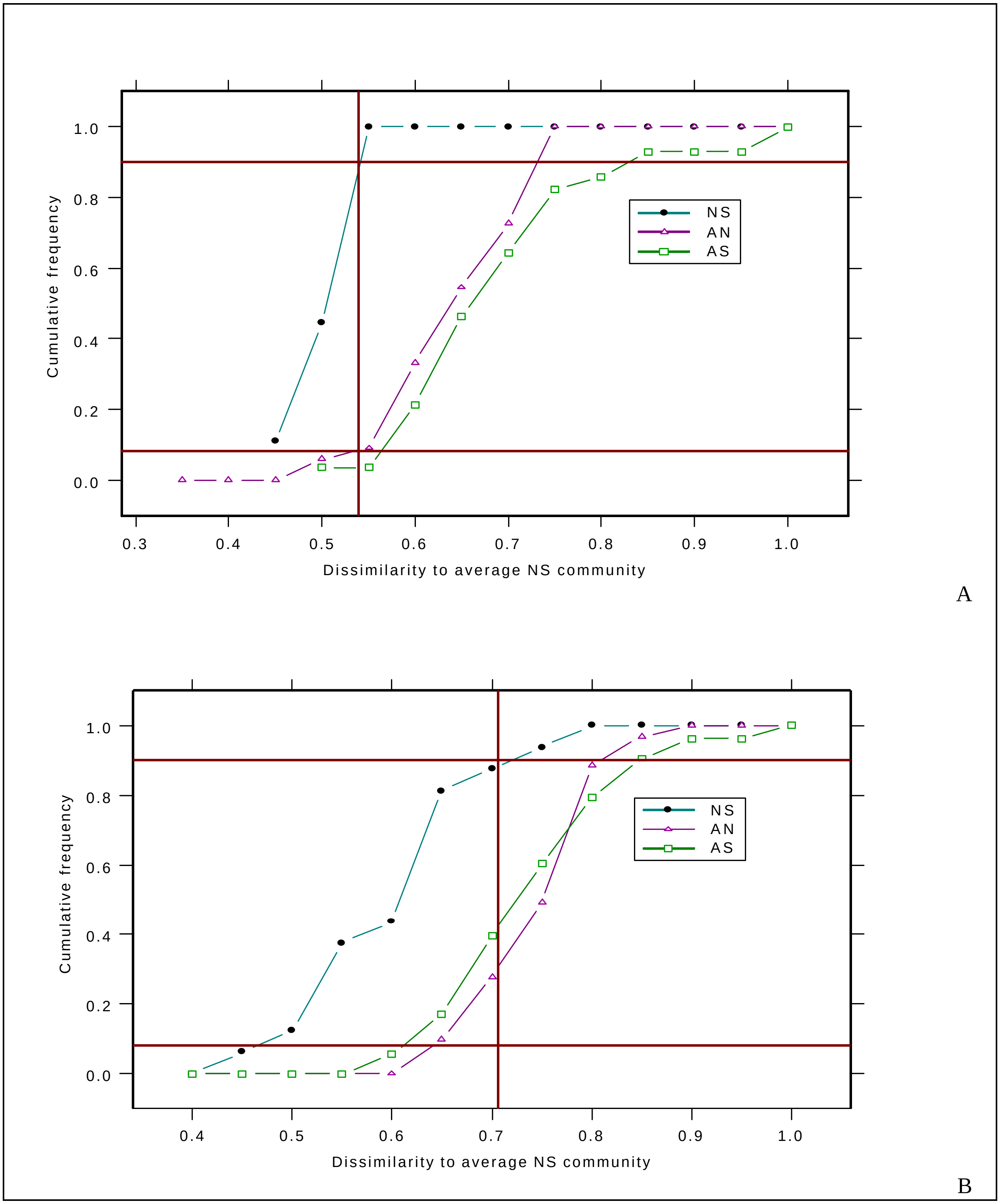

Figure 31 (A) Cumulative frequency distributions to the end of the year 2000 showing the 90% distribution of NS faunal compositions around the "average" NS composition, and the frequency distributions for AS and AN. Less than 10% of the AS and AN compositions fell within the 90% distribution for NS; Figure 31 (B) is the same but includes surveys for AN and NS for April 2001.

