Fauna of Cobalt-Rich Ferromanganese Crust Seamounts

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ISA TECHNICAL STUDY: No. 8

International Seabed Authority
Kingston, Jamaica

National Library of Jamaica Cataloguing-in-Publication Data

Fauna of Cobalt-rich ferromanganese crust seamounts : report / [prepared for the International Seabed Authority by Malcolm Clark … [et al.]].
p. : col. ill., maps ; cm. – (ISA technical study; 8)
Bibliography : p.
ISBN: 978-976-95268-7-7 (pbk)

1. Seamount animals 2. Marine animals 3. Marine mineral resources
4. Submarine topography 5. Oceanography
I. Clark, Malcolm II. Series
578.77 – dc 22

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Photo of coral *Calyptrophora alpha* with squat lobsters and a feather star courtesy of Hawai'i Undersea Research Laboratory

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Foreword

A principal function of the International Seabed Authority is to regulate deep seabed mining and to give special emphasis to ensuring that the marine environment is protected from any harmful effects which may arise during mining activities, including exploration. Recent developments have highlighted the potential of cobalt-rich ferromanganese crusts as a deep-sea mineral resource.

Seamounts in the central-west Pacific Ocean are known to have thick, cobalt-rich ferromanganese crusts. These are of commercial interest for mining. However, very little is known about the faunal communities on these seamounts, and in particular whether they could be different from those that occur on seamounts which do not have thick cobalt-rich crusts. Such information is fundamental to evaluating the potential impacts of mining operations, and formulating environmental guidelines for mining operations. This study was commissioned by the International Seabed Authority to assess patterns of community composition and diversity on seamounts with, and without, cobalt-rich crusts, and the factors that determine these patterns.

This study has provided a considerable advance in the knowledge of the biodiversity of cobalt-rich crusts, and factors that might drive community composition. However, the database and analyses can be expanded to improve the results. In particular, data on substrate type can be incorporated, and analyses can extend beyond presence-absence to include abundance. It is important to examine both of these factors in order to confirm the implication of the present study; that there is no effect of crust composition on the fauna. A workshop is planned in 2011 to review the present results, and to undertake further analyses.

This report was prepared for the International Seabed Authority by Malcolm Clark (NIWA, New Zealand), Christopher Kelley (Hawaiian Underwater Research Laboratory, USA), Amy Baco (Florida State University, USA) and Ashley Rowden (NIWA, New Zealand). The views expressed are those of the authors and do not necessarily reflect those of the International Seabed Authority. The Authority expresses it appreciation to the Census of Marine Life Programme on Seamounts (CenSeam) for its cooperation in making this study possible.

Executive Summary

Seamounts in the central-west Pacific Ocean are known to have thick, cobalt-rich ferromanganese crusts. These are of commercial interest for mining. However, very little is known about the faunal communities on these seamounts, and in particular whether they could be different from those that occur on seamounts which do not have thick cobalt-rich crusts. Such information is fundamental to evaluating the potential impacts of mining operations, and formulating environmental guidelines for mining operations. This study was commissioned by the International Seabed Authority in order to assess patterns of community composition and diversity on seamounts with, and without, cobalt-rich crusts, and the factors that determine these patterns.

Video data were extracted from submersible and ROV dives carried out by the Hawaiian Underwater Research Laboratory on a range of seamount features in the Hawaiian Archipelago between 1983 and 2003. There were 270 dives covering 33 locations, comprising a mixture of potentially commercial cobalt-rich and non cobalt-rich crust sites. Data were checked and edited, and a final total of over 30,000 observational records were extracted.

There were 967 'species' identified from all the dives combined. The majority of these were Cnidarians (corals, anemones and related taxa) with 287 species, Osteichthyes (bony fishes) with 252, Echinoderms (such as starfishes.) with 154, and Crustaceans (crabs, shrimps) with 106. The species seen varied between locations, with 209 recorded only from cobalt-rich sites, 271 from non cobalt-rich sites, and 487 seen at both types of crust sites. A full list of recorded species is provided, showing occurrence on grouped cobalt-rich and non cobalt-rich sites.

Preliminary analyses revealed differences in data between the sampling vehicles, and so a reduced set of presence-absence observations was compiled from just Pisces 4 and Pisces 5 submersible dives for more detailed analysis. This reduced dataset comprised 13,000 records of invertebrate megafauna from 81 dives at 16 sites. Multivariate analyses showed no significant difference in the invertebrate community composition between cobalt-rich and non cobalt-rich sites. However, there was considerable variation between locations. The main determinant of community composition was depth, with three zones defined: approximately 200–350 m; 360–600 m; and 750–1800 m. Cniderian species, especially corals, were commonly the characterizing or discriminating species in these faunal assemblages.

Almost 200 images taken in situ of the main species, or reperesentative species of the major taxa, are provided for Porifera, Cnideria, Mollusca, Crustacea, Echinodermata, Chondrichthyes and Osteichthyes.

Overall, the study has provided a considerable advance in our knowledge of the biodiversity of cobalt-rich crusts, and factors that might drive community composition. However, the database and analyses can be expanded to improve the results. In particular, data on substrate type can be incorporated, and analyses can extend beyond presence-absence to include abundance. It is important to examine both of these factors in order to confirm the implication of the present study; that there is no effect of crust composition on the fauna. A workshop is planned in 2011 to review the present results, and to undertake further analyses.

CHAPTER ONE

Background

1. Background

Seamounts are prominent features of the world's underwater topography. It is estimated there may be as many as 100,000 large seamounts (with an elevation of 1,000 m or greater) (Wessel, 2001), distributed throughout the world's oceans (e.g. Kitchingman et al., 2007), where they provide physically isolated benthic marine habitats in otherwise pelagic and midwater regions. Because of the isolated geographic nature of these habitats, seamounts (as well as ridges, banks and oceanic islands) have been hypothesized to be locations where speciation occurs in deep-sea fauna (e.g. Hubbs, 1959; Wilson and Kaufmann, 1987). Many seamounts and seamount chains have been reported to have high levels of faunal endemicity (Rogers, 1994; Parin et al, 1997; Richer de Forges et al, 2000), although several recent studies and reviews show that this cannot be taken as a generalisation for all seamounts (e.g. Samadi et al, 2006; O'Hara, 2007; Stocks and Hart, 2007; McLain, 2007). Nevertheless, seamounts and similar offshore features are widely accepted as potentially playing an important role in the ecology of the deep-sea (Clark et al, 2010).

Seamounts are well known to attract concentrations of fish, which form the basis of numerous commercial fisheries (e.g. Clark et al, 2007a; Da Silva and Pinho, 2007). However, they are also increasingly of interest for the exploitation of their mineral resources (United Nations-ISA, 2004). Polymetallic massive sulphide deposits can form on seamounts with black smoker and other volcanic activity (e.g. Herzig and Petersen, 2002; Herzig, 2007), and cobalt-rich ferromanganese crusts occur on seamounts, ridges and plateaus where crust minerals precipitate out onto rocky surfaces that currents sweep clean of sediments over long periods (Hein, 2002). These crusts occur universally on exposed rocks throughout the oceans, but form thick pavements (up to 250 mm thick) primarily on large seamounts and guyots in the western and central Pacific Ocean (Hein, 2002; Zhou, 2007; Hein, in press). The chemical composition of the crusts can be high in manganese and iron, and this could have an effect on the animals able to live in such a habitat. Very little research has been conducted on the influence of the chemical composition of a hard substratum on seabed communities. Veillette et al (2007) found no clear relationship between fauna and the geochemical composition of the outer surface of polymetallic nodules from different areas of the seabed. However, they were not able to compare the composition of nodule fauna with that of other hard substratum types at the same water depths. The biological communities associated with the particular chemical environment at, and surrounding, active hydothermal vents have been extensively studied in recent decades (e.g. Van Dover, 2000) but much less is known about the fauna of cobalt-rich crusts on seamounts (Grigg et al., 1987).

Seamount benthic communities are vulnerable to human activities. Bottom trawling and long-lining have been shown to have significant impact on seamount communities, particularly on sedentary structure-forming corals and sponges (e.g. Koslow et al, 2001; Clark and Koslow, 2007; Rowden and Clark, 2009), and the slow growth of such taxa (e.g. Rogers et al., 2007) can prolong recovery from impact. This further highlights the need for scientific data on the ecology and ecosystem function of seamount communities in order to inform appropriate management.

The International Seabed Authority (ISA) has the mandate under the United Nations Convention on the Law of the Sea (UNCLOS) to regulate exploration for, and exploitation of, marine mineral resources in 'The Area' which is beyond the boundaries of national jurisdiction. It has held a number of workshops since 2000, most notably in 2004 and 2006, to bring together available information on the geology and biology of cobalt-rich ferromanganese crusts found predominantly on seamounts in the central-northern Pacific Ocean (CNP). However, it has become clear that seamounts worldwide have been poorly sampled (e.g. Stocks et al, 2004; Clark, 2009), and that very little is known about the CNP seamounts in particular (Koslow, 2007). Much more information was needed to describe and understand the composition of seamount communities, and subsequently to ascertain the potential impact of exploration and mining of these seamount deposits, and to develop robust environmental guidelines for exploration. This has been one of the objectives of the Census of Marine Life programme on seamounts ('CenSeam') (Clark et al, 2007b).

During the ISA workshop in 2006, CenSeam reviewed available data and potential sources of information that could help improve our knowledge of cobalt-rich crust communities, and subsequently gained funding from the ISA to undertake the present study to compile available information on seamounts in the cobalt-rich zone of the CNP from the dive archives of the Hawaii Undersea Research Laboratory (HURL). These dives cover the Hawaiian Archipelago, a portion of which falls within the cobalt-rich zone. The HURL database, therefore, represents a previously untapped source and the best available data on the fauna of cobalt-rich seamounts and other features, and also includes data on features from the non cobalt-rich portion of the Archipelago for comparison. The database includes data not just on seamounts, but also on other seamount-like features including oceanic islands, atolls and banks, and so also provides insights into the degree of uniqueness of the fauna on cobalt-rich seamounts as compared to that of nearby features.

Study objectives

1) To assess patterns of community composition and diversity of fauna at cobalt-rich and non cobalt-rich sites, and the factors that determine these patterns.
2) To examine gaps in current knowledge of these patterns with a view to encouraging collaborative research to address them.
3) To provide the ISA with recommendations to input into formulation of environmental guidelines for future mining contractors.

CHAPTER TWO

Methods

2. Methods

Data

All data used for this study come from the HURL submersible and ROV video logging database. Data were extracted from dives conducted in the Hawaiian Archipelago and nearby seamounts between 1983 and 2003 by the RCV-150 remotely operated vehicle (ROV) and the Makali'i, Pisces 4, and Pisces 5 submersibles. Data selection was discussed with Dr Jim Hein (United States Geological Service), and only dives with data collected from depths greater than 200 m were included in this analysis (shallow, younger, seamounts were thought to have little prospect of having thick cobalt crust). The sites included a mixture of cobalt-rich and non cobalt-rich seamounts. These were defined on the basis of their potential for mining, and hence considered seamount size and shape as well as likely cobalt concentration. The use of the terms "cobalt-rich" and "non cobalt-rich" in this report is therefore not to be treated solely as an indication of cobalt richness in the crust. The selected portion of the database included 30,652 records for 270 dives at 33 locations (Table 1). "Location" refers to an individual feature (seamount, island, atoll or bank). The geographical distribution of cobalt-rich and non cobalt-rich sampling locations is shown in Figure 1.

Each data record consisted of a single row of a Microsoft Excel file, with each species/operational taxonomic unit (hereafter referred to as 'species') observed in a five-minute interval recorded as a separate row. Five-minute intervals with no taxa were recorded as a single row with "none" in the species column. These data were included along with additional columns to record vehicle, dive number, date, site position, observation interval, organism type degree of certainty of species identification, and depth.

Before analysis the database was modified as follows: a) typographical errors and misspellings were corrected; b) taxa with the same species designations but different higher-level taxon designations were made uniform; c) all records with no taxa observed were removed (this is useful information, but not for this particular analysis); and d) all records that listed a taxon as, or were inferred as, "dead" were removed.

Table 1. Summary of data examined for this study. The number of dives per features is supplied, with the number of faunal observations in parentheses. CR=cobalt-rich, NCR=non cobalt-rich

Location	Cobalt	Makali'i	Pisces 4	Pisces 5	ROV
Johnson Atoll	CR	34 (558)			
Cross Seamount	CR		4 (1846)	40 (1691)	3 (149)
Bishop Seamount	CR			1 (146)	
Pensacola Seamount	CR			1 (103)	
East Necker Seamount	CR			2 (1466)	5 (291)
Necker	CR	3 (48)			
East French Frigate Shoals	CR		1 (361)	5 (2618)	6 (354)
French Frigate Shoals	CR	6 (122)			
Bank 66	CR	3 (125)	1 (152)		1 (31)
North FFS Seamount	CR			1 (178)	
Baby Brooks Bank	CR	2 (38)	3 (485)	4 (854)	7 (211)
Nihoa	CR		6 (826)		5 (106)
WestPac Bank	CR			4 (1681)	1 (36)
East Twin Banks	CR			1 (194)	
West St Rogatien Bank	NCR		3 (504)	5 (1409)	10 (247)
Raita Bank	NCR		3 (542)	8 (1996)	13 (594)
Maro Reef	NCR		6 (1344)		8 (347)
East Laysan Seamount	NCR			4 (1638)	
Laysan Bank	NCR				8 (277)
Laysan Island	NCR			1 (169)	1 (64)
East Northhampton Seamount	NCR		2 (404)		3 (52)
West Northhampton Seamount	NCR		2 (316)		2 (40)
Pioneer Bank	NCR			6 (2455)	5 (298)
Pioneer Ridge	NCR				2 (65)
West Lisianski Bank	NCR		1 (351)	2 (432)	4 (212)
East Salmon Seamount	NCR				1 (238)
Salmon Bank	NCR			1 (85)	1 (65)
Pearl and Hermes Atoll	NCR		1 (167)		
Ladd Seamount	NCR		1 (197)		
Nero Seamount	NCR		1 (201)	2 (240)	2 (123)
Kure Atoll	NCR				2 (35)
North Kure Bank	NCR		1 (3)	1 (177)	2 (37)
Northwest Kure Bank	NCR		1 (254)	2 (544)	1 (58)

Specimen photographs

Representative images of the identified species have been taken as frame-grabs from the footage for inclusion in a HURL reference guide to the common fauna of the region. A selection was made from the HURL images for inclusion here to enable the reader to visualize the main species or taxa.

Figure 1.
Location of dive sites

Legend:
Sites highlighted in yellow are cobalt-rich sites; those in white are non cobalt-rich sites.

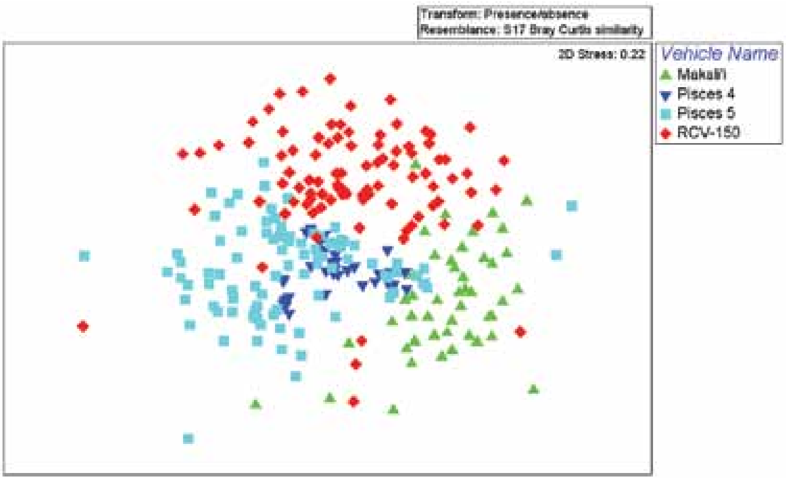
Data pretreatment and multivariate analyses

The modified database was converted to a species by sample matrix, with individual dives as the samples, using the Excel function "Pivot Table". The Excel file was then transferred to the software package PRIMER 6.1.11 (Clarke and Gorley, 2006) for multivariate statistical analyses. All functions and routines discussed below are a part of the PRIMER software package (see references in Clarke and Warwick, 2001). Additional information for dive location, cobalt site designation, feature type (e.g. seamount, atoll, bank), average depth of dive, minimum depth of dive, maximum depth of dive, latitude, longitude, bottom time, Principal Investigator (PI) and summit depth of feature, were extracted from the database and HURL dive logs. These data and vehicle types were then used to construct PRIMER "Environmental" and "Factors" datasets.

Over the course of the 20 years of the database compilation and changes in technology, abundance data and time intervals were not consistently logged across vehicles. There were also multiple cameras on the submersibles and individual organisms may have been observed by more than one camera. These animals would be counted twice and therefore abundance counts from the database would not accurately reflect actual numbers. Because of these issues, the dataset was converted to a presence/absence dataset. This conversion was done using the PRIMER "transform data" function. A ranked similarity matrix was then constructed for the presence/absence data using the Bray-Curtis similarity algorithm. A matching matrix was created for the environmental data using a Euclidean distance metric.

Because there was a difference in camera arrangement, camera type and logging method between the four vehicles used to create the video log, an Analysis of Similarity (ANOSIM, multivariate equivalent of ANOVA) was first carried out using the entire dataset (including fish) to test the null hypothesis that there was no difference in faunal community composition with vehicle type. The null hypothesis was rejected (Global $R = 0.295$, $p = 0.001$) and a multidimensional scaling (MDS) ordination plot showed the clear pattern of difference between most vehicle types (Figure 2). However, the pairwise ANOSIM result revealed that there is no difference in community composition between submersibles Pisces 4 and Pisces 5 ($R = -0.026$, $p = 0.724$). Based on the latter result, a new dataset was constructed of data from only the Pisces 4 and Pisces 5 submersible dives in order to avoid confounding further analyses by vehicle type.

Figure 2. Multidimensional scaling (MDS) on presence/absence transformed data from full HURL dataset



Legend: Individual points represent a single dive. Data cluster by vehicle, although those from Pisces 4 and 5 overlap and are not significantly different.

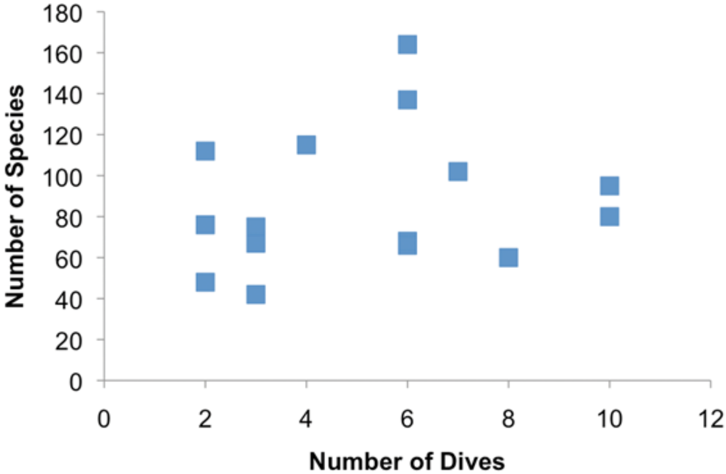
For the remaining multivariate analyses, the following modifications were made to the Pisces 4 and 5 dataset in order to improve the robustness of the planned tests: a) all taxa with a certainty of species identification score of 4 ("problematic") or blank were removed from the dataset to improve taxonomic consistency; b) all fish taxa were removed from the dataset as the focus of this study is on benthic invertebrates; c) all locations with only a single dive were removed because the ANOSIM test requires more than one sample per factor; d) the maximum number of dives per location was set at ten (ten dives out of 38 dives were selected at random from Cross Seamount) in order to remove a positive linear relationship between number of dives and number of species (Figure 3a), and to provide a more balanced design for the ANOSIM test; and e) dives with < 3 species were removed, revealed to be obvious outliers in a preliminary assessment of the MDS P4 106–1 species and P5 462–3 species. The remaining dives had a minimum of six species per dive.