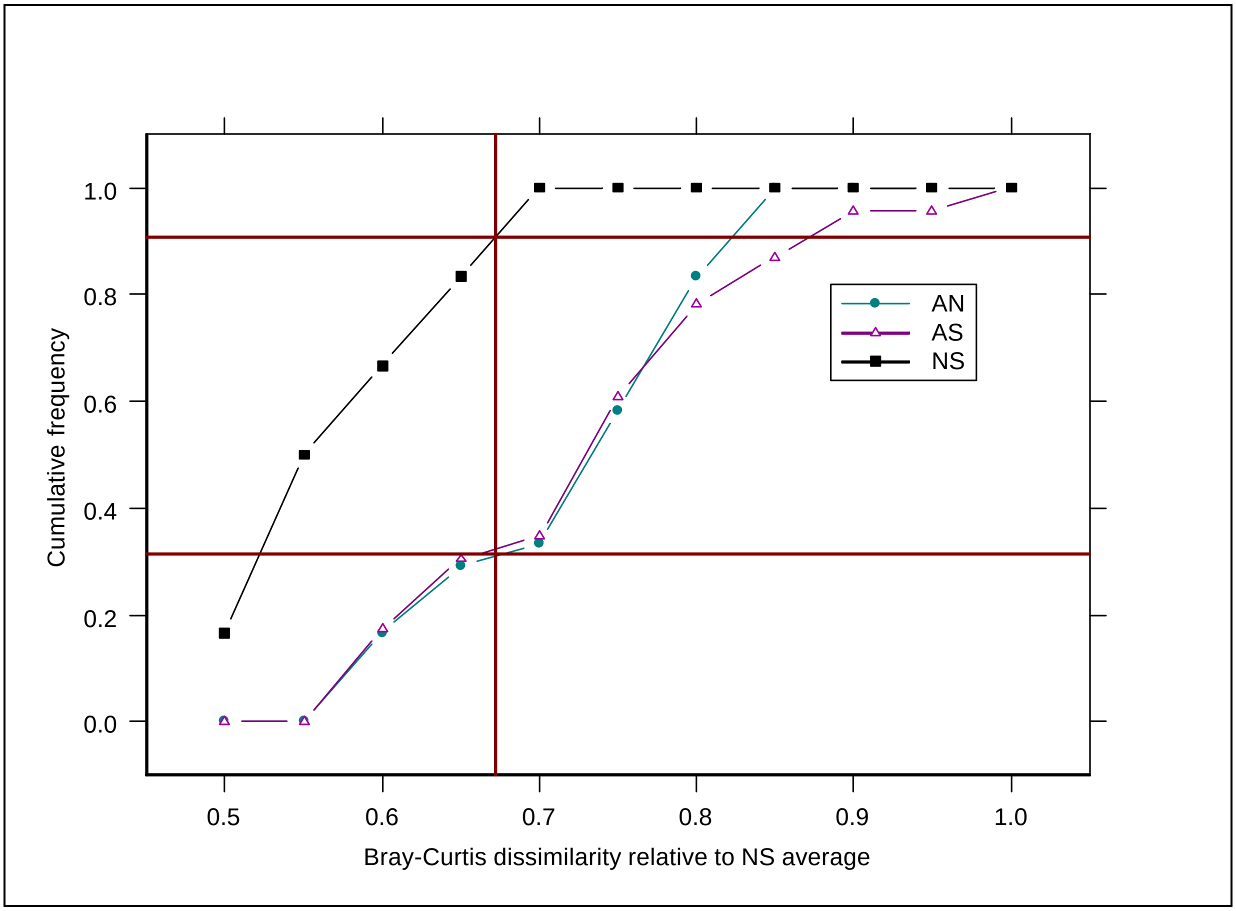

Figure 32. Cumulative frequency distributions for NS, AS and AN as in Figure 23, but using selected diver data only for all surveys.