A plot of length of time on the bottom for each dive versus number of species was also examined to determine if bottom time affected sampling results. There was no correlation between bottom time and number of species (Figure 3b), so no additional dives were removed based on bottom time.

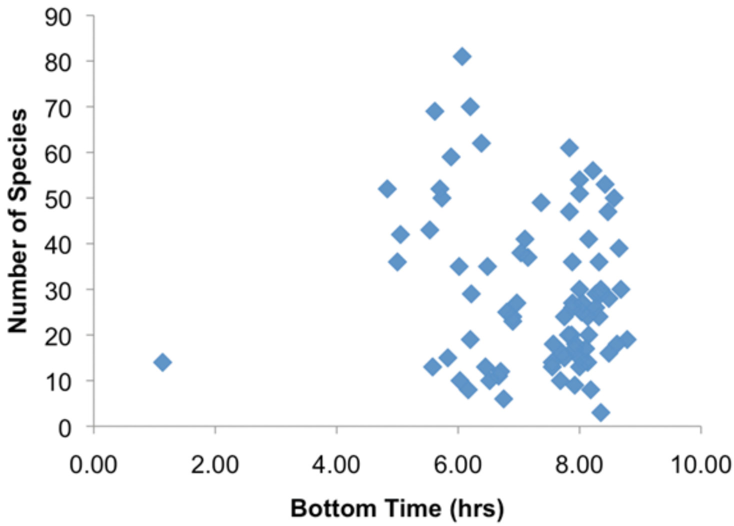
Species accumulation curves indicated that even selecting ten dives would not fully describe the fauna at a location. The plot of species against number of dives for Cross Seamount shows the curve still rising (Figure 4), and continues with no asymptote to the total number of dives.

Figure 3. Number of dives per location (a) and length of bottom time per dive (b) of Pisces 4 and Pisces 5 submersible dives versus the total number of species

(a)

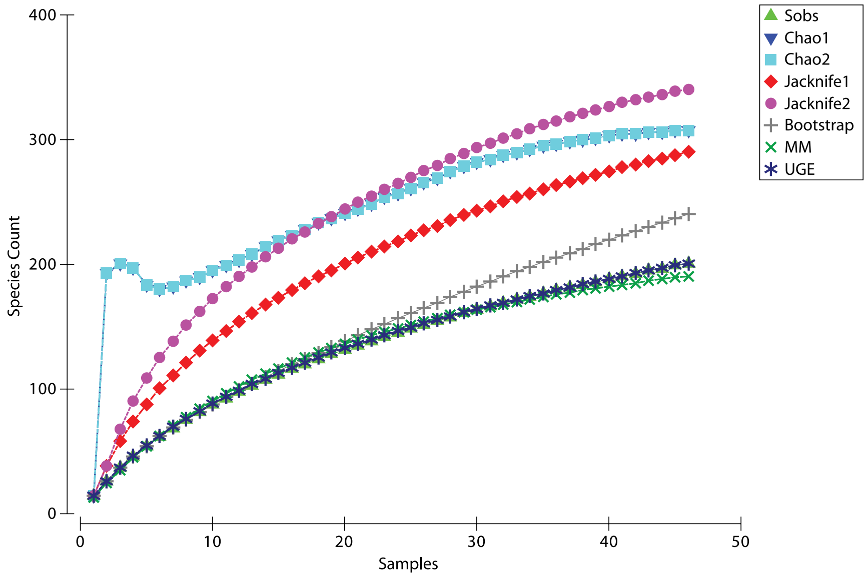


(b)



The reduced dataset for the formal multivariate analysis consisted of 13,175 records, 81 dives, 16 locations and 448 species. Of the 16 locations, six were cobalt-rich, and 10 non cobalt-rich. Dive sites at sampling locations covered a wide range of depths (Table 2). Modified PRIMER "Environmental" and "Factor" datasets were produced for the reduced dataset.

Figure 4. Species accumulation curves for dives on Cross Seamount



Note: several methods of calculation are plotted, note some give nearly identical results and are not visible.

A two-way nested ANOSIM test was carried out to test for differences in community composition between cobalt-rich and non cobalt-rich site groups, and between locations within these groups. MDS ordination plots and the routine CLUSTER, which creates a hierarchial dendrogram of the group-average clustering of sites, were used to visualize the results. The relationships between the community composition and the environmental variables were investigated using the BIOENV correlation procedure. The species contributing to the similarity and dissimilarity between sites within different depth zones (nested within location groups) were investigated using the similarity percentages procedure, SIMPER. Species that consistently 'characterized' the similarity of a community, or 'discriminated' the dissimilarity between communities were those for which the ratio of the average similarity/dissimilarity to the standard deviation was >1.3 (Clarke and Warwick, 2001).

Table 2. Summary of location and dive information for final dataset used for multivariate analyses

Location	Lat. N	Lon. W	Cobalt	Feature	Summit Depth (m)	N. Dive	Depth Range (m)	N. Species	PI
Baby Brooks Bank	24.0	166.7	CR	Bank	54	7	200-552	102	Kelley,Parrish, Baco,Dollar
Cross Smt	18.7	158.3	CR	Seamount	352	10	372-1755	80	Cowen, Malahoff Baco, Mullineaux Grigg, Parrish
E French Frigate Shoals	23.9	165.3	CR	Island Bank	358	6	346-684	137	Baco,Parrish
E Necker	23.3	163.6	CR	Seamount	414	2	1076-1808	112	Baco
Nihoa	23.2	161.8	CR	Emergent	0	6	319-1240	68	Smith
WestPac Bank	23.3	162.6	CR	Bank	339	4	285-521, 1000-1817	115	Baco,Parrish
E Laysan Smt	25.7	171.4	NCR	Seamount	1171	4	1135-1808	115	Baco
E Northampton	25.3	172.0	NCR	Seamount	30	2	278-1044	76	Parrish
Maro Reef	25.5	170.4	NCR	Emergent	0	6	322-1045	66	Baco,Smith
Nero Smt	27.9	177.9	NCR	Seamount	67	3	279-734	42	Baco,Parrish
NW Kure Bank	28.9	179.6	NCR	Bank	362	3	204-595	67	Baco,Parrish
Pioneer Bank	25.8	173.5	NCR	Bank	37	6	405-1825	164	Baco
Raita Bank	25.5	169.6	NCR	Bank	18	10	200-586	95	Kelley,Baco
W Lisianski Bank	26.3	174.5	NCR	Bank	70	3	300-760	75	Baco
W Northampton	25.5	172.3	NCR	Seamount	38	2	240-863	48	Parrish
W St Rogatien Bank	24.5	167.3	NCR	Bank	55	8	200-567	60	Kelley

CHAPTER THREE

Results

3. Results

Seamount fauna

There were 967 'species' identified from all the dives combined. The majority of these were Cnidarians (corals, anemones and related taxa) with 287 species (Table 3), Osteichthyes (bony fishes) with 252, Echinoderms (starfishes etc) with 154, and Crustaceans (crabs, shrimps) with 106. The species seen varied between locations, with 209 recorded only from cobalt-rich sites, 271 from non cobalt-rich, and 487 seen at both types of crust sites.

Table 3. Summary of number of 'species' recorded from all dives broken down by phylum, the numbers seen only at cobalt-rich or non-cobalt-rich sites, and the number recorded at both types of habitat

Phylum	Total	Cobalt-rich	Non cobalt-rich	Both
Algae	7	2	1	4
Protozoa	1	0	1	0
Porifera	82	20	18	44
Cnidaria	287	74	68	145
Ctenophora	2	0	0	2
Annelida	6	2	1	3
Mollusca	36	10	15	11
Arthropoda Chelicerata	1	0	1	0
Arthropoda Crustacea	106	25	37	44
Echiura	1	0	1	0
Bryozoa	1	1	0	0
Echinodermata	154	36	48	70
Tunicata	5	0	3	2
Chondrichtyes	26	3	9	14
Osteichthyes	252	36	67	149
Mammalia	1	0	1	0
Total	967	209	271	487

The full list of species is given in Table 4, with the number of observations reported for the combined locations grouped into cobalt-rich and non cobalt-rich. The numbers should not be interpreted as any indication of abundance (see explanation in the methods section, above) but they help give a general impression of relative abundance; hence they are retained in preference to simply indicating presence or absence. Note that since the study was completed in 2009, some species names may have been changed or revised.

Table 4. Full list of 'species' recorded from cobalt-rich and non cobalt-rich sites in this study

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Algae	algae	algae	127	64
Algae	chlorophyta	chlorophyta	3	2
Algae	chlorophyta	*Ulva fasciata*	1	
Algae	chlorophyta	*Ulva sp*	2	2
Algae	rhodophyta	rhodolith		2
Algae	rhodophyta	rhodophyta	1	4
Algae	rhodophyta	rhodophyta coralline	3	
Protozoa	xenophyophore	xenophyophore		2
Porifera	corallistid	*Corallistes sp*		1
Porifera	demospongiid	demospongiid knob	3	4
Porifera	demospongiid	demospongiid red		1
Porifera	demospongiid	demospongiid white	1	
Porifera	demospongiid	demospongiid yellow	11	
Porifera	euplectellid	*Bolosoma sp*	16	3
Porifera	euplectellid	*Bolosoma sp cf*	1	
Porifera	euplectellid	*Bolosoma sp1*	1	
Porifera	euplectellid	*Bolosoma sp2*	1	
Porifera	euplectellid	bolosominae	9	3
Porifera	euplectellid	Corbitellinae n sp	14	1
Porifera	euplectellid	*Dictyaulus sp*	5	
Porifera	euplectellid	*Euplectella sp*	18	16
Porifera	euplectellid	euplectellid	3	2
Porifera	euplectellid	euplectellid vase	1	7

Table 4. Ctnd...

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Porifera	euplectellid	*Hertwigia sp cf*	13	4
Porifera	euplectellid	*Regadrella sp*	41	52
Porifera	euplectellid	*Regadrella sp1*	18	13
Porifera	euplectellid	*Regadrella sp3*	9	2
Porifera	euplectellid	*Saccocalyx sp*	1	
Porifera	euplectellid	*Saccocalyx sp cf*	2	14
Porifera	euplectellid	*Sericolophus hawaiicus*	17	59
Porifera	euplectellid	*Walteria flemmingi*		1
Porifera	euplectellid	*Walteria leuckarti*	2	
Porifera	euplectellid	*Walteria sp*	5	45
Porifera	euplectellid	*Walteria sp3*	1	
Porifera	euplectellid	*Walteria sp2*		1
Porifera	euplectellid	*Walteria sp4*	3	1
Porifera	euretid	chonelasmatinae club cf	1	
Porifera	euretid	chonelasmatinae ribbon cf	18	44
Porifera	euretid	chonelasmatinid	4	87
Porifera	euretid	*Endorete sp*	8	8
Porifera	euretid	euretinid	1	5
Porifera	farreid	fareid n genus		8
Porifera	farreid	*Farrea occa*	35	19
Porifera	farreid	*Farrea sp*	13	13
Porifera	farreid	*Farrea sp1*		23
Porifera	farreid	farreid		24
Porifera	farreid	farreid stalked cf		1
Porifera	hexactinellid	hexactinellid	199	83
Porifera	hexactinellid	hexactinellid columnar		9
Porifera	hexactinellid	hexactinellid cone	1	
Porifera	hexactinellid	hexactinellid cup	16	9
Porifera	hexactinellid	hexactinellid dish	1	2

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Porifera	hexactinellid	hexactinellid fuzzy		1
Porifera	hexactinellid	hexactinellid ruffle		2
Porifera	hexactinellid	hexactinellid shell		1
Porifera	hexactinellid	hexactinellid spiny club		1
Porifera	hexactinellid	hexactinellid square-top	2	
Porifera	hexactinellid	hexactinellid stalked	8	7
Porifera	hexactinellid	hexactinellid stalked bowl	14	1
Porifera	hexactinellid	hexactinellid stalked tulip	2	
Porifera	hexactinellid	hexactinellid tan	7	1
Porifera	hexactinellid	hexactinellid unknown		1
Porifera	hexactinellid	hexactinellid vase	7	2
Porifera	hexactinellid	hexactinellid waffle	2	
Porifera	hexactinellid	hexactinellid white	5	6
Porifera	petrosiid	*Petrosia sp*	1	
Porifera	pheronematid	pheronematid	8	15
Porifera	pheronematid	pheronematid sp2	22	99
Porifera	pheronematid	*Platylistrum platessa*	146	42
Porifera	pheronematid	*Poliopogon sp*	7	73
Porifera	pheronematid	*Poliopogon sp1*	3	1
Porifera	pheronematid	*Poliopogon sp2*	13	5
Porifera	pheronematid	*Poliopogon sp3*	1	4
Porifera	pheronematid	*Semperella schultzei*	14	46
Porifera	pheronematid	*Semperella sp*	7	5
Porifera	pheronematid	*Semperella sp2*	8	
Porifera	rosellid	rosellid	2	
Porifera	rossellid	*Basthydorus sp*		1
Porifera	rossellid	*Caulophacus sp*	9	1
Porifera	rossellid	*Caulophacus sp1*	6	1
Porifera	rossellid	*Trichasterina sp1*	22	16

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Porifera	rossellid	*Trichasterina sp2*	1	
Porifera	sponge	sponge	5	4
Porifera	sponge	sponge barrel	1	
Porifera	sponge	sponge blue		2
Porifera	sponge	sponge cup		1
Porifera	sponge	sponge orange tube		1
Porifera	sponge	sponge white	97	3
Porifera	tretodictyid	tretodictyid	81	12
Porifera	tretodictyid	tretodictyid waffle	32	
Cnidaria	acanthogorgiid	*Acanthogorgia sp*	18	12
Cnidaria	acanthogorgiid	*Acanthogorgia striata*	12	
Cnidaria	actinernid	*Actinernus nobilis*	15	
Cnidaria	actiniid	*Stylobates aenus*	2	7
Cnidaria	actinoscyphiid	*Actinoscyphia sp*		3
Cnidaria	actinoscyphiid	*Actinoscyphia sp2*	2	1
Cnidaria	actinoscyphiid	*Actinoscyphia sp3*	7	
Cnidaria	actinostolid	actinostolid	4	1
Cnidaria	actinostolid	actinostolid orange		1
Cnidaria	actinostolid	actinostolid tan	31	11
Cnidaria	alcyonacean	alcyonacean	1	4
Cnidaria	alcyonacean	alcyonacean red	7	2
Cnidaria	alcyonacean	alcyonacean red striped		1
Cnidaria	alcyonacean	alcyonacean white		1
Cnidaria	alcyoniid	*Anthomastus fisheri*	22	18
Cnidaria	alcyoniid	*Anthomastus robusta*		1
Cnidaria	alcyoniid	*Anthomastus sp*	2	75
Cnidaria	alcyoniid	*Anthomastus sp red*	2	11
Cnidaria	alcyoniid	*Anthomastus steenstrupi*		3
Cnidaria	alcyoniid	*Anthomastus white*		2

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	alcyoniid	*Bellonella molokaiensis*	3	
Cnidaria	anemone	anemone	5	158
Cnidaria	anemone	anemone banded	1	1
Cnidaria	anemone	anemone barred	1	
Cnidaria	anemone	anemone black	1	
Cnidaria	anemone	anemone brown	47	3
Cnidaria	anemone	anemone burrowing		1
Cnidaria	anemone	anemone clonal	28	
Cnidaria	anemone	anemone clonal brown		1
Cnidaria	anemone	anemone gray	2	
Cnidaria	anemone	anemone orange	32	37
Cnidaria	anemone	anemone orange small		1
Cnidaria	anemone	anemone purple	4	1
Cnidaria	anemone	anemone red	1	3
Cnidaria	anemone	anemone tan	2	
Cnidaria	anemone	anemone white	5	
Cnidaria	anthemiphyllid	*Anthemiphyllia macrolobata*		2
Cnidaria	anthoptilid	*Anthoptilum grandiflorum cf*		2
Cnidaria	anthoptilid	*Anthothela nuttingi*	15	2
Cnidaria	antipatharian	antipatharian	1 6	5
Cnidaria	antipatharian	*Cirrhipathes sp*	1	
Cnidaria	antipatharian	*Cirrhipathes/Stichopathes*	39	189
Cnidaria	antipatharian	*Dendropathes/Myriopathes*	8	1
Cnidaria	antipathid	*Antipathes griggi*	3	
Cnidaria	antipathid	*Antipathes sp*	25	9
Cnidaria	antipathid	*Antipathes subpinnata*	7	3
Cnidaria	antipathid	antipathid		5
Cnidaria	antipathid	*Aphanipathes sp1*	63	5
Cnidaria	antipathid	*Stichopathes sp*	6	3

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	boloceroid	*Bolocera sp cf*	2	
Cnidaria	boloceroid	*Boloceroides daphneae*	1	
Cnidaria	caryophylliid	*Caryophyllia diomedeae*		5
Cnidaria	caryophylliid	*Caryophyllia rugosa*	3	
Cnidaria	caryophylliid	caryophylliid	2	5
Cnidaria	caryophylliid	*Desmophyllum dianthus*	3	21
Cnidaria	caryophylliid	*Trochocyathus aithoseptatum*	6	
Cnidaria	ceriantharian	ceriantharian		1
Cnidaria	cerianthid	*Aracnanthus sp*	2	
Cnidaria	cerianthid	cerianthid	1	4
Cnidaria	cerianthid	cerianthid banded		6
Cnidaria	cerianthid	cerianthid brown	1	1
Cnidaria	cerianthid	cerianthid cf		1
Cnidaria	cerianthid	cerianthid gray	1	
Cnidaria	cerianthid	cerianthid green	1	
Cnidaria	cerianthid	cerianthid tan	1	
Cnidaria	chrysogorgiid	*Chrysogorgia chryseis*	3	
Cnidaria	chrysogorgiid	*Chrysogorgia geniculata*	9	5
Cnidaria	chrysogorgiid	*Chrysogorgia sp*	8	9
Cnidaria	chrysogorgiid	*Chrysogorgia stellata*	1	15
Cnidaria	chrysogorgiid	chrysogorgiid	1	67
Cnidaria	chrysogorgiid	*Iridogorgia bella*	25	54
Cnidaria	chrysogorgiid	*Iridogorgia magnispiralis cf*	37	1
Cnidaria	chrysogorgiid	*Iridogorgia sp*	32	24
Cnidaria	chrysogorgiid	*Metallogorgia melanotrichos*	76	39
Cnidaria	chrysogorgiid	*Pleurogorgia militaris*	1	
Cnidaria	chrysogorgiid	*Radicipes spiralis cf*		2
Cnidaria	chrysogorgiid	*Rhodaniridogorgia superba*	2	18
Cnidaria	cladopathid	*Trissopathes pseudotristicha*	4	2

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	clavulariid	*Clavularia grandiflora*		38
Cnidaria	clavulariid	*Telestula corregata*		2
Cnidaria	clavulariid	*Telestula sp*	4	
Cnidaria	clavulariid	*Telestula sp2*	6	
Cnidaria	clavulariid	*Telestula spiculocola*	1	
Cnidaria	cnidarian	cnidarian	61	26
Cnidaria	cnidarian	cnidarian orange	2	6
Cnidaria	cnidarian	cnidarian red	8	
Cnidaria	cnidarian	cnidarian white	1	1
Cnidaria	cnidarian	cnidarian white cluster	1	33
Cnidaria	cnidarian	cnidarian yellow		2
Cnidaria	coralliid	corallid yellow		1
Cnidaria	coralliid	*Corallium abyssale*	7	4
Cnidaria	coralliid	*Corallium ducale*	3	
Cnidaria	coralliid	*Corallium kishinouyei*	4	5
Cnidaria	coralliid	*Corallium laauense*	4	2
Cnidaria	coralliid	*Corallium regale*	159	48
Cnidaria	coralliid	*Corallium secundum*	71	8
Cnidaria	coralliid	*Corallium secundum cf*	1	
Cnidaria	coralliid	*Corallium sp*	88	2
Cnidaria	coralliid	*Paracorallium tortuosum*	9	1
Cnidaria	coralliid	*Paracorallium tortuosum cf*		2
Cnidaria	corallimorpharian	*corallimorpharian white tipped*	5	8
Cnidaria	corymorphid	*Corymorpha sp*	2	4
Cnidaria	dendrophylliid	*Balanophyllia sp cf*	5	
Cnidaria	dendrophylliid	*dendrophylliid*	91	19
Cnidaria	dendrophylliid	*Eguchipsammia fistula*	4	7
Cnidaria	dendrophylliid	*Eguchipsammia fistula cf*	1	
Cnidaria	dendrophylliid	*Eguchipsammia serpentina*		7

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	dendrophylliid	*Eguchipsammia sp*		7
Cnidaria	dendrophylliid	*Enallopsammia rostrata*	46	138
Cnidaria	flabellid	*Flabellum pavoninum*	1	
Cnidaria	flabellid	*Flabellum sp*		1
Cnidaria	flabellid	*Javania lamprotichum*	23	8
Cnidaria	flabellid	*Javania sp*	6	9
Cnidaria	flabellid	*Polymyces wellsi*	1	3
Cnidaria	flabellid	*Truncatoflabellum sp*	1	1
Cnidaria	funiculinid	funiculinid		1
Cnidaria	gardineriid	*Gardineria hawaiiensis*	5	13
Cnidaria	gorgonian	gorgonian	444	12
Cnidaria	gorgonian	gorgonian blue	1	
Cnidaria	gorgonian	gorgonian branched	2	5
Cnidaria	gorgonian	gorgonian brush	1	
Cnidaria	gorgonian	gorgonian fan	3	
Cnidaria	gorgonian	gorgonian leather	1	
Cnidaria	gorgonian	gorgonian maze	2	
Cnidaria	gorgonian	gorgonian purple	2	
Cnidaria	gorgonian	gorgonian red	2	1
Cnidaria	gorgonian	gorgonian tan	2	2
Cnidaria	gorgonian	gorgonian two branch		1
Cnidaria	gorgonian	gorgonian wavy stem	2	
Cnidaria	gorgonian	gorgonian white	11	7
Cnidaria	gorgonian	gorgonian white single stalk	45	
Cnidaria	gorgonian	gorgonian white small		4
Cnidaria	gorgonian	gorgonian yellow	16	2
Cnidaria	haleciid	*Hydrodendron gorgonoides*	8	1
Cnidaria	halipterid	*Halipterus sp*		17
Cnidaria	halipterid	*Halipterus willemoesi*	9	45

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	hormathiid	hormathiid	35	86
Cnidaria	hormathiid	hormathiid cf	1	
Cnidaria	hormathiid	hormathiid sp1	4	5
Cnidaria	hormathiid	hormathiid sp2	2	2
Cnidaria	hormathiid	hormathiid sp3	2	
Cnidaria	hormathiid	hormathiid sp4	4	1
Cnidaria	hormathiid	hormathiid sp5	3	
Cnidaria	hormathiid	hormathiid sp6		1
Cnidaria	hydrozoan	hydromedusa		1
Cnidaria	hydrozoan	hydrozoan	5	23
Cnidaria	hydrozoan	hydrozoan feather	2	1
Cnidaria	isidid	isidid	11	111
Cnidaria	isidid	isidid branched	16	8
Cnidaria	isidid	isidid bushy		1
Cnidaria	isidid	isidid cf	5	
Cnidaria	isidid	isidid curly	2	
Cnidaria	isidid	isidid lyrate		1
Cnidaria	isidid	isidid lyrate n genus A	1	
Cnidaria	isidid	isidid nodal		9
Cnidaria	isidid	isidid nodal bushy orange	82	6
Cnidaria	isidid	isidid nodal lyrate	6	32
Cnidaria	isidid	isidid nodal lyrate n genus A	1	
Cnidaria	isidid	isidid nodal planar genus 3		2
Cnidaria	isidid	isidid nodal planar pink		1
Cnidaria	isidid	isidid nodal planar white		9
Cnidaria	isidid	isidid nodal spider	78	189
Cnidaria	isidid	isidid planar	7	
Cnidaria	isidid	isidid spiral	1	
Cnidaria	isidid	*Keratoisis flabellum cf*		45

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	isidid	*Keratoisis grandis cf*		11
Cnidaria	isidid	*Keratoisis sp*	2	9
Cnidaria	isidid	*Keratoisis sp orange*	1	
Cnidaria	isidid	*Keratoisis sp yellow*	1	
Cnidaria	isidid	*Keratoisis sp4*	8	
Cnidaria	isidid	*Lepidisis olapa cf*	33	119
Cnidaria	isidid	*Lepidisis sp cf*	97	238
Cnidaria	isidid	*Lepidisis sp cf branched*	12	33
Cnidaria	isidid	*Lepidisis sp cf red*	22	1
Cnidaria	isophelliid	*Telmatactis sp*		2
Cnidaria	kereoidid	*Kereiodes mosaica*	4	26
Cnidaria	kereoidid	*Keroeides pallida*	2	4
Cnidaria	kophobelemnid	*Calibelemnon symmetricum*	229	124
Cnidaria	kophobelemnid	kophobelemnid cf		1
Cnidaria	kophobelemnid	*Kophobelemnon stelliferum cf*	1	19
Cnidaria	leiopathid	*Leiopathes sp*	57	31
Cnidaria	liponematid	*Liponema brevicornis*	5	17
Cnidaria	liponematid	*Liponema sp*	6	15
Cnidaria	marianactid cf	*Marianactis sp cf*		2
Cnidaria	myriopathid	*Myriopathes ulex*	2	
Cnidaria	nemanthid cf	*Nemanthus sp cf*	2	
Cnidaria	nidaliid	*Nidalia sp*		2
Cnidaria	nidaliid	*Siphonogorgia alexanderi*	6	7
Cnidaria	nidaliid	*Siphonogorgia collaris*	5	37
Cnidaria	nidaliid	*Siphonogorgia sp*		1
Cnidaria	oculinid	*Madrepora kauaiensis*	8	49
Cnidaria	oculinid	*Madrepora oculata*		2
Cnidaria	oculinid	*Madrepora sp*		3
Cnidaria	olindidiid	*Monobrachium sp*		9

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	paragorgiid	*Paragorgia dendroides*	19	44
Cnidaria	paragorgiid	*Paragorgia regalis*	35	15
Cnidaria	paragorgiid	*Paragorgia sp*	3	
Cnidaria	paragorgiid	*Paragorgia sp1*	26	19
Cnidaria	paragorgiid	*Paragorgia sp2*	17	
Cnidaria	paramuriceid	*Anthomuricea tenuispina*		19
Cnidaria	paramuriceid	*Bebryce brunnea*	8	
Cnidaria	paramuriceid	*Muriceides tenuis*	2	
Cnidaria	paramuriceid	paramuriceid	5	4
Cnidaria	paramuriceid	paramuriceid blue	122	2
Cnidaria	paramuriceid	paramuriceid tan	116	24
Cnidaria	paramuriceid	paramuriceid yellow	1	
Cnidaria	parazoanthid	*Gerardia sp*	336	356
Cnidaria	parazoanthid	*Gerardia sp cf*	1	1
Cnidaria	parazoanthid	*Parazoanthus sp*	9	15
Cnidaria	parazoanthid	*Parazoanthus sp1 brown*	77	62
Cnidaria	parazoanthid	*Parazoanthus sp2 white*	37	1
Cnidaria	pennatulacean	pennatulacean	52	2 2
Cnidaria	pennatulacean	pennatulacean twisted		3
Cnidaria	pennatulacean	pennatulacean white	2	44
Cnidaria	pennatulid	*Pennatula flava cf*	1	4
Cnidaria	pennatulid	*Pennatula inflata*	1	19
Cnidaria	pennatulid	*Pennatula perceyi cf*	1	5
Cnidaria	pennatulid	*Pennatula sp*	18	4
Cnidaria	pennatulid	*Pennatula sp4 cf*		4
Cnidaria	periphyllid	periphyllid		1
Cnidaria	plexaurid	*Anthomuricea sp*	1	
Cnidaria	plexaurid	*Eunicella sp*		2
Cnidaria	plexaurid	*Paracis miyajimai*	1	1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	plexaurid	*Paramuricea sp*	2	
Cnidaria	plexaurid	*Pseudothesea sp*		5
Cnidaria	plexaurid	*Swiftia sp cf*		2
Cnidaria	pocilloporid	*Madracis kauaiensis*	2	
Cnidaria	primnoid	*Amphilaphis circumoperculum*	69	
Cnidaria	primnoid	*Callogorgia formosa*	5	6
Cnidaria	primnoid	*Callogorgia formosa cf*		1
Cnidaria	primnoid	*Callogorgia gilberti*	29	2
Cnidaria	primnoid	*Callogorgia sp*	15	4
Cnidaria	primnoid	*Calyptrophora alpha*		1
Cnidaria	primnoid	*Calyptrophora alpha cf*	87	23
Cnidaria	primnoid	*Calyptrophora sp*	18	7
Cnidaria	primnoid	*Calyptrophora sp lyrate*	3	4
Cnidaria	primnoid	*Calyptrophora sp2*	2	6
Cnidaria	primnoid	*Calyptrophora sp4*		4
Cnidaria	primnoid	*Calyptrophora spinosa*	13	
Cnidaria	primnoid	*Calyptrophora versluysi*	5	
Cnidaria	primnoid	*Calyptrophora wyvillei*	17	1
Cnidaria	primnoid	*Calyptrophora wyvillei cf*	9	
Cnidaria	primnoid	*Candidella gigantea*	72	43
Cnidaria	primnoid	*Candidella helminthopora*	16	2
Cnidaria	primnoid	*Candidella sp unbranched*	1	
Cnidaria	primnoid	*Fanellia euthyeia*	1	22
Cnidaria	primnoid	*Fanellia euthyeia cf*	2	2
Cnidaria	primnoid	*Narella dichotoma*	97	82
Cnidaria	primnoid	*Narella gigas*	69	11
Cnidaria	primnoid	*Narella macrocalyx*	8	27
Cnidaria	primnoid	*Narella sp*	177	58
Cnidaria	primnoid	*Narella sp cf*	1	

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	primnoid	primnoid	98	34
Cnidaria	primnoid	primnoid bushy	34	
Cnidaria	primnoid	primnoid lyrate	8	
Cnidaria	primnoid	primnoid planar	1	
Cnidaria	primnoid	*Thouarella hilgendorfi*	2	13
Cnidaria	protoptilid	*Protoptilum sp*	9	2
Cnidaria	protoptilid	*Protoptilum sp cf*		1
Cnidaria	rhopalonematid	*Colobonema sp*		1
Cnidaria	schizopathid	*Bathypathes alternata*	1	4
Cnidaria	schizopathid	*Bathypathes branched*	6	
Cnidaria	schizopathid	*Bathypathes conferta*	115	36
Cnidaria	schizopathid	*Bathypathes patula*	2	5
Cnidaria	schizopathid	*Bathypathes sp*	3	28
Cnidaria	schizopathid	*Dendropathes bacotaylorae*	2	
Cnidaria	schizopathid	*Stauropathes sp*	1	
Cnidaria	schizopathid	*Stauropathes staurocrada*	2	16
Cnidaria	schizopathid	*Umbellapathes helioanthes*	2	11
Cnidaria	scleractinian	scleractinian	58	36
Cnidaria	scleractinian	scleractinian orange		4
Cnidaria	scleractinian	scleractinian single polyp	24	15
Cnidaria	scyphozoan	scyphozoan	3	25
Cnidaria	scyphozoan	scyphozoan satellite		5
Cnidaria	solanderiid	Solanderia sp	4	1
Cnidaria	stoloniferan	stoloniferan	8	
Cnidaria	stylasterid	*Distichopora anceps*		18
Cnidaria	stylasterid	*Distichopora asulcata*		7
Cnidaria	stylasterid	*Distichopora violacea*	12	1
Cnidaria	stylasterid	*Stylaster griggi*		1
Cnidaria	stylasterid	stylasterid		1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Cnidaria	tubulariid	tubulariid	4	14
Cnidaria	tubulariid	tubulariid sp2		3
Cnidaria	umbellulid	*Umbellula sp*	9	1
Cnidaria	virgulariid	*Virgularia abies cf*		2
Cnidaria	virgulariid	*Virgularia sp*	3	5
Cnidaria	zoanthinarian	zoanthinarian	12	3
Ctenophora	coeloplanid	*Lyrocteis sp*	38	41
Ctenophora	ctenophore	ctenophore	1	7
Annelida	bristleworm	bristleworm	1	1
Annelida	polychaete	polychaete		1
Annelida	scaleworm	scaleworm	1	
Annelida	serpulid	serpulid	1	
Annelida	tube worm	tubeworm	9	2
Annelida	worm	worm	1	1
Mollusca	bivalve	bivalve		16
Mollusca	cassidid	*Phalium kurodai*	1	1
Mollusca	cephalopod	cephalopod	1	1
Mollusca	cerithiid	*Cerithium matukense*	3	
Mollusca	cerithiid	*Cerithium sp*		1
Mollusca	cirroteuthid	*Cirrothauma magna cf*	8	
Mollusca	conid	conid w/pargurid		1
Mollusca	conid	*Conus smirna*		3
Mollusca	conid	*Conus sp*		1
Mollusca	cymatiid	*Charonia sp*	1	
Mollusca	cypraeid	*Cypraea tessellata*		1
Mollusca	decapod	decapod cf	1	
Mollusca	gastropod	gastropod	8	12
Mollusca	gastropod	gastropod with anemone		1
Mollusca	histioteuthid	*Histioteuthis cerasina*	1	

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Mollusca	joubiniteuthid	*Joubiniteuthis portieri*		2
Mollusca	mollusk	mollusk	7	
Mollusca	octopodid	*Berrya hoylei*	3	4
Mollusca	octopodid	*Callistoctopus cf ornatus*	2	
Mollusca	octopodid	octopodid	7	3
Mollusca	octopodid	*Octopus sp*	5	14
Mollusca	octopodid	*Octopus sp1*	7	
Mollusca	ommastrephid	*Nototodarus hawaiiensis*	6	7
Mollusca	opisthoteuthid	*Grimpoteuthis sp*	7	2
Mollusca	pectinid	pectinid		3
Mollusca	pinnid	*Pinna muricata*		1
Mollusca	pleurobranchid	*Koonsia sp*		1
Mollusca	pleurobranchid	*Pleurobranchella nicobarica*	2	7
Mollusca	pleurobranchid	pleurobranchid	8	3
Mollusca	pleurobranchid	*Pleurobranchus mammalatus*		1
Mollusca	polycerid	polycerid	21	
Mollusca	ranellid	*Charonia tritonis*		1
Mollusca	tonnid	*Tonna dolium*		1
Mollusca	tonnid	*Tonna melanostoma*		1
Mollusca	tonnid	*Tonna sp*	2	
Mollusca	tritoniid	*Tritonia sp*		2
Arthropoda Chelicerata	pycnogonid	pycnogonid		3
Arthropoda Crustacea	amphipod	amphipod	5	8
Arthropoda Crustacea	amphipod	amphipod cf		3
Arthropoda Crustacea	aristeid	aristeid		1
Arthropoda Crustacea	aristeid	*Aristeus semidentatus*		2
Arthropoda Crustacea	aristeid	*Benthesicymus laciniatus*	1	8
Arthropoda Crustacea	barnacle	barnacle	5	
Arthropoda Crustacea	barnacle	barnacle stalked		1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Arthropoda Crustacea	barnacle	barnacle unstalked	1	
Arthropoda Crustacea	barnacle	barnacle unstalked large white	3	
Arthropoda Crustacea	calappid	*Calappa pokipoki*	1	
Arthropoda Crustacea	calappid	calappid		2
Arthropoda Crustacea	calappid	*Mursia hawaiiensis*		1
Arthropoda Crustacea	chirostylid	chirostylid	4	8
Arthropoda Crustacea	chirostylid	chirostylid cf		2
Arthropoda Crustacea	chirostylid	*Eumunida balssi*	2	2
Arthropoda Crustacea	chirostylid	*Eumunida sp*	2	2
Arthropoda Crustacea	chirostylid	*Eumunida treguieri*	4	26
Arthropoda Crustacea	chirostylid	*Gastroptychus sp*	1	
Arthropoda Crustacea	chirostylid	*Gastroptychus sp one stripe*		1
Arthropoda Crustacea	chirostylid	*Pseudomunida fragilis*	2	
Arthropoda Crustacea	cirripedia	cirripedia unidentified	1	
Arthropoda Crustacea	crab	crab	51	6
Arthropoda Crustacea	crab	crab unknown		1
Arthropoda Crustacea	crustacean	crustacean	2	4
Arthropoda Crustacea	decapod	decapod	15	11
Arthropoda Crustacea	diogenid	*Dardanus sp*		3
Arthropoda Crustacea	dynomenid	*Dynomene devaneyi*	4	2
Arthropoda Crustacea	galatheid	*Babamunida n sp1*	2	7
Arthropoda Crustacea	galatheid	galatheid	86	68
Arthropoda Crustacea	galatheid	galatheid banded	1	
Arthropoda Crustacea	galatheid	*Munida normani*	5	
Arthropoda Crustacea	galatheid	*Munida plexaura*	5	1
Arthropoda Crustacea	galatheid	*Munida sp*	7	1
Arthropoda Crustacea	galatheid	*Munidopsis sp*	3	3
Arthropoda Crustacea	galatheid	*Paramunida hawaiiensis*	3	8
Arthropoda Crustacea	galatheid	*Paramunida hawaiiensis cf*		1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Arthropoda Crustacea	geryonid	geryonid	2	12
Arthropoda Crustacea	geryonid	*Neopilumnoplax major*	18	5
Arthropoda Crustacea	geryonid	*Progeryon mus*	2	
Arthropoda Crustacea	heterolepadid	*Heteralepas sp cf*	1	1
Arthropoda Crustacea	homolid	*Homola dickensoni*	1	1
Arthropoda Crustacea	homolid	*Homola sp*		2
Arthropoda Crustacea	homolid	homolid	6	2
Arthropoda Crustacea	homolid	*Lamoha williamsi*	1	
Arthropoda Crustacea	homolid	*Paramola alcocki*	11	2
Arthropoda Crustacea	homolid	*Paromola japonica*	9	1
Arthropoda Crustacea	homolid	*Paromola sp*	1	19
Arthropoda Crustacea	latreillid	*Latreilla velida*		1
Arthropoda Crustacea	latreillid	*Latreilla velida*		1
Arthropoda Crustacea	leucosiid	leucosiid	1	
Arthropoda Crustacea	leucosiid	leucosiid cf		1
Arthropoda Crustacea	leucosiid	*Randallia distincta*	7	3
Arthropoda Crustacea	lithodid	*Lithodes longispinna*		5
Arthropoda Crustacea	lithodid	*Lithodes nintokuae*	3	
Arthropoda Crustacea	lithodid	lithodid		2
Arthropoda Crustacea	lithodid	*Neolithodes sp*	3	4
Arthropoda Crustacea	majid	*Cyrtomaia smithi*	9	1
Arthropoda Crustacea	majid	*Cyrtomaia sp*	1	
Arthropoda Crustacea	majid	*Sphenocarcinus carbunculus*		3
Arthropoda Crustacea	mysid	mysid	2	
Arthropoda Crustacea	nematocarcinid	nematocarcinid		1
Arthropoda Crustacea	nematocarcinid	*Nematocarcinus tenuirostris*	13	2
Arthropoda Crustacea	odontodactylid	*Odontodactylus hawaiiensis*		2
Arthropoda Crustacea	pagurid	*Ciliopagurus hawaiiensis*	2	4
Arthropoda Crustacea	pagurid	pagurid	25	1 6