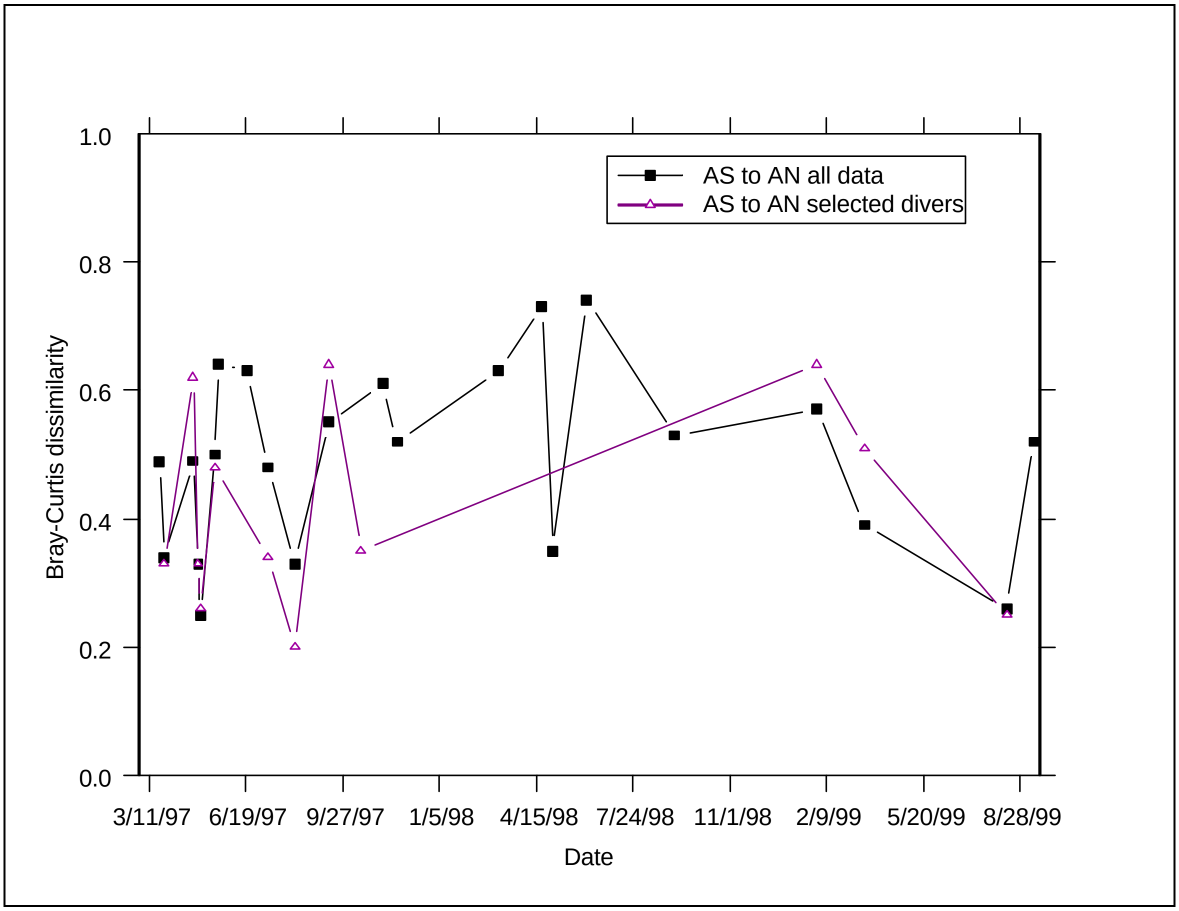

Figure 33. Pair-wise dissimilarities between artificial reefs for concurrent dives, based on total and selected (untransformed) data. This shows that there was little difference between the two data treatments for any given time.

Data Interpretation

Sampling Bias and Errors

The first purpose of this report was to assess the sources and general scale of errors inherent in this type of volunteer diver survey. Volunteer diver surveys of artificial and natural reefs has been documented and assessed for a number of locations (c.f. Schmitt and Sullivan 1996, Bohnsack 1996, Halusky et al. 1994, Darwall and Dulvy 1996, Mumby et al. 1995). Mumby et al. (1995) examined the accuracy of coral reef surveys by over 900 trained volunteer divers and found that the accuracy of survey results drops off in deeper water, due mainly to ………… An overall accuracy of 52-70% was found. Surprisingly, there was no clear trend of improved accuracy and consistency following greater survey experience. A number of recommendations arise from these studies.

Because there was no "baseline" quantitative data available or more rigorous scientific survey data with which to compare the results of the volunteer diver surveys, it was not possible to quantify the accuracy of results. It was possible from the dives with multiple divers, to assess the variability in what the divers saw. This simple assessment of sampling precision indicates that only 12% (5 out of 42 dive events) of the multi-diver surveys has a sampling precision (standard error as a proportion of the mean abundance – see Elliott 1977) higher than 20%, which is generally considered to be acceptable for standard quantitative benthic surveys (c.f. Elliott 1977, Downing 1979). This is surprisingly consistent. Four of the 5 surveys with unacceptable value for the sampling precision occurred on the natural reef.