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Arthropoda Crustacea	pagurid	pagurid big claw		3
Arthropoda Crustacea	pagurid	pagurid in cone shell		1
Arthropoda Crustacea	pagurid	pagurid in natacid shell		1
Arthropoda Crustacea	pagurid	pagurid with anemone		2
Arthropoda Crustacea	pandalid	*Heterocarpus ensifer*	5	3
Arthropoda Crustacea	pandalid	*Heterocarpus laevigatus*	13	14
Arthropoda Crustacea	pandalid	*Heterocarpus sp*		2
Arthropoda Crustacea	pandalid	pandalid	5	1
Arthropoda Crustacea	pandalid	*Plesionika alcocki*	15	
Arthropoda Crustacea	pandalid	*Plesionika edwardsii*	1	1
Arthropoda Crustacea	pandalid	*Plesionika martia*		3
Arthropoda Crustacea	pandalid	*Plesionika normani*		2
Arthropoda Crustacea	pandalid	*Plesionika pacifica*	6	5
Arthropoda Crustacea	pandalid	*Plesionika sp*	12	7
Arthropoda Crustacea	pandalid	*Plesionika sp flag*	1	
Arthropoda Crustacea	pandalid	*Plesionika sp1*		3
Arthropoda Crustacea	pandalid	*Plesionika sp2*	1	5
Arthropoda Crustacea	pandalid	*Plesionika sp3*		2
Arthropoda Crustacea	pandalid	*Plesionika sp4*		1
Arthropoda Crustacea	pandalid	*Plesionika sp5*		1
Arthropoda Crustacea	parapagurid	parapagurid		1
Arthropoda Crustacea	parapagurid	*Sympagurus birkenroadi*		13
Arthropoda Crustacea	parapagurid	*Sympagurus dofleini*	17	11
Arthropoda Crustacea	parapagurid	*Sympagurus sp*	1	
Arthropoda Crustacea	parthenopid	parthenopid	1	
Arthropoda Crustacea	parthenopid	*Tutankhamen pteromerus*	3	
Arthropoda Crustacea	penaeid	*Aristaeopsis edwardsiana*	44	39
Arthropoda Crustacea	poecilasmatid	*Megalasma sp cf*		1
Arthropoda Crustacea	poecilasmatid	*Octolasmis hawaiiense cf*	1	

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Arthropoda Crustacea	polychelid	*Homeryon asper*	1	3
Arthropoda Crustacea	polychelid	polychelid	1	
Arthropoda Crustacea	protosquillid	*Echinosquilla sp*	2	2
Arthropoda Crustacea	raninid	raninid		2
Arthropoda Crustacea	scalpellid	*Alcockianum cf alcockianum*	1	
Arthropoda Crustacea	shrimp	shrimp	141	196
Arthropoda Crustacea	shrimp	shrimp red	4	4
Arthropoda Crustacea	shrimp	shrimp white	4	
Arthropoda Crustacea	shrimp	shrimp white dot		3
Arthropoda Crustacea	squillid	squillid	1	1
Arthropoda Crustacea	xanthid	xanthid	1	
Echiura	echiuroid	echiuroid		1
Bryozoa	bryozoan	bryozoan	1	
Echinodermata	antedonid	*Antedon sp*	1	
Echinodermata	antedonid	*Antedon sp tan*	1	
Echinodermata	antedonid	*Antedon sp yellow*	1	2
Echinodermata	antedonid	*Antedon sp yellow cf*		2
Echinodermata	aspidodiadematid	*Aspidodiadema hawaiiensis*	6	3
Echinodermata	aspidodiadematid	*Aspidodiadema sp*	2	6
Echinodermata	aspidodiadematid	*Aspidodiadema sp cf*		4
Echinodermata	asteriid	*Sclerasterias euplecta*	3	
Echinodermata	asteriid	*Tarsastrocles verrilli*	4	
Echinodermata	asterinid	*Anseropoda insignis*		4
Echinodermata	asteroid	asteroid	62	59
Echinodermata	asteroid	asteroid 1 arms	1	
Echinodermata	asteroid	asteroid 7 arms	1	
Echinodermata	asteroid	asteroid 9 arms white		1
Echinodermata	asteroid	asteroid orange	2	3
Echinodermata	asteroid	asteroid white	6	2

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Echinodermata	asteroid	asteroid white long arms	3	
Echinodermata	asteroschematid	*Asteroschema caudatum*	1	2
Echinodermata	asteroschematid	*Asteroschema sp*	17	7
Echinodermata	asteroschematid	*Ophiocreas oedipus*	1	
Echinodermata	asterostomatid	*Phrissocystis multispina*		7
Echinodermata	astropectinid	astropectinid		1
Echinodermata	astropectinid	*Ctenophoraster hawaiiensis*		4
Echinodermata	astropectinid	*Dipsacaster nesiotes*		1
Echinodermata	atelecrinid	*Atelecrinus conifer*	3	
Echinodermata	brisingid	*Brisinga alberti*	1	
Echinodermata	brisingid	*Brisinga fragilis*	1	2
Echinodermata	brisingid	*Brisinga panopla*	3	2
Echinodermata	brisingid	*Brisinga sp*	3	
Echinodermata	brisingid	brisingid	3	48
Echinodermata	brisingid	*Hymenodiscus sp*	3	
Echinodermata	brissid	*Brissus laticarinatus*		1
Echinodermata	charitometrid	charitometrid		1
Echinodermata	cidarid	*Acanthocidaris hastigera*	5	7
Echinodermata	cidarid	*Acanthocidaris sp*		13
Echinodermata	cidarid	*Actinocidaris thomasii*	3	21
Echinodermata	cidarid	cidarid	16	24
Echinodermata	cidarid	cidarid white	3	
Echinodermata	cidarid	*Histocidaris variabilis*	16	3
Echinodermata	cidarid	*Stereocidaris hawaiiensis*	117	112
Echinodermata	cidarid	*Stylocidaris calacantha*	4	9
Echinodermata	cidarid	*Stylocidaris rufa*	6	39
Echinodermata	cidarid	Stylociterinae cf	1	
Echinodermata	comatulid	comatulid	5	6
Echinodermata	comatulid	comatulid black	8	

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Echinodermata	comatulid	comatulid brown	3	15
Echinodermata	comatulid	comatulid orange		1
Echinodermata	comatulid	comatulid red	21	18
Echinodermata	comatulid	comatulid spotted		1
Echinodermata	comatulid	comatulid tan	4	2
Echinodermata	comatulid	comatulid white		4
Echinodermata	comatulid	comatulid yellow	1	2
Echinodermata	crinoid	crinoid	17	73
Echinodermata	crinoid	crinoid black	3	
Echinodermata	crinoid	crinoid yellow	4	1
Echinodermata	crinoid stalked	crinoid stalked		2
Echinodermata	crinoid stalked	crinoid stalked red	4	3
Echinodermata	crinoid stalked	crinoid stalked small white	1	
Echinodermata	crinoid stalked	crinoid stalked white	4	
Echinodermata	crinoid stalked	crinoid stalked yellow	1	2
Echinodermata	deimatid	deimatid	2	
Echinodermata	deimatid	*Orphnurgus sp*	2	1
Echinodermata	diadematid	*Chaetodiadema pallidum*		2
Echinodermata	diadematid	diadematid	1	6
Echinodermata	diadematid	diadematid cf		1
Echinodermata	diadematid	*Leptodiadema purpureum cf*	1	
Echinodermata	echinasterid	echinasterid		2
Echinodermata	echinasterid	*Henricia pauperrima*	6	7
Echinodermata	echinasterid	*Henricia robusta*	6	4
Echinodermata	echinasterid	*Henricia sp*	2	5
Echinodermata	echinid	echinid		1
Echinodermata	echinid	echinid cf		2
Echinodermata	echinoid	echinoid	14	36
Echinodermata	echinoid	echinoid black		3

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Echinodermata	echinoid	echinoid gray	1	
Echinodermata	echinothurid	*Araeosoma sp*	1	9
Echinodermata	echinothurid	echinothurid	2	34
Echinodermata	echinothurid	echinothurid gray	7	1
Echinodermata	echinothurid	echinothurid white	2	2
Echinodermata	echinothurid	echinothuroida	27	12
Echinodermata	echinothurid	*Phormosoma bursarium*	3	15
Echinodermata	echinothurid	*Sperosoma obscurum*	2	3
Echinodermata	elasipodid	*Oneiophanta mutabilis*	1	
Echinodermata	elphidiid cf	*Amperima sp cf*	1	
Echinodermata	goniasterid	*Anthenoides epixanthus*	7	18
Echinodermata	goniasterid	*Astroceramus callimorphus*		1
Echinodermata	goniasterid	*Astroceramus sp*		8
Echinodermata	goniasterid	*Astroceramus sp1*	3	2
Echinodermata	goniasterid	*Calliaster pedicellaris*	7	4
Echinodermata	goniasterid	*Calliderma spectabilis*	1	1
Echinodermata	goniasterid	*Ceramaster bowersi*	1	7
Echinodermata	goniasterid	*Circeaster sp*	1	1
Echinodermata	goniasterid	*Evoplosoma forcipifera*		1
Echinodermata	goniasterid	*Gilbertaster anacanthus*	1	1
Echinodermata	goniasterid	goniasterid	74	67
Echinodermata	goniasterid	goniasterid bat	1	
Echinodermata	goniasterid	*Hippasteria imperialis*	2	3
Echinodermata	goniasterid	*Hippasteria imperialis cf*		1
Echinodermata	goniasterid	*Mediaster ornatus*	8	47
Echinodermata	goniasterid	*Mediaster ornatus cf*		1
Echinodermata	goniasterid	*Nereidaster bowersi cf*		1
Echinodermata	goniasterid	*Peltaster micropeltus*		1
Echinodermata	goniasterid	*Plinthaster ceramoidea*	7	3

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Echinodermata	goniasterid	*Pseudarchaster myobrachius*	1	
Echinodermata	goniasterid	*Sphaeriodiscus ammophilus*	25	14
Echinodermata	gorgonocephalid	*Astrospartus sp*		6
Echinodermata	gorgonocephalid	gorgonocephalid	5	117
Echinodermata	holothuroid	holothuroid	6	41
Echinodermata	hyocrinid	*Ptilocrinus sp*		2
Echinodermata	labiasteriid	*Coronaster eclipes*	5	16
Echinodermata	labiasteriid	*Coronaster sp white*		1
Echinodermata	laetmogonid	*Pannychia moseleyi*	4	
Echinodermata	laganid	*Laganum fudsiyama*	2	7
Echinodermata	loveniid	*Lovenia sp*		1
Echinodermata	luidiid	*Luidia magnifica*	1	
Echinodermata	micropygid	*Micropyga tuberculata*	66	1
Echinodermata	micropygid	*Micropyga tuberculata cf*	2	4
Echinodermata	myxasterid	*Asthenactis papyraceus*	8	3
Echinodermata	myxasterid	myxasterid		2
Echinodermata	novodiniid	*Novodinia pacifica*	1	1
Echinodermata	ophiacanthid	ophiacanthid	2	1
Echinodermata	ophiacanthid	ophiacanthid banded		3
Echinodermata	ophiacanthid	ophiacanthid red		2
Echinodermata	ophiacanthid	ophiacanthid starred	1	
Echinodermata	ophidiasterid	ophidiasterid		1
Echinodermata	ophidiasterid	*Tamaria scleroderma*	4	6
Echinodermata	ophidiasterid	*Tamaria sp*		1
Echinodermata	ophidiasterid	*Tamaria tenella*		5
Echinodermata	ophidiasterid	*Tamaria triseriata*		2
Echinodermata	ophiothricid	*Macrophiothrix lepidus*	3	
Echinodermata	ophiothricid	*Ophiomyxa fisheri*	4	
Echinodermata	ophiurid	ophiuroid	91	11

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Echinodermata	ophiurid	ophiuroid white	5	
Echinodermata	ophiurid	ophiuroid yellow		1
Echinodermata	pedinid	*Caenopedina hawaiiensis*	6	3
Echinodermata	pedinid	*Caenopedina pulchella*	6	1
Echinodermata	pedinid	*Caenopedina sp*		3
Echinodermata	pedinid	pedinid		1
Echinodermata	pelagothuriid	*Enypniastes eximia*	4	1
Echinodermata	porphyrocrinid	porphyrocrinid	6	
Echinodermata	proisocrinid	*Proisocrinus ruberrimus*	8	2
Echinodermata	spatangid	spatangid		4
Echinodermata	spatangoid	spatangoid		2
Echinodermata	synallactid	*Hansenothuria benti*	1	2
Echinodermata	synallactid	*Mesothuria cf meseres*	1	
Echinodermata	synallactid	*Paelopatides cf retifer*	5	154
Echinodermata	synallactid	*Synallactes sp*		4
Echinodermata	synallactid	synallactid	1	4
Echinodermata	synallactid	synallactid cf	2	
Echinodermata	thalassometrid	thalassometrid black	2	
Echinodermata	thalassometrid	thalassometrid red		1
Echinodermata	thalassometrid	thalassometrid yellow	1	
Echinodermata	zenometrid	zenometrid striped		5
Echinodermata	zoroasterid	*Zoroaster spinulosus*		3
Chordata Tunicata	octacnemid	octacnemid		2
Chordata Tunicata	perophorid	*Perophora sp*		1
Chordata Tunicata	pyrosome	pyrosome	6	7
Chordata Tunicata	siphonophore	siphonophore		2
Chordata Tunicata	thaliacean	thaliacean	11	16
Chondrichthyes	carcharhinid	*Carcharhinus amblyrhynchos*	8	
Chondrichthyes	carcharhinid	*Carcharhinus galapagensis*	1	1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Chondrichthyes	carcharhinid	*Carcharhinus plumbeus*	1	
Chondrichthyes	carcharhinid	*Carcharhinus sp*		3
Chondrichthyes	centrophorid	*Centrophorus granulosus cf*		1
Chondrichthyes	centrophorid	*Centrophorus sp*	2	1
Chondrichthyes	centrophorid	*Centrophorus tesselatus*	1	1
Chondrichthyes	echinorhinid	*Echinorhinus cookei*	85	2
Chondrichthyes	etmopterid	*Centroscyllium nigrum*	3	1
Chondrichthyes	etmopterid	etmopterid	5	3
Chondrichthyes	etmopterid	*Etmopterus lucifer*		1
Chondrichthyes	etmopterid	*Etmopterus pusillus*		1
Chondrichthyes	etmopterid	*Etmopterus sp*		3
Chondrichthyes	etmopterid	*Etmopterus sp1*		1
Chondrichthyes	hexanchid	*Hexanchus griseus*	1	1
Chondrichthyes	hexatrygonid	*Hexatrygon bickelli*		1
Chondrichthyes	odontaspid	*Odontaspis ferox*		7
Chondrichthyes	plesiobatid	*Plesiobatis daviesi*	8	14
Chondrichthyes	pseudotriakid	*Pseudotriakis microdon*	13	8
Chondrichthyes	scylliorhinid	*Apristurus sp*	3	2
Chondrichthyes	shark	shark	12	19
Chondrichthyes	sphyrnid	*Sphyrna sp*	2	
Chondrichthyes	squalid	squalid	5	4
Chondrichthyes	squalid	*Squalus mitsukurii*	19	87
Chondrichthyes	torpedinid	*Torpedo tokionis*		1
Chondrichthyes	chimaerid	*Hydrolagus purpurescens*	11	5
Osteichthyes	acropomatid	*Synagrops argyreus*		1
Osteichthyes	acropomatid	*Synagrops sp*	9	
Osteichthyes	alepocephalid	alepocephalid		1
Osteichthyes	ammodytiid	*Ammodytoides pylei*	3	19
Osteichthyes	ammodytiid	*Ammodytoides sp*		13

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	argentinid	*Glossanodon struhsakeri*	8	33
Osteichthyes	ariommatid	*Ariomma brevimanum*		2
Osteichthyes	ariommatid	*Ariomma luridum*		1
Osteichthyes	ateleopodid	*Ijimaia plicatellus*	41	8
Osteichthyes	barbourisiid	*Barbourisia rufa*	2	
Osteichthyes	bathygadid	bathygadid	7	14
Osteichthyes	bathygadid	*Bathygadus bowersi*		4
Osteichthyes	bathygadid	*Gadomus melanopterus*	1	4
Osteichthyes	bembrid	*Bembradium roseum*	11	4
Osteichthyes	berycid	*Beryx decadactylus*	139	33
Osteichthyes	berycid	*Beryx sp*	3	12
Osteichthyes	berycid	*Beryx splendens*	7	3
Osteichthyes	bothid	bothid	9	2
Osteichthyes	bothid	*Bothus thompsoni*		1
Osteichthyes	bothid	*Chascanopsetta crumenalis*		3
Osteichthyes	bothid	*Chascanopsetta prorigera*	4	6
Osteichthyes	bothid	*Parabothus coarctatus*		5
Osteichthyes	bothid	*Taeniopsetta radula*		3
Osteichthyes	bramid	*Taractichthys steindachneri*	6	1
Osteichthyes	callanthiid	*Grammatonotus laysanus*	39	17
Osteichthyes	callanthiid	*Grammatonotus macrophthalmus*	1	1
Osteichthyes	callanthiid	*Grammatonotus sp*	12	32
Osteichthyes	callanthiid	*Grammatonotus sp1*	6	5
Osteichthyes	caproid	*Antigonia eos*	47	14
Osteichthyes	caproid	*Antigonia sp*	199	1 3
Osteichthyes	carangid	carangid		1
Osteichthyes	carangid	*Caranx lugubris*	13	
Osteichthyes	carangid	*Decapterus sp*	18	4
Osteichthyes	carangid	*Decapterus tabl*	21	3

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	carangid	*Pseudocaranx dentex*	1	89
Osteichthyes	carangid	*Seriola dumerili*	45	33
Osteichthyes	carangid	*Seriola rivoliana*		1
Osteichthyes	carangid	*Seriola sp*	13	4
Osteichthyes	carapid	carapid	1	5
Osteichthyes	carapid	carapid cf		1
Osteichthyes	carapid	*Pyramodon ventralis*	1	12
Osteichthyes	carapid	*Snyderidia canina*	1	4
Osteichthyes	centrolophid	*Hyperoglyphe japonica*		2
Osteichthyes	cepolid	*Sphenanthias sp*	35	
Osteichthyes	chaetodontid	chaetodontid	1	
Osteichthyes	chaetodontid	*Heniochus diphreutes*	1	
Osteichthyes	chaetodontid	*Prognathodes basabei*		1
Osteichthyes	chaetodontid	*Roa excelsa*	24	31
Osteichthyes	chaunacid	*Chaunacops cf melanostomus*	6	1
Osteichthyes	chaunacid	*Chaunax sp*	7	
Osteichthyes	chaunacid	*Chaunax umbrinus*	47	16
Osteichthyes	chlorophthalmid	chlorophthalmid	1	2
Osteichthyes	chlorophthalmid	*Chlorophthalmus japonicus*	4	1
Osteichthyes	chlorophthalmid	*Chlorophthalmus proridens*	3	18
Osteichthyes	chlorophthalmid	*Chlorophthalmus proridens cf*	2	
Osteichthyes	chlorophthalmid	*Chlorophthalmus sp*	12	
Osteichthyes	congrid	*Bathycongrus guttulatus*	3	3
Osteichthyes	congrid	*Bathyuroconger vicinus*		5
Osteichthyes	congrid	*Conger oligoporus*	4	2
Osteichthyes	congrid	congrid	6	7
Osteichthyes	congrid	congrid blunt nose		2
Osteichthyes	congrid	congrid white fins	7	8
Osteichthyes	congrid	congrid white-fins		1

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	congrid	*Gnathophis nystromi*	1	
Osteichthyes	congrid	*Gnathophis sp*	8	18
Osteichthyes	congrid	*Uroconger lepturus*	2	6
Osteichthyes	cynoglossid	*Symphurus undatus*	1	
Osteichthyes	eel	eel	46	27
Osteichthyes	eel	eel like	3	
Osteichthyes	eel	eel small white	1	
Osteichthyes	eel	eel small white fins		1
Osteichthyes	emmelichthyid	emmelichthyid	1	2
Osteichthyes	emmelichthyid	*Erythrocles scintillans*	2	7
Osteichthyes	epigonid	epigonid	3	5
Osteichthyes	epigonid	*Epigonus atherinoides*	18	2
Osteichthyes	epigonid	*Epigonus devaneyi*	5	15
Osteichthyes	epigonid	*Epigonus fragilis*	26	2
Osteichthyes	epigonid	*Epigonus glossodontus*	9	7
Osteichthyes	epigonid	*Epigonus sp*	33	54
Osteichthyes	fish	fish	147	297
Osteichthyes	fish	fish black	1	
Osteichthyes	fish	fish small	1	
Osteichthyes	flatfish	flatfish		1
Osteichthyes	gempylid	*Epinnula magistralis*	1	
Osteichthyes	gempylid	gempylid	7	19
Osteichthyes	gempylid	*Nealotus tripes*		3
Osteichthyes	gempylid	*Rexea nakamurai*	4	12
Osteichthyes	gempylid	*Ruvettus pretiosus*	6	11
Osteichthyes	gonostomatid	*Araiophos gracilis*		1
Osteichthyes	gonostomatid	gonostomatid		2
Osteichthyes	grammicolepid	*Grammicolepis brachiusculus*	77	53
Osteichthyes	halosaurid	*Aldrovandia phalacra*	1	2

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	halosaurid	*Aldrovandia sp*	1	48
Osteichthyes	halosaurid	halosaurid	3	18
Osteichthyes	holocentrid	holocentrid	3	9
Osteichthyes	holocentrid	*Myripristis chryseres*	2	
Osteichthyes	holocentrid	*Ostichthys archiepiscopus*		1
Osteichthyes	holocentrid	*Pristilepis oligolepis*	1	8
Osteichthyes	hoplichthyid	*Hoplichthys citrinus*		5
Osteichthyes	ipnopid	*Bathypterois atricolor*	1	8
Osteichthyes	ipnopid	*Bathytyphlops marionae*		7
Osteichthyes	labrid	*Bodianus bathycapros*	1	26
Osteichthyes	labrid	*Bodianus cylindriatus*	2	4
Osteichthyes	labrid	labrid	2	1
Osteichthyes	labrid	*Polylepion russelli*	4	
Osteichthyes	labrid	*Suezichthys notatus*	4	55
Osteichthyes	lophiid	*Lophiodes bruchius*	7	
Osteichthyes	lophiid	*Lophiodes miacanthus*		4
Osteichthyes	lophiid	*Sladenia remiger*	2	4
Osteichthyes	lutjanid	*Etelis carbunculus*	3	19
Osteichthyes	lutjanid	*Etelis coruscans*	76	65
Osteichthyes	lutjanid	lutjanid	12	27
Osteichthyes	lutjanid	*Pristipomoides auricilla*	3	3
Osteichthyes	lutjanid	*Pristipomoides filamentosus*	6	55
Osteichthyes	lutjanid	*Pristipomoides sieboldii*	1	2
Osteichthyes	lutjanid	*Pristipomoides zonatus*	34	48
Osteichthyes	lutjanid	*Randallichthys filamentosus*	2	2
Osteichthyes	macroramphosid	macroramphosid		4
Osteichthyes	macroramphosid	*Macrorhamphosus scolopax*		1
Osteichthyes	macrourid	*Caelorinchus aratrum*	2	12
Osteichthyes	macrourid	*Caelorinchus doryssus*		9

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	macrourid	*Caelorinchus sp*	5	8
Osteichthyes	macrourid	*Caelorinchus sp4*		1
Osteichthyes	macrourid	*Caelorinchus sp5*		1
Osteichthyes	macrourid	*Caelorinchus spilonotus*	13	12
Osteichthyes	macrourid	*Caelorinchus tokiensis*	6	11
Osteichthyes	macrourid	*Cetonurus crassiceps*	2	
Osteichthyes	macrourid	*Coryphaenoides sp1*	4	2
Osteichthyes	macrourid	*Coryphaenoides sp2*	12	14
Osteichthyes	macrourid	*Haplomacrourus nudirostris*		4
Osteichthyes	macrourid	*Hymenocephalus antraeus*		2
Osteichthyes	macrourid	*Hymenocephalus sp*		6
Osteichthyes	macrourid	*Lucigadus sp*	1	
Osteichthyes	macrourid	*Lucigadus sp cf*	1	3
Osteichthyes	macrourid	*Lucigadus sp1*		4
Osteichthyes	macrourid	macrourid	63	16
Osteichthyes	macrourid	macrourid cf	2	1
Osteichthyes	macrourid	macrourid or bathygadid	1	
Osteichthyes	macrourid	*Malacocephalus boretzi*	27	73
Osteichthyes	macrourid	*Nezumia burragei*		1
Osteichthyes	macrourid	*Nezumia or Kumba sp*		1
Osteichthyes	macrourid	*Nezumia propinqua*		3
Osteichthyes	macrourid	*Nezumia sp*	1	
Osteichthyes	macrourid	*Nezumia sp1*	3	1
Osteichthyes	macrourid	*Sphagemacrurus gibber*		4
Osteichthyes	macrourid	*Ventrifossa sp*		3
Osteichthyes	macrourid	*Ventrifossa atherodon*	1	6
Osteichthyes	macrourid	*Ventrifossa ctenomelas*	5	13
Osteichthyes	macrourid	*Ventrifossa ctenomelas cf*		1
Osteichthyes	macrourid	*Ventrifossa sp cf*	1	

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	morid	*Gadella molokaiensis*	3	4
Osteichthyes	morid	*Gadella sp*	3	15
Osteichthyes	morid	*Gadella sp2*		2
Osteichthyes	morid	*Guttigadus sp*	3	
Osteichthyes	morid	*Laemonema rhodochir*	14	75
Osteichthyes	morid	morid	17	45
Osteichthyes	morid	morid juvenile		1
Osteichthyes	morid	*Physiculus grinnelli*	1	3
Osteichthyes	morid	*Physiculus nigripinnis*	12	18
Osteichthyes	morid	*Physiculus rhodopinnis*	7	17
Osteichthyes	morid	*Physiculus sp*	2	1
Osteichthyes	morid	*Physiculus sterops*	2	13
Osteichthyes	muraenid	*Gymnothorax berndti*	5	6
Osteichthyes	muraenid	*Gymnothorax nudivomer*	3	
Osteichthyes	muraenid	*Gymnothorax nuttingi*	4	6
Osteichthyes	muraenid	*Gymnothorax sp*		25
Osteichthyes	muraenid	*Gymnothorax steindachneri*	2	2
Osteichthyes	muraenid	*Gymnothorax ypsilon*		1
Osteichthyes	myctophid	myctophid	9	6
Osteichthyes	myctophid	myctophid cf		9
Osteichthyes	neoscopelid	neoscopelid		1
Osteichthyes	neoscopelid	*Neoscopelus macrolepidotus*	14	2
Osteichthyes	neoscopelid	*Neoscopelus macrolepidotus cf*		1
Osteichthyes	nettastomatid	*Nettastoma parviceps*	11	18
Osteichthyes	nettastomatid	*Nettastoma solitarium*		8
Osteichthyes	nettastomatid	*Nettastoma sp*		8
Osteichthyes	nettastomatid	nettastomatid	2	6
Osteichthyes	nettastomatid	*Nettenchelys gephyra*	3	1
Osteichthyes	nettastomatid	*Saurenchelys stylurus*	2	9

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	notacanthid	notacanthid cf		1
Osteichthyes	ogcocephalid	*Malthopsis sp*		3
Osteichthyes	ophichthid	*Myrichthys magnificus*	2	
Osteichthyes	ophichthid	myrophine	11	
Osteichthyes	ophichthid	ophichthid	52	9
Osteichthyes	ophichthid	*Ophichthus kunaloa*		
Osteichthyes	ophidiid	ophidiid	1	19
Osteichthyes	ophidiid	ophidiid new	1	
Osteichthyes	ophidiid	ophidiid white fins	1	2
Osteichthyes	ophidiid	*Ophidion muraenolepis*		1
Osteichthyes	ophidiid	*Pycnocraspedum armatum*	3	1
Osteichthyes	paralepidid	paralepidid		1
Osteichthyes	pentacerotid	*Pentaceros japonicus*		1
Osteichthyes	pentacerotid	*Pseudopentaceros wheeleri*	6	52
Osteichthyes	percophid	*Bembrops filifera*		9
Osteichthyes	percophid	*Bembrops sp1*	1	4
Osteichthyes	percophid	*Chrionema chryseres*	8	14
Osteichthyes	percophid	*Chrionema sp*	1	8
Osteichthyes	percophid	*Chrionema squamiceps*	8	4
Osteichthyes	percophid	percophid		2
Osteichthyes	peristediid	*Satyrichthys engyceros*	34	19
Osteichthyes	peristediid	*Satyrichthys hians*	2	13
Osteichthyes	peristediid	*Satyrichthys sp*	2	
Osteichthyes	pinguipedid	*Parapercis roseoviridis*	4	24
Osteichthyes	pleuronectid	*Poecilopsetta hawaiiensis*	3	2
Osteichthyes	polymixiid	*Polymixia berndti*	171	2
Osteichthyes	polymixiid	*Polymixia japonica*	342	19
Osteichthyes	polymixiid	*Polymixia sp*	18	21
Osteichthyes	pomacentrid	*Chromis struhsakeri*	5	25

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	priacanthid	*Cookeolus japonicus*	2	3
Osteichthyes	priacanthid	priacanthid	1	1
Osteichthyes	priacanthid	*Priacanthus alalaua*	5	4
Osteichthyes	priacanthid	*Priacanthus sp*		2
Osteichthyes	scorpaenid	*Phenacoscorpius megalops*		1
Osteichthyes	scorpaenid	*Pontinus macrocephalus*	24	71
Osteichthyes	scorpaenid	scorpaenid	151	29
Osteichthyes	scorpaenid	*Scorpaenodes sp*	1	
Osteichthyes	scorpaenid	*Scorpaenopsis altirostris*		2
Osteichthyes	scorpaenid	*Setarches guentheri*	58	35
Osteichthyes	serranid	*Caprodon unicolor*	7	21
Osteichthyes	serranid	*Epinephelus quernus*	7	317
Osteichthyes	serranid	*Liopropoma aurora*		4
Osteichthyes	serranid	*Liopropoma maculatum*		4
Osteichthyes	serranid	*Luzonichthys earlei*	7	14
Osteichthyes	serranid	*Odontanthias elizabethae*	28	111
Osteichthyes	serranid	*Odontanthias fuscipinnis*	2	1
Osteichthyes	serranid	*Plectranthias helenae*	1	
Osteichthyes	serranid	*Plectranthias kelloggi*	36	123
Osteichthyes	serranid	*Pseudanthias fucinus*	24	19
Osteichthyes	serranid	*Pseudanthias hawaiiensis*	1	
Osteichthyes	sternoptychid	*Argyripnus sp*		1
Osteichthyes	swimmer	swimmer	3	
Osteichthyes	symphysanodontid	*Symphysanodon maunaloae*	2 9	3 5
Osteichthyes	symphysanodontid	*Symphysanodon typus*	9	42
Osteichthyes	synaphobranchid	*Meadia abyssalis*	29	12
Osteichthyes	synaphobranchid	synaphobranchid	7	14
Osteichthyes	synaphobranchid	synaphobranchid cf		1
Osteichthyes	synaphobranchid	*Synaphobranchus affinis*	44	4

Phylum	Group	'Species'	Cobalt-rich	Non Cobalt-rich
Osteichthyes	synaphobranchid	*Synaphobranchus brevidorsalis*	4	
Osteichthyes	synaphobranchid	*Synaphobranchus sp*	24	24
Osteichthyes	synodontid	synodontid	1	2
Osteichthyes	synodontid	*Synodus kianus*		7
Osteichthyes	tetraodontid	*Canthigaster inframacula*	1	1
Osteichthyes	tetraodontid	*Sphoeroides pachygaster*	2	
Osteichthyes	trachichthyid	*Aulotrachichthys sp*		2
Osteichthyes	trachichthyid	*Hoplostethus crassispinus*	6	1
Osteichthyes	trachichthyid	trachichthyid	1	1
Osteichthyes	trachichthyid	trachichthyid cf	4	1
Osteichthyes	triacanthodid	*Hollardia goslinei*	5	21
Osteichthyes	trichiurid	trichiurid	3	4
Osteichthyes	zeid	*Cyttomimus stelgis*	9	16
Osteichthyes	zeid	*Stethopristes eos*	3	1
Osteichthyes	zeid	zeid	2	2
Osteichthyes	zeid	*Zenopsis nebulosus*	12	24
Mammalia	phocid	*Monachus schauinslandi*		3

Multivariate analyses

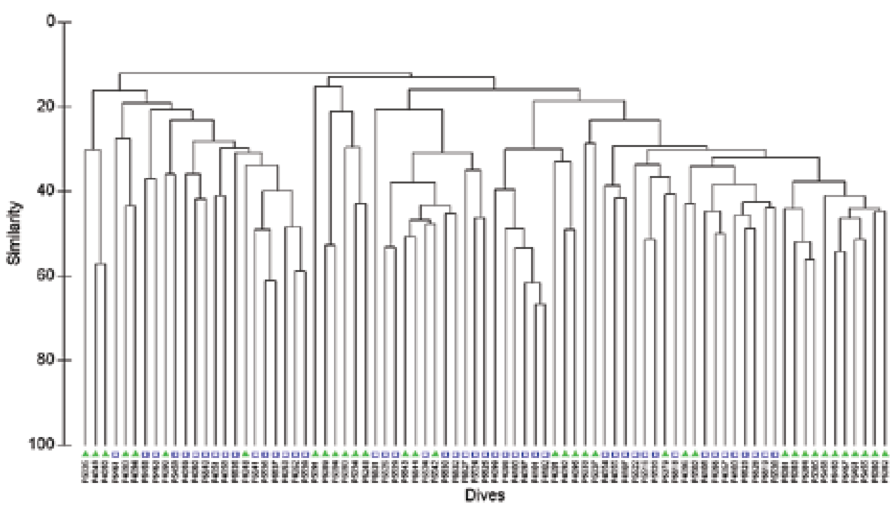
Testing for community patterns

The results of the two-way ANOSIM test showed no significant difference in the invertebrate community composition between cobalt and non-cobalt sites (R = 0.042, p=0.315), but there was a significant difference in composition between locations (R = 0.465, p=0.001). The cluster diagram (Figure 5) shows a mixture of cobalt-rich and non cobalt-rich sites in all cluster groupings, with no discernible pattern in their distribution throughout the clusters. The MDS plot of these data (Figure 6) reflects the same mixed pattern, with no clear separation or grouping of sites by cobalt classification. However, when the same results are plotted by location (Figure 7), clustering becomes more evident, with individual sites tending to group closely (e.g. Maro Reef, East French Frigate Shoals) or separately from other locations (e.g. Cross Seamount, West St Rogatien).

Explaining community patterns

BIOENV results indicated that, when combined, the two variables "average depth of dive" and "number of species observed on the dive" provided the best explanation of the overall pattern of invertebrate community composition, with a correlation value of 0.525. However, the BIOENV results for single variables indicated that average depth of dive alone had a correlation of 0.522, which was much higher than any other single variable (Table 5). The results for the combined variables also showed that any other factor with average depth of dive gave a correlation value of 0.525, indicating that the inclusion of any other variable adds very little to the explanation of the overall pattern observed. Thus average depth of dive alone is considered the variable that best explains the observed pattern of invertebrate community composition.