By using information obtained from the "expert" divers, some indication of diver bias could be obtained, and the extreme outliers (inexperienced divers, one "splitter") could be identified. Accuracy of species identifications by different divers is probably the most important source of potential error, which is inherent in any volunteer diver program. For this reason, Mumby et al. (1996) recommend a simple method for species weightings based on the variability in accuracy of identifications between divers. The weightings are proportional to the frequency with which each species is correctly identified, and is a procedure commonly used in conservation assessments. However, this would require an experimental "trial" of concurrent log entries for "expert" and other divers. This could be done at the beginning and end of a survey program.

It was evident that some aspects of the survey design would have hampered the accuracy of results from all divers, including the experts. For example, volunteer diver survey counts are usually done on either an ordinal scale (1 to 5 abundance categories) or a log abundance scale, which was the approach used in the SPARS survey. Both suffer from some loss of information, but are appropriate in surveys where the organisms being enumerated occur on a geometric size and abundance scale from very large and rare, to very small and abundant (i.e. abundances of encrusting tunicates versus lingcod). Conceptually, this is appropriate, but each diver may estimate the scale differently. More importantly, some types of organisms do not lend themselves well to any attempt to quantify individuals. Thus, some of the encrusting or colonial sponges, tunicates, hydrozoans, acorn barnacles, and all macroalgae are best described in terms of percent cover. In addition, there is a need to make notations about which parts of the round reef balls are occupied (light side or dark side, inside or outside, top side or underside, etc.) in order to understand the dynamics of recolonization. This is somewhat complicated for divers who are trying to count or estimate individuals in these patches of organisms.

In addition, the more diverse the focus of the dive surveys, the more likely it is that some aspect(s) will be under-sampled or subject to high error. Many volunteer survey programs focus only on fish species (c.f. Darwall and Dulvy 1996, Bohnsack 1996, Schmitt and Sullivan 1996). Attempting to identify and enumerate algal cover, fish, mobile and sessile invertebrates and patches of encrusting colonial forms in single dives from each diver may be too ambitious.

Biological Patterns Evident on Artificial Reefs

The second purpose of this report was to examine any biological patterns in colonization, development and seasonality of the artificial reefs. The sources of sampling error described for the SPARS survey procedure result in a limited ability to make definitive statements about the development of these reefs. Large-scale or gross and consistent patterns are reliable, with the more subtle shifts in species abundances and richness more questionable.

Normalization of Artificial Reefs to Natural Reef Composition

After the initial colonization phase (spring 1997), there were no clear differences in overall faunal abundance between the two artificial reefs and the natural reef over time. Total species observed per survey date and reef suggest that the natural reef had 15-30 taxa (based on the list used), for surveys in which at least 2 divers were deployed. When mean taxa numbers for selected (expert) divers was considered, this range could probably be modified to about 12-24 taxa. For the first 6 months after the artificial reefs were deployed, they had considerably lower total taxa numbers, but by the summer of 1998, there was a dramatic increase in both reefs to a maximum, which subsequently declined somewhat, then fluctuated within the same range as the artificial reef for the entire survey period. Thus, in general terms, it appears that the artificial reefs were fully colonized within about 6 months after deployment.

When the multivariate composition of the reefs are compared, more detailed information can be obtained about changes in species composition over time. Using simple similarity measures (Bray-Curtis for species abundance data and Sorensen's Index for presence/absence), pair-wise comparisons of overall reef compositions (irrespective of time) can be made. The power analyses for cluster dendrograms show that, overall, there were no significant differences between reefs in terms of mean species abundance compositions, either using total data, selected diver data or a subset of fish or invertebrates. However, the presence/absence data do show a significant difference with high power between the taxa present on AN and AS.

The temporal plots of similarity between reefs shows a dramatic change in fauna at AN and AS in the first 6 months after deployment, and an on-going greater similarity between artificial reefs than between either artificial reef and the natural reef. Natural variability over time seems to run within the range of 55-80% for the natural reef. Concurrent data are limited, but there may be a trend towards increased similarity between AS and NS over time. However, the high dissimilarity of AN to NS in the final survey is a clear indication that there is no such trend towards a more similar community between reefs over time.

When the overlap in frequency distributions of faunal composition for each reef are examined, however, it appears that 90% of the AS and AN reef compositions over time were outside the 90% range around the mean composition for NS Reef up until November 2000. The final survey in April 2001 changed this pattern by introducing considerable changes in the composition of NS Reef in particular, and greatly increasing the variability of composition around the mean value. This was reflected in the dramatic increase in sessile colonial forms such as sponges, orange social tunicates, and orange sea cucumber at NS, with a concurrent decline in the relative (but not absolute) abundance of predaceous sea-stars. Concurrently, AN showed an increase in abundance of sunflower starfish and tubesnout fish above normal levels, with a marked lack of the sessile species noted at NS Reef at the same time. With the long time gap between surveys, particularly in NS, it is difficult to get a clear picture of natural variability over time.