Figure 5. Cluster dendrogram of the reduced presence/absence invertebrate data

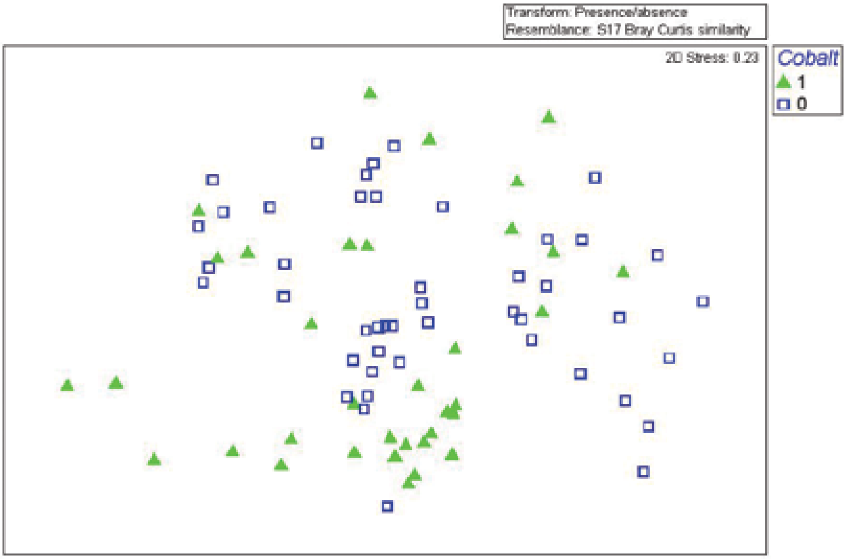


Legend: Filled green triangles indicate cobalt-rich sites, open blue squares indicate non cobalt-rich sites.

Table 5. Results of BIOENV analyses of the reduced dataset for each single variable

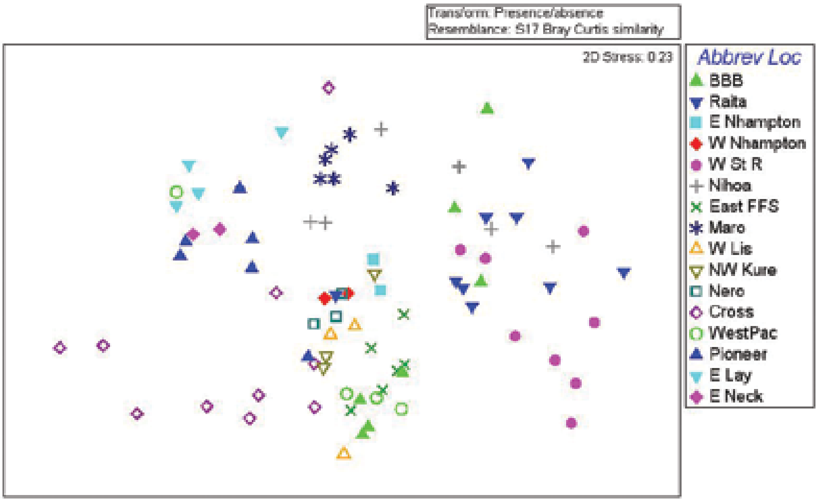
Variable	Correlation value
Average Depth of Dive	0.522
Minimum Depth of Dive	0.473
Maximum Depth of Dive	0.416
PI - Kelley	0.371
PI - Other	0.251
Number of Species Observed	0.247
Summit Depth of Feature	0.221
Bottom Time of Dive	0.190
Feature Type – Seamount	0.157
Latitude	0.150
PI - Baco	0.148
Longitude	0.111
Feature Type – Bank	0.092
PI – Smith and Vetter	0.088
Feature Type – Emergent	0.045
Feature Type – Island Bank	-0.127
PI - Parrish	-0.179

Figure 6. MDS plot of the reduced presence/absence invertebrate data



Legend: Filled green triangles indicate cobalt-rich sites, open blue squares indicate non cobalt-rich sites.

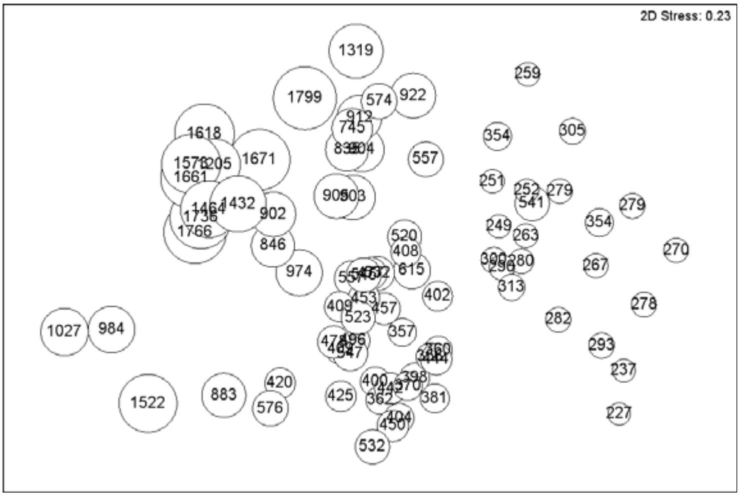
Figure 7. MDS plot of the reduced presence/absence invertebrate data*



*Symbols represent location (see legend).

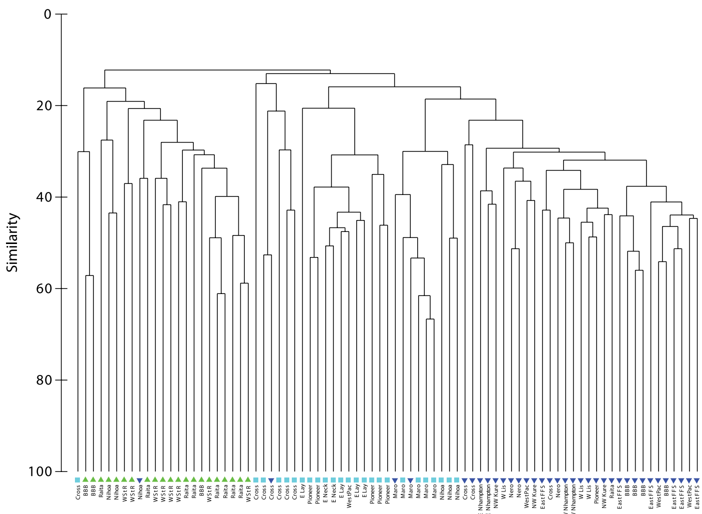
Figure 8 provides the MDS plot with a bubble overlay for the average depth of each dive. This figure shows that the pattern of invertebrate community composition at sites generally reflects a gradient of average depth. Shallower dives (primarily within an average depth range of 227-354m) occur on the right side of the plot, and site depth generally increases moving left along the x-axis, with a second cluster of dive sites primarily within average depths of 356-615 m in the lower centre of the plot, and a third more dispersed cluster to the left side of the plot that primarily includes dives within an average depth range of 745-1799 m.

Figure 8. MDS plot of the reduced presence/absence invertebrate data overlaid with values for average depth of dive and bubbles that increase in size with increasing depth



The apparent structuring of invertebrate communities with average depth of dive is even clearer in the cluster diagram of locations with average depth of dive (Figure 9). The three depth zones (from here referred to as shallow, intermediate and deep) derived from the MDS plot separate dives at the same location, generally clustering with their respective depth group. Within each depth group many sites show the highest similarity with other dives from the same location, with the general pattern being that location is nested within depth zone. Five dives are outliers to this pattern: two intermediate-depth dives from Maro Reef and one intermediate dive from Cross Seamount cluster with the deep dives from the same site; one deep dive from Cross Seamount clusters with the shallow depth group with highest similarity to dives from Brooks Banks; and one intermediate depth dive from Nihoa falls into the shallow cluster most closely with a dive from Raita Bank.

Figure 9. Cluster dendrogram of the reduced presence/absence invertebrate data by depth zone



Legend: Green triangles indicate depths of 227-354 m, blue squares 357-615 m, and inverted blue triangles 745-1799 m. Locations are given along the x-axis.

The two-way crossed analysis of species similarity (SIMPER) using location and average depth of dive (divided into the three depth zones outlined above) indicated that a large number of taxa contributed a small amount to the overall similarity of the invertebrate community found at sites within each depth zone. This may in part be an artefact of using data without any consideration of relative abundance (i.e. presence/absence data) (Clarke and Gorley, 2006). The shallow depth zone had only one species that met the 'characterizing' criterion; that was the antipatharian *Cirrhipathes/Stichopathes*, which contributed about 16 % of the community similarity value of 29.2% (Table 6). The community of the intermediate depth zone had two characterizing species, an unspecified gorgonian and *Gerardia* sp. (a zoanthid), which together contributed about 15% of the similarity value of 39.48% for this depth zone. The invertebrate community of the deep depth zone, with a similarity value of 32.68%, had no species which met the characterizing species criterion.

Table 6. Species contributing the most to similarity within a given depth zone

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%
Shallow (Av. Sim=29.20)				
Cirrhipathes/Stichopathes	0.86	4.63	**1.55**	15.87
pagurid	0.64	3.56	1.18	12.18
Micropyga tuberculata	0.59	2.43	0.82	8.32
Stylocidaris rufa	0.41	1.93	0.62	6.62
pennatulacean	0.5	1.54	0.58	5.28
crab	0.5	1.29	0.48	4.42
Lyrocteis sp	0.5	1.15	0.46	3.95
Siphonogorgia collaris	0.36	1.02	0.47	3.51
shrimp	0.5	0.95	0.43	3.25
asteroid	0.41	0.93	0.4	3.19
Intermediate (Av. Sim=39.48)				
gorgonian	0.97	3.32	**1.79**	8.4
Gerardia sp	0.82	2.57	**1.43**	6.51
Corallium secundum	0.59	1.66	0.92	4.2
Aphanipathes sp1	0.38	1.29	0.99	3.28
shrimp	0.68	1.28	0.8	3.24
anemone	0.62	1.18	0.68	2.99
asteroid	0.53	1.1	0.7	2.79
Narella gigas	0.35	1.07	0.85	2.71
Paromola sp	0.53	1.06	0.84	2.69
hexactinellid	0.59	1.03	0.74	2.61
Deep (Av. Sim=32.68)				
gorgonian	0.72	2.34	0.68	7.17
ophiuroid	0.56	2.17	0.65	6.65
hexactinellid	0.64	1.95	0.7	5.95
pennatulacean	0.6	1.41	0.78	4.3
shrimp	0.56	1.22	0.68	3.73
anemone	0.56	1.1	0.61	3.36
Iridogorgia bella	0.48	0.85	0.5	2.61
Metallogorgia melanotrichos	0.56	0.78	0.49	2.37
Paelopatides cf retifer	0.32	0.76	0.47	2.31
Lepidisis sp cf	0.48	0.66	0.64	2.01

Legend: Av. Abund=average abundance - for presence/absence data this equates to frequency of occurrence, Av.Sim=similarity. Bold Sim/SD=met 'Characterizing' criterion.

The top ten species that contributed the most to the dissimilarity observed between the invertebrate communities of each depth zone, and the 'discriminating' species are listed in Table 7. The largest dissimilarity between communities from different depths was for the shallow versus deep depth zones (84.5%). The species that contributed the most to the dissimilarity between these depth zones were a mix of major taxa, including the cniderians *Corallium regale, Gerardia* sp., *Calibelemnon symmetricum,* and *Paragorgia* sp1, and a ribbon-like chonelasmatinid sponge. The average dissimilarity between communities at dive sites in the intermediate and deep depth zones was 78.57%. The species that contributed the most to the dissimilarity between these depth zones were the gold coral *Gerardia* sp. and a primnoid coral, but neither met the discriminating criterion. The observed dissimilarity between the shallow and intermediate depth zones (77.94%) was most clearly represented by differences in the occurrence of six discriminating species (all cniderians except for two Paramola crabs).

Table 7. Species that had consistently the largest contribution to distinguishing depth zones

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD
Shallow-Intermediate (Av. Diss = 77.94)				
Corallium regale	0	0.38	1.41	**1.7**
Gerardia sp	0.09	0.82	1.32	**1.45**
Cirrhipathes/Stichopathes	0.86	0.35	1.29	**1.27**
Calibelemnon symmetricum	0	0.44	1.2	**1.42**
Paragorgia sp1	0	0.24	1.2	**1.42**
pennatulacean	0.5	0.47	1.13	1.19
Lyrocteis sp	0.5	0.12	1.1	1.04
Callogorgia gilberti	0.09	0.29	1.09	1.22
chonelasmatinae ribbon cf	0.05	0.24	1.09	**1.38**
Corallium sp	0.09	0.59	1.08	1
Shallow-Deep (Av. Diss = 84.50)				
hexactinellid	0.18	0.64	3.11	**6**
Lyrocteis sp	0.5	0	3.11	**6**
Paromola japonica	0.09	0	3.11	**6**
Paromola sp	0.36	0	3.11	**6**
pennatulacean	0.5	0.6	3.11	**6**
primnoid	0.18	0.32	3.11	**6**
hexactinellid stalked	0	0.28	2.17	1.24
Paelopatides cf retifer	0	0.32	2.17	1.24
Caulophacus sp	0	0.32	1.85	1.29
crinoid	0.32	0.4	1.85	1.29
Intermediate-Deep (Av. Diss = 78.57)				
Gerardia sp	0.82	0.04	1.76	0.92
primnoid	0.41	0.32	1.7	0.97
Corallium secundum	0.59	0.04	1.51	0.88
hexactinellid	0.59	0.64	1.48	0.82
ophiuroid	0.44	0.56	1.42	0.84
asteroid	0.53	0.44	1.39	0.79
Metallogorgia melanotrichos	0.24	0.56	1.3	0.76
pennatulacean	0.47	0.6	1.24	0.74
goniasterid	0.56	0.4	1.24	0.8
Iridogorgia bella	0.03	0.48	1.18	0.81

Legend: Av. Abund=average abundance - for presence/absence data this equates to frequency of occurrence. Bold = taxa which met the 'discriminating criterion'

The results of the location component of the findings are not presented here because the SIMPER analysis was primarily conducted in order to reveal which species were responsible for the differences in community composition with respect to average depth zone. That is because depth was the environmental variable indicated by the BIOENV analysis as having the greatest correlation with the overall pattern of community composition, whilst accounting for the effect of location (hence the crossed analysis with the factor location).

Specimen photographs

Frame grabs of specimen images have been taken from the video, and then standardized for size and resolution and labelled.

Images are available for most of the 'species' identified in this study. However, displaying such a large number is problematic in a report. A web server which hosts all of the HURL specimen images is accessible (ftp://ftp.soest.hawaii.edu/ckelley/outgoing/HURLAnimalGuide/). For the purposes of this report examples are given of selected specimen images which include representative taxa and main species for the major taxonomic groups:

Porifera (Figure 10)

Cnidaria (Figure 11)

Mollusca (Figure 12)

Crustacea (Figure 13)

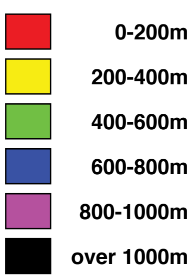
Echinodermata (Figure 14)

Chondrichthyes (Figure 15)

Osteichthyes (Figure 16)

Above each image is the taxonomic name, and dive number. Depth is also indicated through a colour-coded square:

Depth Range Key



Note: this represents the depth at which the animal in the photograph was found, not the depth range for all of HURL's records for that species.

Figure 10. Representative images of Porifera 'species' (sponge)

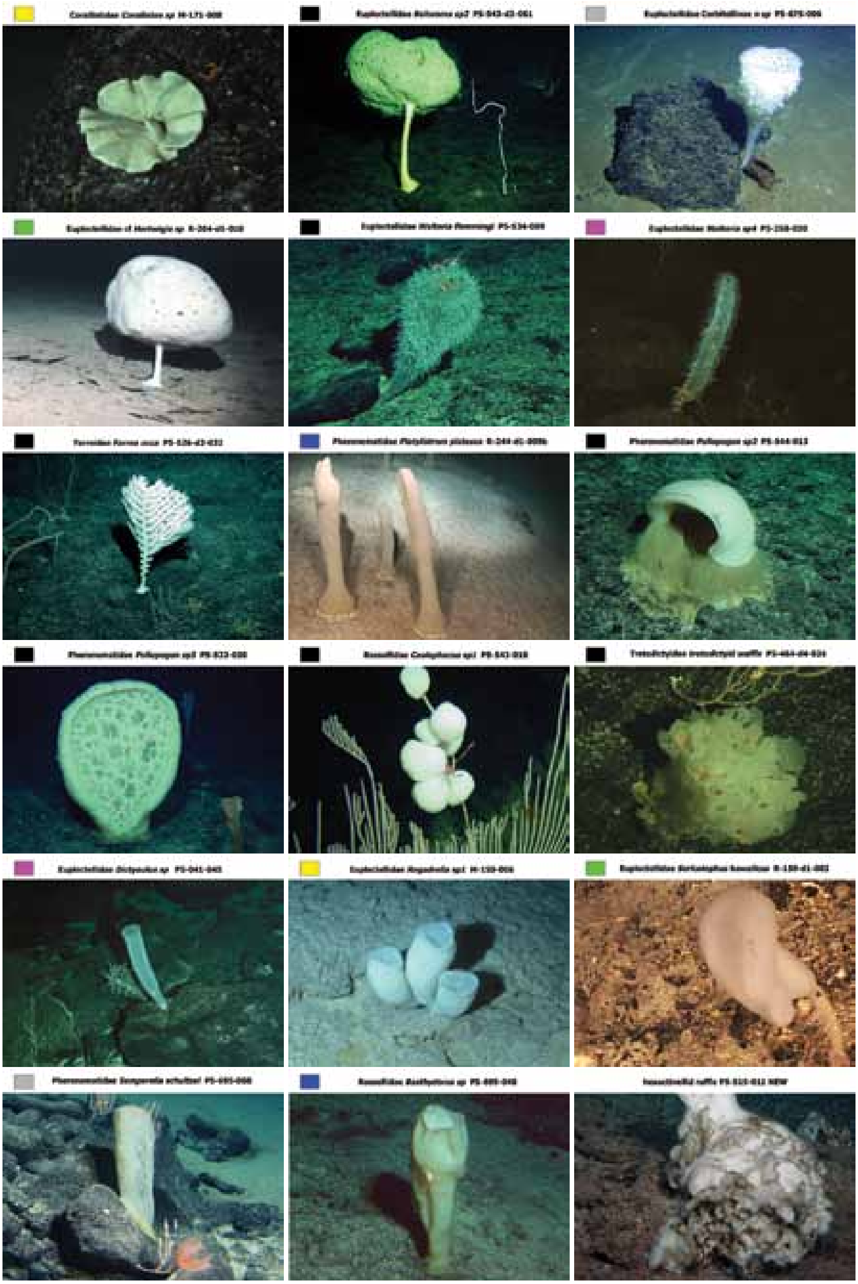


Figure 11. Representative images of Cnidaria 'species' (anemones, soft corals, sea pens)