The multivariate patterns noted above did not change when using selected diver data only, fish data only, invertebrate data only, or total log transformed data.

Colonization, Recruitment and Seasonality of Artificial Reefs

Artificial reefs potentially provide extra substrate for attached and mobile benthic invertebrates and macroalgae, shelter from predation and currents, recruitment or nursery habitat for commercial and other species, and some relief of harvesting pressure on natural reefs (Pickering and Whitmarsh 1996). All of this may occur with or without an actual increase in regional biomass of commercial and recreational species. What does seem likely, and has been shown by some researchers, is that benthic invertebrate and attached macroalgal biomass increases because of the increased heterogeneity and attachment space. As these components provide food for higher trophic levels, it is conceivable, but not incontrovertible, that the reefs increase the biomass of commercial and other species. If suitable habitat is the limiting factor in fish and mobile shellfish production, then the addition of reef structures should enhance their productivity locally. However, a concern with the use of most commercially available reef structures, is that they are designed principally for adult fish and invertebrates, and may attract or enhance larger, predaceous forms, without providing adequate shelter and habitat for juveniles. Certainly the complexity and size of openings in reef structures will reflect the size of commercial species likely to colonize them (for review see Baine 2001). The argument has been made that such structures may actually disrupt the age/size class distributions of some species or species assemblages locally, thus creating an imbalance in community structure on the reef, and counteract any potential productivity increases.

Perhaps the most notable factor missing from the SPARS survey procedure was that there was no attempt to separate enumerations of new recruitment (juveniles) from immigration or drifting by adults. Since the issue of increased productivity versus attraction is related to the usefulness of the reef for juveniles, this issue is important.

In addition to size and complexity of the reef, light exposure, current and sedimentation are factors known to affect species recruitment and evolution on artificial reefs (Pickering and Whitmarsh 1996). Differences in species colonizing vertical and horizontal surfaces, up-current and down-current, light exposed or shaded areas is evident in a number of studies. For SPARS, the general light level was highest on the south side of each reef, with some additional shading of AN possible from the Pier. In addition, the up-current side of the reefs was also the more shaded (north) side.

Some patterns of recolonization noted for other artificial reefs can also be seen in the SPARS project. For example, Jensen et al. (1992) found that algal species dominate the horizontal surfaces of artificial reefs whereas fauna dominate the vertical surfaces. By association, algal feeders will tend to be dominant on the upper surfaces. Cave communities tend to dominate the inside of artificial reefs (Relini et al. 1994b – in Pickering). In the SPARS project, shrimp and some fish were commonly found hiding inside the balls. Temperature-related settlement patterns are expected for some seasonal taxa, and a knowledge of their requirements may help to understand settlement patterns on artificial reefs. Thus, special requirements of the orange social tunicate (*Metandrocarpa taylori)* may explain why it was highest in abundance on the south artificial reef, moderate in abundance on the natural reef, but not observed on AN. More dramatically, a colonizing patch of rock oysters (*Pododesmus macrochisma*) was found only on the AS 4 years into the survey. In addition, juvenile rockfish were evident in abundance only on the AN in the first year of the survey, after which they were seen only once on the natural reef, and sporadically in single sightings on the other two reefs thereafter. Both dominant perch species (*Cymatogaster aggregata* – Shiner; *Damalicthys vacca*: Pile) and tubesnout (*Aulorhynchus flavidus*) were observed almost exclusively on the artificial reefs during the entire survey, which may reflect their preference for certain types of "uncluttered" structures such as piers.

There were a few taxa present (orange sea cucumber: *Cucumaria miniata*, a variety of nudibranchs, whelks) on NS which showed no tendency to colonise the artificial reefs. Notably, the sea-cucumbers showed a marked seasonality at the NS, with high relative abundances in summer and relatively lower abundances in spring. This pattern was not evident in spring 2001, however, when orange sea cucumbers were unusually abundant.