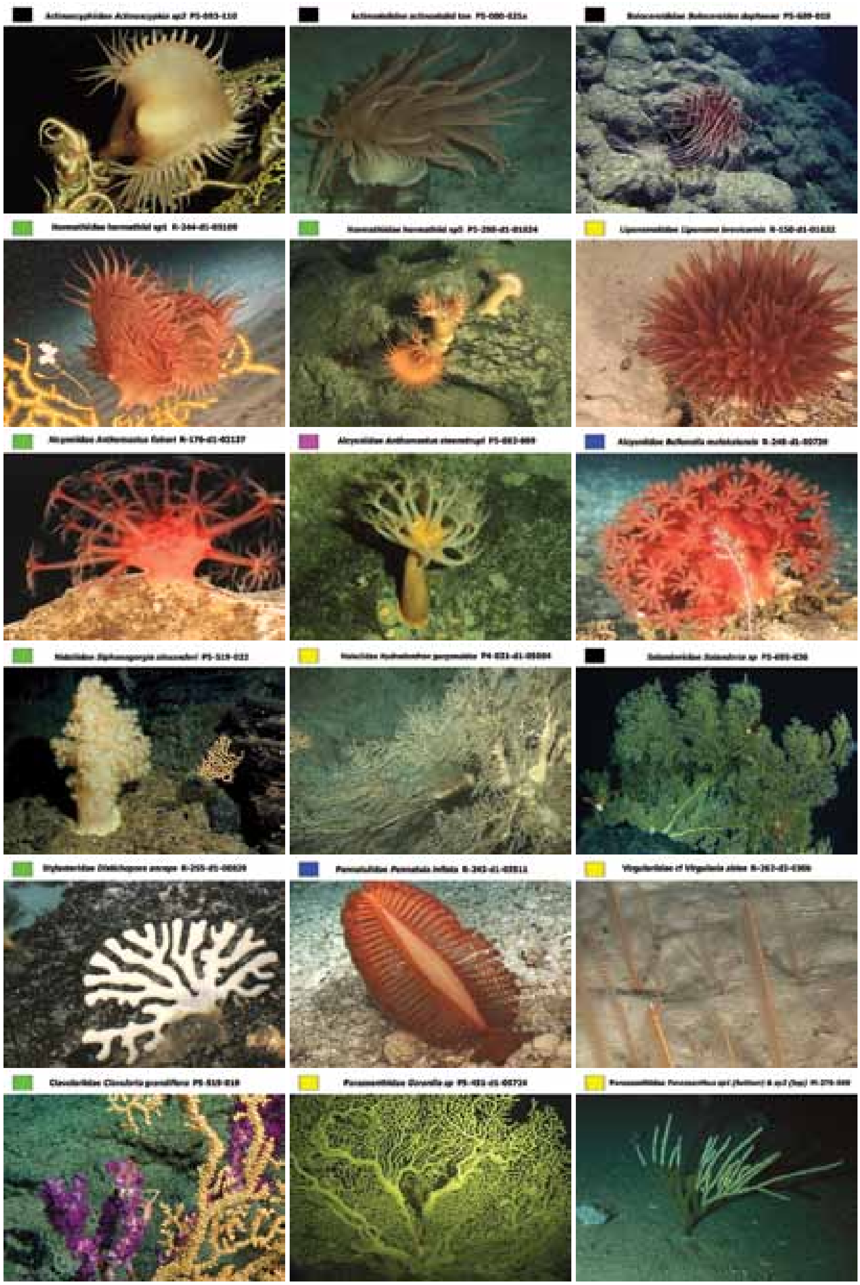


Figure 11 (cont). Representative images of Cnidaria 'species' (black and gorgonian corals)

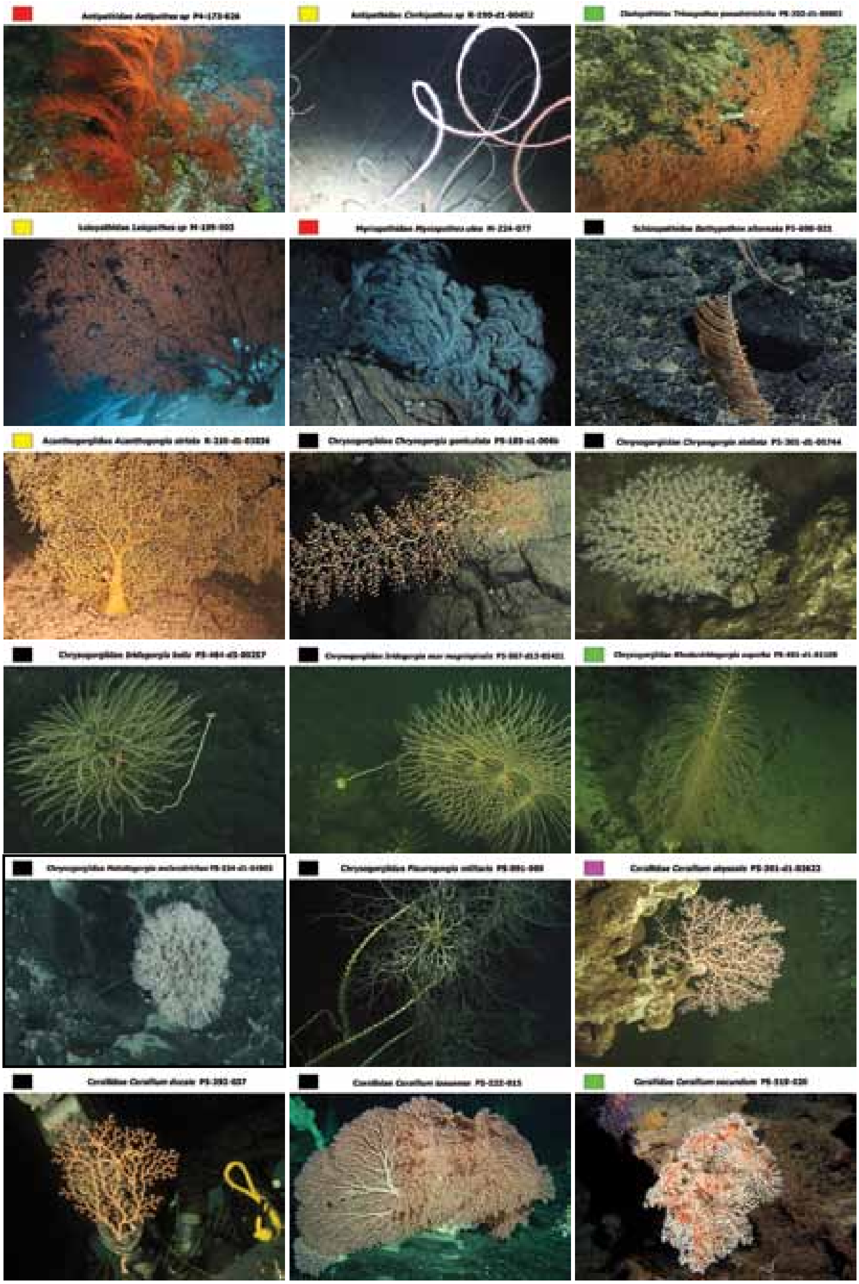


Figure 11 (cont). Representative images of Cnidaria 'species' (black and gorgonian corals)

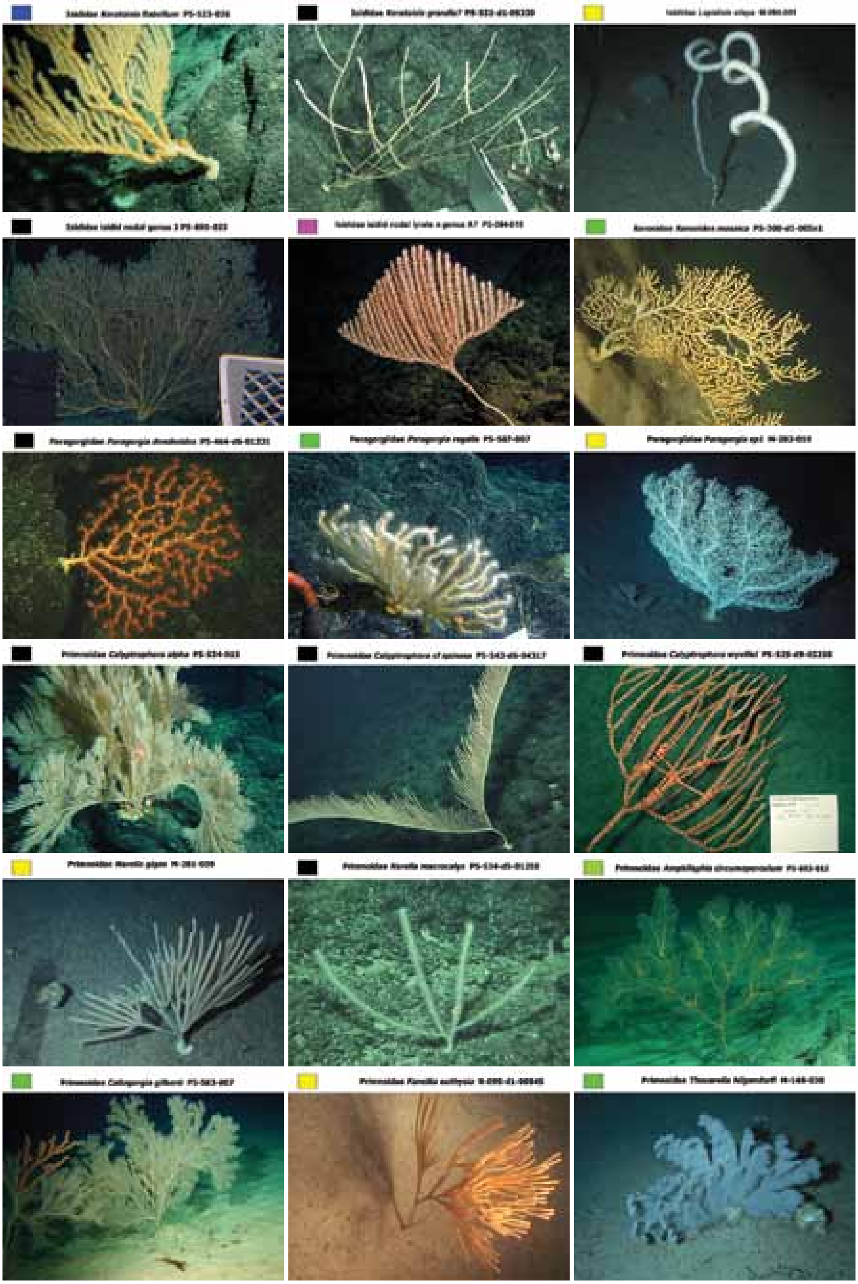


Figure 11 (cont). Representative images of Cnidaria 'species' (stony corals)

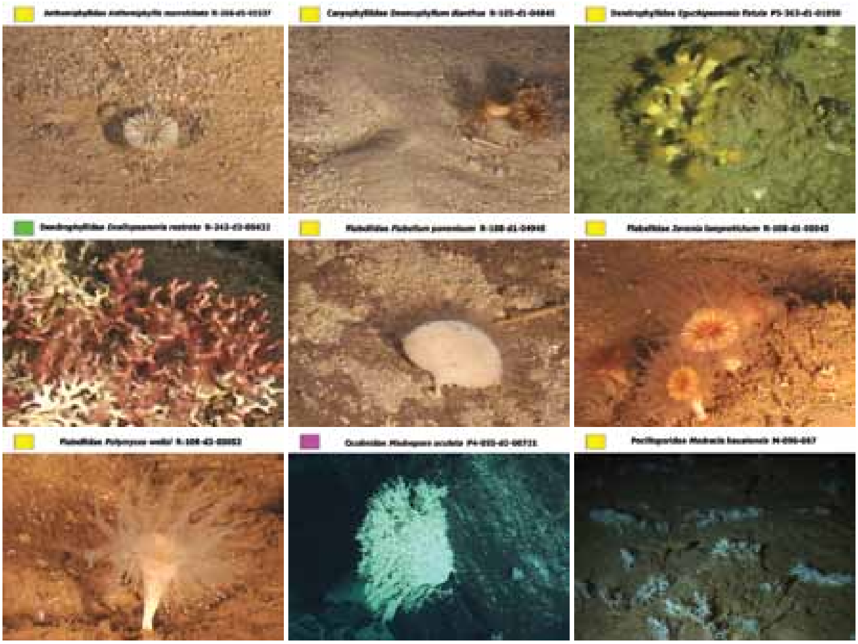


Figure 12. Representative images of Mollusc 'species' (bivalves, gastropods, cephalopods)

Figure 13. Representative images of Crustacea 'species' (hermit crabs, squat lobsters, shrimps, crabs)

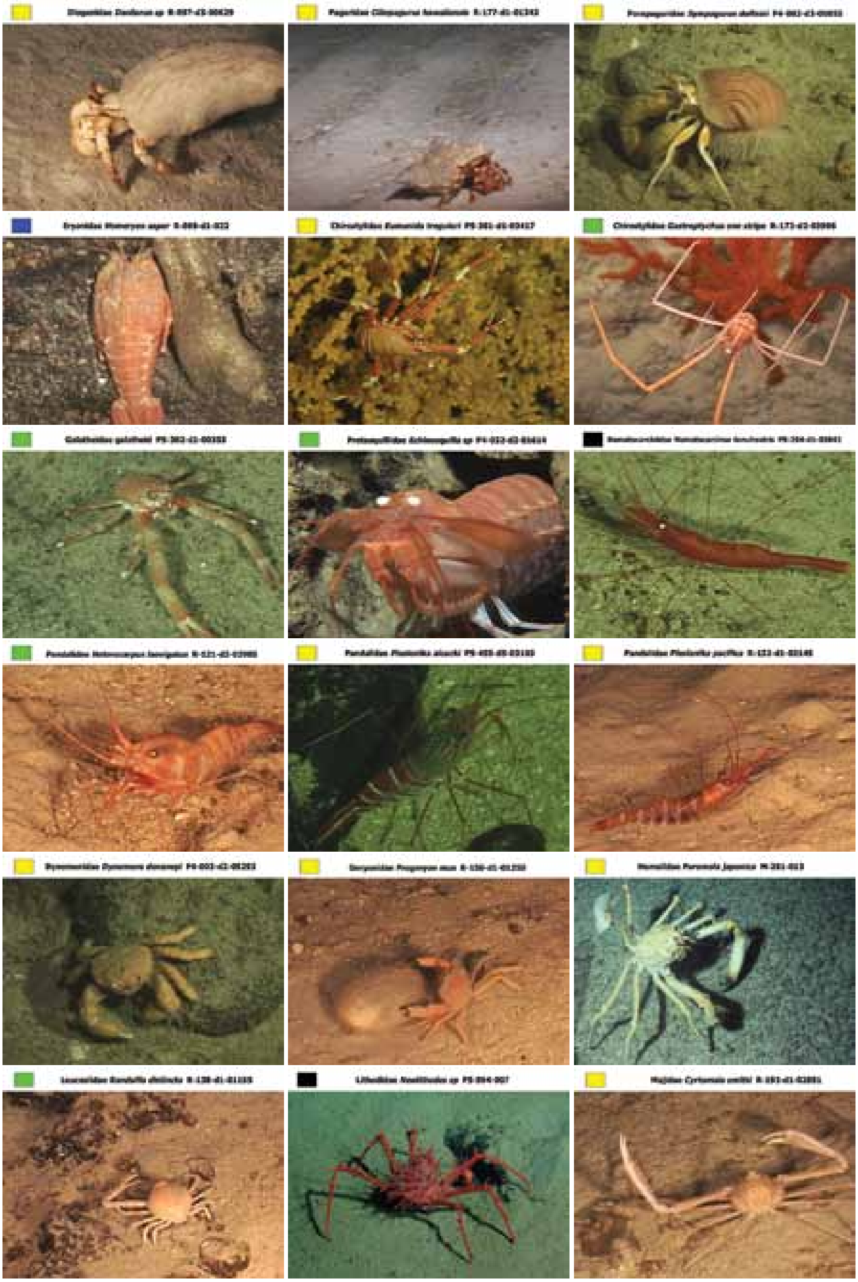


Figure 14. Representative images of Echinoderm 'species' (sea stars, brittle stars, urchins, sea cucumbers)

Figure 15. Representative images of Chondrichthyes 'species' (sharks, chimaeras, and eels)

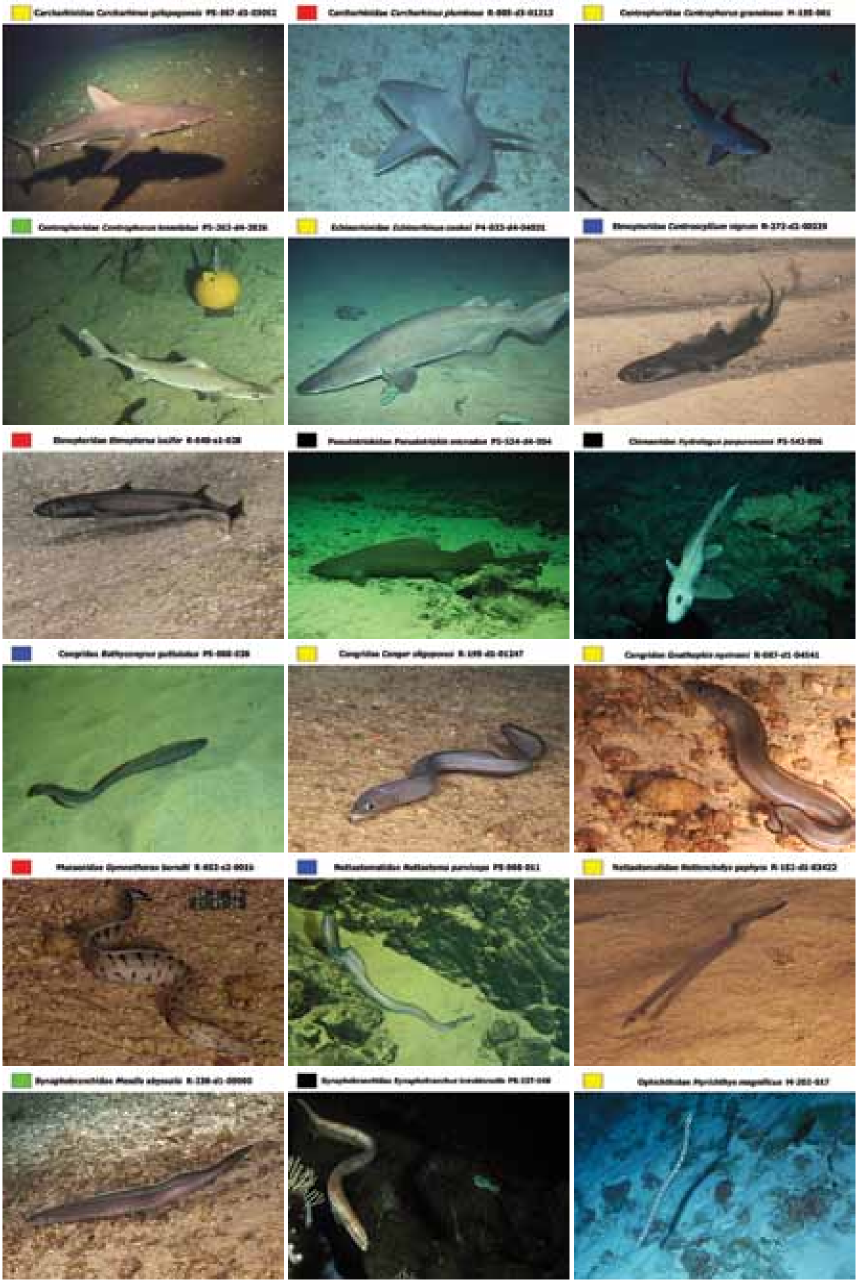


Figure 16. Representative images of Osteichthyes 'species' (bony fish)