In addition, some expected features of reef colonization were observed. Barnacles (*Balanus crenatus*) were not evident in any abundance on the artificial reefs until May-June 1997, and were never abundant on the natural reef. By contrast, some sunflower starfish (*Pycnopodia helianthoides*) and anemones (*Metridium senile*) were very early colonizers, evident on the first survey 4 months after deployment. The anemones were markedly more common on the AN than on AS. However, these were not necessarily small juveniles; examination of the videos suggests that they are larger forms which probably drifted in from the north with the currents, or emigrated. What is surprising is that despite being early colonizers, all three of the aforementioned species show their highest abundance on one of the artificial reefs relatively late in the survey (Nov/01 or Apr/02), suggesting that the development of these reefs may still be in flux. A similar pattern was evident in the later colonizer, the orange social tunicate.

There were clear seasonal patterns in the four dominant fish species. The only species for which juveniles were enumerated separately (copper rockfish), showed a predominant distribution of adults in summer and early fall, and juveniles in spring and late fall. Rockfish use shallow rocky reefs as juvenile nursery grounds and may therefore be particularly attracted to the reef ball structures. Juvenile rearing would appear to occur mainly in spring and late fall. The department of Fisheries and Oceans Canada consider rockfish to be relatively low in abundance in the Strait of Georgia at present, and there has been some concern about the need to conserve or protect these species (see http://www.pac.dfo-mpo.gc.ca/ops/fm/Sport/rockfish.htm). To this end, opportunistic monitoring of all species of rockfish is important. They are slow-growing and reproduce at a relatively advanced age (up to 15-20 years), and are thus vulnerable prior to sexual maturation.

Shiner perch and tubesnout were clearly late summer to fall visitors, and striped perch were most common in late fall through winter. The tubesnout generally lives in eel-grass beds and kelp in near-shore silty waters, and eats small fish. They aggregate once a year, but can also be seen in schools at night. Shiner perch generally give birth to live young in the summer. The perch species are definitely seasonal on-shore off-shore migrators, that mate in fall to winter, and use shallow water eel-grass and kelp beds and rocky niches to rear their young (late summer to early winter). The perches are opportunistic feeders on algae, crustaceans and other invertebrates and fish eggs.

Dungeness crab were most common in late spring through fall. Since this species is generally found deeper on sandy substrates, but moves into shallow water to moult, this may be a common moulting time. Red rock crab and northern kelp crab seem to be ubiquitous on all reefs at all times.

Water circulation is, of course, important for larval transport, nutrient and oxygen supply and suspended particulate food. A relatively high current will prevent excessive siltation, whereas too high a current can cause detachment or damage. During the SPARS survey period, winter storms may set back colonization, although there was no clear evidence of such an event in this survey. The El Nino/La Nina cycle was evident in the temperature profiles, with winter 1997 and spring 1998 warmer than either the previous or next year. Again, there was no clear change in biota related to the oceanic regime, except for a general impression from the videos that algal cover was more intense in late winter through spring of 1998 than the previous or following years.

Recommendations for future artificial reef surveys

The final purpose of this report was to make recommendations about improvements to volunteer diver surveys on artificial reef structures.

Taxa list

1. The identification of various types of rockfish (*Seabastes* spp.) appeared to be a problem. In a number of cases, the natural variability of the copper rockfish markings and shape appeared to confuse some divers, who identified species that were never seen by the experts and were not likely there.

2. Taxa which are not reef dwellers such as several ophiuroid species and incidental pelagic fish should be eliminated from the taxa list.

3. In general, the taxa list needs to be reduced in number and/or simplified to help avoid mis-identifications. More rigorous training of the divers in species identification is another solution.

Diver Bias

1. Detailed diver debriefing is essential at the end of each dive to pick up discrepencies between divers, but also to more clearly delineate how each diver counts and identifies different organisms. For example, Diver A might say that there were 1000's of barnacles on a reef, whereas his dive partner noted 100's. In order to apply fuzzy logic mathematical weighting schemes to this type of data, a clear knowledge of what each diver actually "sees" is vital. This debriefing can also be vital to help inexperienced divers identify species that they could not identify during the dive, or clear up any ambiguous notations on their dive sheets.

2. Extra habitat and behavioral information should be obtained and added to dive logs after dives, such as whether certain taxa tended to be obvious or hiding, on the north or south sides, on the upper or under sides of the reef, "clumped" together or territorial, associated or not with certain other organisms, and so on.

3. Shrimp appeared to be ubiquitous and numerous on all reefs right from the beginning of the survey, but were frequently missed by divers because of the animals' hiding and "scattering" behaviour. Therefore, it is not feasible to count these taxa, and they probably contribute little to the assessment of reef development by diver surveys.