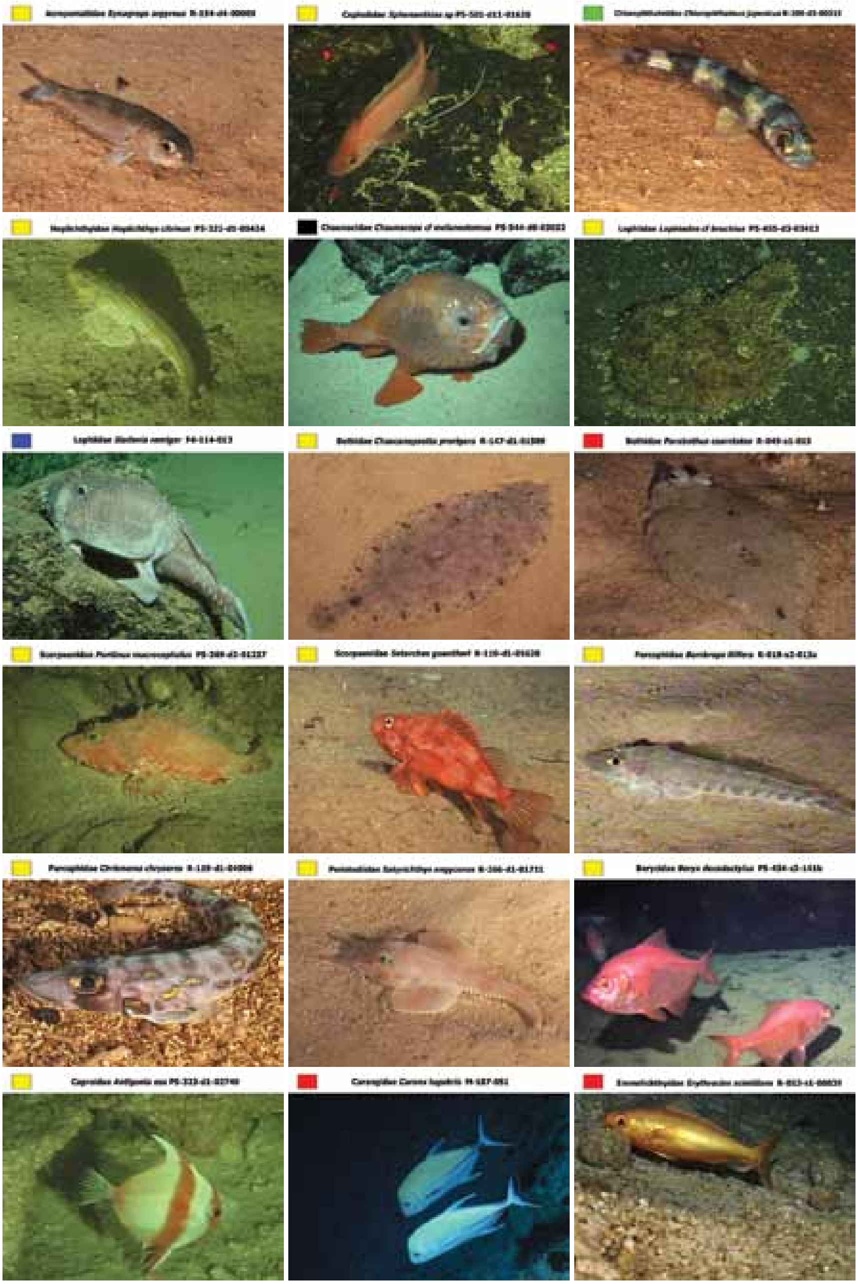


Figure 16 (cont). Representative images of Osteichthyes 'species' (bony fish)

CHAPTER FOUR

Discussion

4. Discussion

The study successfully achieved all its objectives. The project developed a detailed set of faunal records from dives carried out by HURL submersibles and ROVs from numerous sites in the Hawaiian Archipelago, which provided a comprehensive data set for analysis of the biodiversity of cobalt-rich crust seamounts. We stress again that the definition of "cobalt-rich crust" is based on whether the seamounts are in a region of likely commercial potential, and hence are indirectly "cobalt-rich". It does not mean that all cobalt-rich locations have high cobalt crust concentrations, or that non cobalt-rich locations could not have high cobalt levels. Results suggest there are no strong differences in the community composition of benthic invertebrates between cobalt-rich and non cobalt-rich crust sites. Depth, and to a lesser extent, locality, appear to be the main factors determining faunal distribution patterns. Below we discuss various aspects of the data or interpretation of results that highlight gaps in our current knowledge, and future research directed towards a workshop planned for 2011 that will review these findings and discuss their input to the formulation of environmental guidelines for future mining operations.

The dataset

The Hawaiian Archipelago falls on the periphery of the cobalt-rich region of seamounts of the CNP. The HURL video log database from Pisces submersible dives throughout the Archipelago and nearby seamounts represents one of the only datasets available to characterize the fauna of cobalt-rich seamounts. Although the dataset had to be reduced for the more detailed multivariate analyses carried out for this report, the data available for the final analyses still exceed those used for most other community analyses of seamounts and associated geomorphological features worldwide. The HURL database, therefore, represents a valuable resource for seamount analyses on a wider geographical scale than just the Hawaiian Islands region, as the data will be comparable to those from similar biodiversity studies being undertaken in the Southwest Pacific and North Atlantic Oceans.

Re-examining the data from the dives was a time consuming exercise as it entailed a great deal of additional work. However, this was necessary as recording practices had changed over time, and the taxonomic naming of species had also varied. As photographic records become an increasingly common and important part of scientific research, efforts worldwide have increased to utilize as much information in images as possible. CenSeam has sponsored two workshops, the most recent jointly with the Monterey Bay Aquarium Research Institute in May 2009, focused on improving identification of fauna and data analysis from video and still photographs taken of the seafloor. HURL researchers were present, and revisions were made to the database as a result of that workshop. The database is constantly being updated as species identifications are revised.

The database contained more data fields than could be used in the analyses. We were limited in our ability to use abundance information, because the records were combined from multiple cameras, and contained multiple records of the same animal if the vehicle was stationary for periods of time. Substrate information was also recorded for many dives, but was not used because it was incomplete for a number of dives examined early in the research project before substrate was routinely included in the re-examination protocol. Both these data sources are potentially important for evaluating the significance of the presence-absence results, and we hope to be able to carry out further analyses in the future which include these variables.

Sampling level

The species accumulation curve shown for Cross Seamount clearly demonstrates that the level of sampling at all locations was insufficient to describe the full bioversity of the invertebrate megafauna (let alone the smaller macrofauna and infauna). Hence, rare species may not have been detected. Although efforts were made to standardize sampling between locations, the number of dives per location was still uneven, and this could influence results as more species were recorded on sites with more dives. The list of species from cobalt-rich and non cobalt-rich sites showed that a large number were only recorded at one or the other, and some species were rare and only found at very few sites even within a habitat type. This is partly due to sampling intensity, but may also reflect species which do in fact have a restricted distribution. More effort is needed to evaluate the likely distribution of these rare species.

Recent NOAA surveys in 2003 and 2004 involved submersible dives on a number of locations included in the present study: East Laysan, Pioneer, East Necker, Raita, Northwest Kure, West Lisianski Bank, Cross Seamount and Nero seamount. These dives found many species new to science, including 11 new species of octocorals, two new genera and several new species of antipatharians, three new stylasterid species, one new zoanthid species, and several new records of Scleractinia. Hence, although an extensive species list exists for the Hawaiian Archipelago, the high rate of discovery of new species and new records implies that the Archipelago is undersampled for deep-sea corals. Other invertebrate taxa associated with the corals and deep-sea sponges that are also abundant within these same habitats are poorly known taxonomically.

Drivers of faunal composition

Our analyses indicated that cobalt-rich sites do not appear to have a different invertebrate community composition from non-cobalt rich sites in the Hawaiian Archipelago. Neither do there appear to be differences in community composition that are related to the geomorphological classification (e.g. seamount, island, bank or atoll) of the features. The study, therefore, appears to produce conclusions consistent with a growing set of results indicating that seamount communities in many cases share species from a wider regional pool, rather than having strongly isolated and endemic faunas (e.g. O'Hara, 2007; Clark et al, 2010).

The invertebrate communities within the study area is structured both by location and depth. There was a statistically significant difference in the community composition among locations, although the difference was not particularly pronounced. It appears from the results of the analyses that depth has the strongest correlation with community composition, with three depth zones identified as having different community types: a shallow depth zone between 227 and 354m; an intermediate depth zone between 356 and 615m; and a deeper zone between 745 and 1,799 m. These depth zones match those identified by qualitative observations of deep-sea coral communities (from submersible dives which were a part of the data set (Parrish and Baco 2007; Baco, 2007). That invertebrate communities would be structured by depth is not surprising given that changes in community composition with depth have frequently been noted for communities at the depths sampled (see review by Carney, 2005).

Location appears to be secondary to depth as a factor. However, it is still likely to have considerable influence on community composition in the Hawaiian Archipelago, as illustrated by the tendency for dives from the same location to cluster together within a depth zone. There were also locations like Maro Reef (non cobalt-rich), where dives clustered together (i.e. have similar community composition), independent of depth zone.

As already mentioned, substrate was not included in the analysis. Substrate type is known to be an important factor in determining the composition of benthic fauna (e.g. Gage and Tyler, 1991), and it seems likely that different sediment types could be important in the Hawaiian Archipelago. Cobalt crusts may provide a much harder substrate for attaching organisms than, for example, carbonate or soft sediments, and could also stabilize and prevent erosion of carbonate areas on the flanks of islands and seamounts (authors' personal observations). What is unknown is whether hard, cobalt-rich crust is different from hard, non cobalt-rich crust. The non cobalt-rich crusts to the northwest also started their geological 'lives' in the cobalt-rich zone, slowly moving with the spreading of the Pacific Plate. More needs to be known about the physical composition of the crust surfaces on the features.

The similarity of invertebrate communities on seamounts and rises in a chain like the Hawaiian Archipelago will depend to a large extent on the dispersal capabilities of fauna (e.g. Parker and Tunnicliffe, 1994). Many shallow-water invertebrate species are thought to have limited dispersal capabilities, on average less than 100 km (Kinlan and Gaines, 2003), but little is known about the genetic connectivity of seamount invertebrates (Clark et al., 2010). Separation of communities by geographic distance (particularly trends along the Hawaiian Archipelago) were not examined in this study, but are suggested for future analysis.

The finding that oceanic islands, banks and seamounts in this study have similar communities has also been the result of comparisons of deep-water corals on oceanic islands and seamounts in the Atlantic (Hall-Spencer et al., 2007). Genetic studies have also indicated that chyrostylid crabs on the slope of the island of New Caledonia are well mixed genetically with those on nearby low-relief 'seamount' features (Samadi et al., 2006). Additionally, ophiuroids collected from oceanic islands were found to cluster with ophiuroids from their nearest seamounts (O'Hara, 2007). Although each of these studies focuses on a particular taxon, the results agree well with those from the much larger and diverse dataset analysed here; that the geomorphological definition of a seamount as non-emergent features (e.g. Pitcher, T.J. and T. Morato et al., 2007) is not necessarily a biologically meaningful unit. Seamount-like features rising from the seafloor, regardless of the depth (and possibly emergence) of the summit can be considered in the same category as seamounts when considering biological research questions and management issues.

Management implications

The results of our analyses indicate that whether or not a seamount has a cobalt-rich crust may not be a factor structuring seamount communities, at least among the features of the Hawaiian Archipelago. Instead, the main driver of invertebrate community composition appears to be depth (or other environmental variables that co-correlate with depth), with at least three depth 'zones' between 200 m and 2000 m which is the range where cobalt-rich crusts are found. Variability between locations is also likely to be important. A key issue for management, then, is how widespread any prospective mining operation is likely to be, and whether this would cover the geographical range of features which have similar invertebrate fauna, thus potentially placing benthic communities at risk.

Grigg et al (1987) recorded low biodiversity and abundance of megafauna on Cross Seamount, which is regarded as a cobalt-rich crust feature. They defined "sparse" and "barren" zones down the flanks of the seamount where the thickest crusts occurred, and noted that isolation from the main island chain, current flow directions, and the small relative size of the seamount could all be factors limiting the recruitment of species, and contributing to these patterns. They went on to suggest that this meant the environmental impacts on the benthic megafauna produced by manganese crust mining operations would be minimal. However, it is clear from the exploration of Cross Seamount in recent years, and the results of this study, that a lot is still unknown about the composition, distribution and abundance of seamount fauna. Caution is therefore needed before reaching the conclusion that low diversity and low abundance equate to low risk. An important limitation is that photographic images may not give useful data on small invertebrates, below a size of 2-3 cm. It is possible that below this size, diversity is high, and may not show the same patterns we have found for macrofauna.

The present study has greatly improved our knowledge of patterns of faunal composition and distribution on cobalt-rich crust seamounts. However, further work is necessary to build on the findings presented here to better describe the more detailed and comprehensive community composition on cobalt-rich crusts, to confirm the main factors driving the structure and function of the communities, and how they may be affected by any mineral exploration activity. In the section below we summarize some of the key items for future research, and in particular issues that can be tackled at the workshop planned for 2011.

Future work

The workshop planned for 2011 would firstly review the results of the present study, and then focus on progressing further analyses to improve our understanding of cobalt-rich crust biodiversity, before advancing recommendations for environmental guidelines.

1. Database

The HURL data used for this study have been extensively checked and groomed. However, there are still issues with the taxonomic identity and verification of some species. HURL is continuing to work with taxonomists to ensure the data are as complete and consistent as possible. Substrate information can be improved with further re-examination of some of the earlier Pisces 5 dives, so that the reduced dataset used for the multivariate analyses would have complete substrate information. However, this could be time consuming and may require additional funding.

2. Enhanced cobalt-rich versus non cobalt-rich analyses

The existing data can provide a basis for more detailed analysis of cobalt-rich versus non cobalt-rich crust communities. Substrate could be incorporated into multivariate analyses, as discussed above. In particular, efforts can be made to convert the species' presence-absence records into a measure of relative abundance. Abundance is important if crustal composition affects biomass as well as, or rather than, diversity. It is possible that the species compositions on cobalt-rich and non cobalt-rich crusts are similar, but faunal densities might be very different. Converting the data to provide abundance information is not an easy task, but CenSeam can utilize the skills of members of its Data Analysis Working Group, who are very experienced in dealing with this kind of data. It may also be possible to apply predictive techniques to estimate relative species composition and diversity (e.g. habitat suitability, niche factor, maximum species number, techniques). CenSeam has a working relationship with members of the Census of Marine Life programme, FMAP, who undertake this type of analysis (e.g. Tittensor et al, 2009).

3. Regional context analyses

The faunal lists (species locality records) presented here need to be compared with the growing datasets on biodiversity of seamounts in the Pacific Ocean generally. Seamounts Online (http://pacific.sdsc.edu/seamounts/) has records from biological surveys undertaken in the 1960s and 1970s from a number of seamounts in the CNP region. These include Allison, Horizon, Agassiz, Darwin, Hamilton and Hess seamounts and guyots (Wilson et al, 1985). Although sampling was not extensive, faunal lists are available for a number of groups. The taxonomic identification of the species lists needs to be checked and updated before any comparisons can be made. CenSeam has also compiled several detailed datasets of fauna from seamounts in the southwest Pacific Ocean. Before the workshop, efforts were made to access any available data, in particular from SeamountsOnline, in order to improve knowledge of the wider regional fauna and provide an improved geographical context to evaluate how representative or unique the cobalt-rich communities are. This wider data set may also enable a determination of whether the fauna of the larger guyots (potentially of greater commercial interest than smaller volcanic peaks) differs from smaller seamounts.

A compilation of global octocoral distribution datasets is currently approaching completion by researchers at the Zoological Society of London. CenSeam members have been very active in this, and if such data are made available, this could give detailed regional information to compare with the HURL records from the Hawaiian Archipelago used in the present study.

4. Proximity comparison

The current research indicates that there is considerable variation in community composition between locations. However, an analysis was not possible in the time available to investigate the relationship of distance between seamounts and community structure. More detailed examination of between-location data may reveal discontinuities in distributions that are not apparent in the grouped cobalt-rich and non cobalt-rich comparisons. This could help with the interpretation of the spatial scales at which biological changes may occur. This is important for understanding the geographical scale at which management of any mining activity would be required.

5. Chemical influences

The mineral composition of the cobalt-rich ferromanganese crusts is well known (e.g. Hein, 2002). However, very little is known about the influence of crust composition on the settlement or survival of benthic invertebrates. A literature search revealed no published research comprehensively addressing this subject. However, chemical toxicity may be important and we believe warrants further attention, as additional considerations for management of mining are the potential effects of enhanced sedimentation and the release of metals bound up in the crusts from any mining operations (Koslow, 2007).

6. Recommendations for key tasks at 2011 workshop

- Update HURL data records, complete substrate re-examination (pre-workshop).
- Compile other Pacific regional datasets (e.g. Seamounts Online, CenSeam) (pre-workshop).
- Undertake review of the results of the present study.
- Run new multivariate analyses with substrate information included.
- Re-analyse data based on abundance information.
- Evaluate results from the Hawaiian Archipelago sites against data from the wider Pacific Ocean region.
- Provide recommendations based on the workshop findings to the ISA for formulation of environmental guidelines.

Acknowledgments

The authors are grateful to Edith Chave and Jane Culp (both HURL) for their extensive help with dive video logging, creation of the photo gallery and data corrections. We also acknowledge the following taxonomists: Rich Mooi (echinoids), Gary Williams (pennatulaceans), Tomio Iwamoto (macrourids), John McCosker (ophichthids), Robert Van Syoc (barnacles), Dan Cohen (ophidiids), Janet Voight (cephalopods), Henry Reiswig (sponges), Robert Moffitt (crabs and shelled gastropods), Steven Cairns (scleractinians and primnoids), Les Watling (isidids), Cory Pittman (seaslugs), Dave Pawson (holothurians), Andrey Gebruk (holothurians) Daphne Fautin (anemones and corallimorpharians), Dennis Opresko (antipatharians), Chris Mah (asteroids), Allen Collins (sponges), and Charles Messing (crinoids). Thanks to Don Robertson and Mireille Consalvey (both NIWA) for helpful comments on the manuscript.

This project was funded by the International Seabed Authority. The authors extend their thanks to Nii Odunton and Adam Cook for their support of the study.

CHAPTER FIVE

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Seamounts in the central-west Pacific Ocean are known to have thick, cobalt-rich ferromanganese crusts. These are of commercial interest for mining. However, very little is known about the faunal communities on these seamounts, and in particular whether they could be different from those that occur on seamounts which do not have thick cobalt-rich crusts. Such information is fundamental to evaluating the potential impacts of mining operations, and formulating environmental guidelines for mining operations. This study was commissioned by the International Seabed Authority to assess patterns of community composition and diversity on seamounts with, and without, cobalt-rich crusts, and the factors that determine these patterns.

This study has provided a considerable advance in the knowledge of the biodiversity of cobalt-rich crusts, and factors that might drive community composition. However, the database and analyses can be expanded to improve the results. In particular, data on substrate type can be incorporated, and analyses can extend beyond presence-absence to include abundance. It is important to examine both of these factors in order to confirm the implication of the present study; that there is no effect of crust composition on the fauna. A workshop has been completed to review the present results, and to undertake further analyses.

ISBN 978-976-95268-7-7