4. A video of each transect on each dive date would allow some corrections for mis-identifications, as well as a method to help standardize the different "search images" of paired divers.

5. Potential divers and core voluntees should have training sessions using video and professional biologists to help clear up any misidentifications. This would also provide an objective means to determine "counting" bias by different observers.

Survey Methods

1. More systematic seasonal sampling is required. The actual number of dive dates could be reduced considerably, but should include an intensive set of surveys 4 times a year, ideally at about the same times each year.

2. Each reef and date should be surveyed by at least one “expert” research diver, and preferably two, with auxilliary divers providing additional data. Specifically, the expert diver(s) should attempt the enumeration and detailed identification procedures, whereas auxiliary divers map the general distribution of sessile organisms and rooted algaes. At the end of the dive, the expert and auxiliary divers can compare notes and match identifications with the maps, thus augmenting the training of the auxiliary divers, and more accurately defining the patterns of primary and seasonal colonization of the reefs.

3. The natural reef (or reference) should be surveyed on every dive date.

4. Divers should always use underwater lights to aid in species searching and identification.

5. Some distinction should be made between juvenile and non-juvenile fish and crabs. In addition, general size ranges for important colonizers such as barnacles, anemones and starfish will help to determine if these immigrate as adults, or by settling as juveniles.

6. The survey protocol should include a minimum survey time as well as required time expended by the diver for each pass reef. Training must stress that the divers are required to swim the entire transect during the prescribed time, and no more.

7. There should be separate counting strategies such as percent cover and reef location for colonial vegetative reproducers like some tunicates, anemones and sponges. Species that tend to settle en masse such as acorn barnacles should probably also be counted using the same method.

8. Rooted algae should be consistently surveyed as percent cover as usually standard for hard substrate surveys, on a rank scale appropriate to each species. This seasonal coverage is vital for understanding the distribution and abundance of fish and invertebrate organisms. Algal coverage data could also be obtained from systematic video transects rather than diver counts, freeing up the divers for more detailed biotic work.

Data Management

1. More attention, time and effort are required on data standardization, both immediately following dives and at the time of data entry. This is important particularly for data from untrained divers. As such the post-dive protocols need to be tightened, especially those pertaining to the project's data manager.

2. Dive conditions such as visibility need to be recorded carefully and consistently.

3. Periodic testing procedures to assess diver bias in identifications and counting or coverage techniques should be conducted to help standardize data.

Conclusions

The SPARS project was ambitious and somewhat experimental in nature. As such, the most important result is the suite of lessons learned. Future volunteer diver projects can benefit from an examination of the results and limitations of the SPARS program. Reef surveys in temporate waters using volunteers are relatively uncommon, partially because the luxuriant, seaonal macro-algal growth and notorious variations in visibility can make accurate surveys very difficult.

It is always true in this type of survey that the more limited the tasks for each diver, the more accurate the results should be. Therefore, survey objectives limited for example to enumerating only the fish and crabs, or only specific sessile invertebrates, could be more focused and efficient, both for diver training and field surveys. A series of recommendations to this end are included in the report.

Perhaps the most clear lesson from SPARS is that there is a particular need to assess the relative abundance of age and/or size classes of certain organisms, in order to better assess the artificial reef's potential for increased recruitment and nursery habitat. Without these added data, it is more difficult to determine if the reef balls are useful refugia and habitat for adults only or for all life stages.

Despite the potential sources of error in applying the SPARS protocols for volunteer divers, some fairly clear patterns in the development of the reefs was evident. Seasonality of major fish and crab species was clearly evident. There were distinct differences in preference of certain taxa either for artificial or natural reef, or between the north and south artificial reefs. By combining data, it was evident that significant differences between reefs were evident at the species presence/absence level and for the overall species abundance composition until November 2000. However, the five year span shows that long-term variability in sessile invertebrates can be high, even on the natural reef. This may prove to be a serious confounding factor in any temporal survey program.

References

Baine, M. 2001. Artificial reefs: a review of their design, application, management and performance. Ocean and Coastal Management 44: 241-259.

Bray, J.R. and Curtis, J.T. 1957. An ordination of the upland forest communities of southwestern Wisconsin. Ecol. Monogr. 27: 325-349.

Bohnsack, J.A. 1996. Two visually based methods for monitoring coral reef fishes. A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing **the** Biota and Habitat Conditions of Coral Reefs, Annapolis, MD (USA), 26-27 Jan 1995, ED: Crosby, MP; Gibson, GR; Potts, KW (eds)

Burd, B.J., Macdonald, R. and Boyd, J. 2000. Recovery of sediments and benthic infauna over 15 years following mine tailings deposition in a British Columbia fjord. Mar. Env. Res. 49: 145-175.

Burd, B.J. 2002. Evaluation of mine tailings effects on a benthic marine infaunal community over 29 years. Mar. Env. Res. 53: 481-519.

Conley, K.W., Cosgrove, J.A., P. Lambert and Smiley, B.D. 2001. Reefkeepers Guide for monitoring subtidal habitats of Canada's Pacific waters. Unpublished manuscript - Five Modules, Fisheries and Oceans Canada, Science Branch, Institute of Ocean Sciences, Sidney, B.C.

Darwall, W.R.T. and Dulvy, N.K. 1996. An evaluation of the suitability of non-specialist volunteer researchers for coral reef fish surveys. Maria Island, Tanzania – a case study. Biol. Conserv. 78: 223-231.

Downing, J.A. 1979. Aggregation, transformation and the design of benthos sampling programs. JFRBC 36: 1454-1463.

Elliott, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. 2nd edn. Scientific Publications of the Freshwater Biological Association, No. 25.

Environment Canada (EC) 1998. Benthic Invertebrate Community Expert Working Group Final Report. Recommendations from Cycle 1 Pulp and Paper Environmental Effects Monitoring Program Review. EEM/1997/7.

Halusky, J.G., Seaman, W. Jr. and Strawbridge, E.W. 1994. Effectiveness of trained volunteer divers in scientific documentation of artificial aquatic habitats. Fifth Int. Conf. Aquatic Habitat Enhancement, 1991, Bull. Mar. Sci. 55: 939-959.

Harper, J.R., Emmett, B., Howes, D.E. and McCullough, D. 1998a. Seabed imaging and mapping system - seabed classification of substrate, epiflora and epifauna. *In* Proceedings of the 1998 Canadian Hydrographic Conference, Victoria, BC, 13p.

Harper, J.R., McCullough, D., Emmett, B., Thuringer, P. and Ledwon, A. 1998b. Seabed imaging and mapping system, pilot project results. Contract Report by Coastal & Ocean Resources Inc., Sidney, BC. For the Land-Use Coordination Office (LUCO), Victoria, BC, 30p. including appendices.

Jensen, A.C., Collins, K.L., Lockwood, A.P.M. and Mallison, L. 1992. Artificial reefs and lobsters: The Poole Bay Project. In: Proceedings fo the 23rd annual shellfish conference 19th-20th May 1992. The Shellfish Association of Great Britain, London, pp. 69-84.

Lenth, R.V. 2001. Some practical guidelines for effective sample size determination. American Statistician 55: 187-193.

Mumby, P.J., Harborne, A.R., Raines, P.S. and Ridley, J.M. 1995. A critical assessment of data derived from Coral Cay Conservation volunteers. Bull. Mar. Sci. 56: 737-751.

Mumby, P.J., Clarke, K.R. and Harborne, A.R. 1996. Weighting species abundance estimates for marine resource assessment. Aquat. Conserv.: Mar. Freshwat. Ecosyst. 6: 115-120.

Nemec, A.F.L. and Brinkhurst, R.O. 1988. Using the bootstrap to assess statistical significance in the cluster analysis of species abundance data. CJFAS 45: 971-975.

Nemec, A.F.L. 2000. Bootstrap estimation of the statistical power of hierarchical cluster analysis. Ch. 4 in: Development of a Receiving Environment Monitoring Approach to Liquid Waste Management. Progress Workshop 2, December 6, 2000. Draft Technical Report for Greater Vancouver Regional District, Burnaby, B.C.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16: 229-311.

Pickering, H. and Whitmarsh, D. 1996. Artificial reefs and fisheries exploitation: a review of the Attraction versus Production debate, the influence of design and its significance for policy. CEMARE Research Paper 107, Portsmouth, UK.

Relini, M., Zamboni, N., Tixi, F. and Torchia, G. 1994. Patterns of sessile macrobenthos community development on an artificial reef in the Gulf of Genoa (Northwestern Meditteranean). Bull. Mar. Sci. 55: 745-771.

Schmitt, E.F. and Sullivan, K.M. 1996. Analysis of volunteer method for collecting fish presence and abundance data in the Florida keys. Bull. Mar. Sci. 59: 404-416.

Thomson, R.O. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56, 291pp.

APPENDICES

NOT INCLUDED IN THIS IMCOMPLETE DRAFT