Vol. 371: 91–107, 2008
doi: 10.3354/meps07618

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published November 19

Ecology and distribution of soft-sediment benthic communities off Viti Levu (Fiji)

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ABSTRACT: Information on biodiversity and community structure is vital for monitoring the effects of climate change and other anthropogenic impacts. Benthic ecosystems of 5 sites off Viti Levu (Fiji), comprising 50 stations were sampled quantitatively revealing 13 128 individuals of 230 species at a mean density of 273.5 ind. m^{-2}. Common taxa included polychaetes (89 species), crustaceans (84 species), molluscs (50 species) and echinoderms (7 species). No species occurred in all 50 stations; the maximum distribution range was 45 stations occupied by the polychaete *Aglaophamus* sp. A total of 81 species (35.2%) were restricted to single sites ('uniques'), highlighting spot endemism. Species richness and rarefaction curves provided high estimates of diversity. Multivariate analyses incorporating biological abundances and environmental factors showed 3 distinct clusters among sites characterising differences in benthic community structure. Strongest determinants of faunal distribution were depth, distance from reef and river, and sand content. The presence of heterogeneous faunal assemblages suggests the interplay of these factors at each site. Fauna in Nadi Bay (Shannon-Weiner diversity index H': 3.26), Suva Harbour (H': 3.19) and Laucala Bay Lagoon (H': 3.06) had high diversity indicative of biologically accommodated communities. Rewa River Estuary (H': 2.42) and Nukubuco Reef drop-off (H': 2.48) had low diversities, typical of habitats subjected to fluctuating environmental conditions. Benthic community structure in the lagoons around Viti Levu was rich and diverse. Biodiversity was greater than previously recorded from the Great Astrolabe Reef, Fiji (207 to 211 species) and Australia's Great Barrier Reef (154 species), but lower than in New Caledonia (311 species) and Tahiti (315 species).

KEY WORDS: Benthic communities · Marine biodiversity · Community structure · Spatial patterns · Uniques · Spot endemism

INTRODUCTION

Fiji has one of the largest developed coral reef systems in the South Pacific (L. Zann 1992 unpubl. report), rated 6th in the world in terms of total coral area (Spalding et al. 2001). The 1000 or so reefs in Fiji include barrier, fringing and platform reefs, which are considered to be in good condition except those near the large urban centres, where pollution from sewage wastes, industries, poor land use and coastal development has impacted reefs (Nair 2003). The largest, most developed and populated of the Fiji Islands is Viti Levu, which is estimated to have approximately 150 000 ha of coral reefs (WRI 1999).

Coral reefs support high biodiversity (Reaka-Kudla 1996, Gray 1997, Schlacher et al. 1998), while sedimentary habitats adjacent to reef structures in lagoons (Schlacher et al. 1998) are considered important in cross-habitat exchanges of material and energy. Various authors (Warwick & Ruswahyuni 1987, Alongi 1990, Richer de Forges 1991, Newell & Clavier 1997, Frouin & Hutchings 2001) have highlighted the importance of tropical soft sediments in sheltering an abundant and diverse benthic fauna.

The 'Coral Triangle' is rich and diverse in marine life (WWF 2008) and within the Indo-Pacific covers all or parts of countries including Indonesia, Malaysia, Papua New Guinea and Philippines. Neighbouring

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countries (Fiji, Australia, New Caledonia) are also known to contain rich, but somewhat lower biodiversities. Roberts et al (2002) found that species richness peaked in the 'Coral Triangle' and fell eastwards across the Pacific. Although some ecological studies have been carried out on Fijian reef systems (Whippy-Morris & Pratt 1998, Coppard & Campbell 2005, Zann 1992 unpubl. report) information on the country's benthic invertebrate biodiversity and distribution is minimal (Vuki et al. 2000). This lack of knowledge on invertebrate diversity and factors affecting community structure makes benthic ecological studies difficult, and diversity comparisons with neighbouring reef systems, islands and countries impossible. The need for baseline information for Fiji and knowledge of the ecological processes underpinning its benthic marine environments is crucial to the understanding and preservation of its biodiversity. Accordingly, we: (1) evaluated species richness and spatial pattern diversity within ecological communities in the lagoons around Viti Levu, (2) compared ecological communities among neighbouring lagoonal areas, (3) examined the interrelation between environmental variables and benthic community properties, and (4) compared diversity and community structure with similar habitats in the South Pacific.

Soft-bottom benthic communities have been used to investigate the effects of anthropogenic inputs and perturbations on coastal marine ecosystems (Pearson & Rosenberg 1978, Keough & Quinn 1991, Frouin 2000). Our study provides an overview of the community structure in lagoons around Viti Levu and will act as a baseline to help future monitoring and conservation programmes.

MATERIALS AND METHODS

Location and description. Fiji, a tropical archipelago, is located between latitudes 15° and 22° S, and between longitudes 177° and 175° E. Viti Levu (Fig. 1A) is by far the largest (10 388 km^2) and most populated island, with many of the major cities, industries and tourism facilities. Viti Levu is estimated to have about 150 000 ha of coral reefs. This estimate is based on the total area of coral reefs in Fiji (an estimated 1 million ha, WRI 1999).

In order to distinguish between the different areas sampled and their associated communities, each area was assigned the term 'site' and a descriptive name was given to each based on location. Five sites were identified along the Viti Levu coastline. Sites 1 (Suva Harbour), 2 (Laucala Bay Lagoon), 3 (Rewa River Estuary) and 4 (Nukubuco Reef) were situated on the south/southeastern coastline, which is windward and consists of outer-shelf barrier reefs, with classic fore-reef, reef crest and back reef zones (Fig. 1B). Site 5 (Nadi Bay) was located on the northwestern coastline, which is on the island's leeward side and consists of mid- and inner-shelf platform reefs (Fig. 1C). A total of 50 stations were sampled from these 5 sites.

Site 1: Suva Harbour. Suva Harbour is a shallow, rectangular embayment, approximately 3 km long (northeast to southwest) and 2 km wide. The north-eastern end of the harbour is shallow (<30 m). The harbour deepens seaward. To the southwest, the boundary of the harbour is marked by irregular bathymetric highs and channels. The floors of Suva Harbour and the inlets incised into the margins of the harbour are blanketed by thick, ubiquitous deposits of fine-grained organo-calcareous sediment (Shorten 1993).

Site 2: Laucala Bay Lagoon. Laucala Bay Lagoon is confined by Suva peninsula to the northwest, Rewa Delta to the northeast and Sosoikula and Nukubuco reefs to the south. The lagoon has 2 reef passages that allow access and interchange of water between lagoon and ocean. The water at the bottom of the lagoon moves northeastwards during high tides and southwards during ebb tides. The lagoon environment is mainly controlled by the Rewa River, which supplies high siliclastic sediment and dissolved chemical input (Schneider et al. 1995) along with a large supply of freshwater.

Site 3: Rewa River Estuary. The Rewa River is approximately 78000 m in length and drains approximately one-quarter of the entire Viti Levu land mass (predominantly southwards). Consequently high rates of sedimentation occur at the mouth of the river, contributing to increased turbidity as well as dissolved chemicals (pesticides, herbicides) and nutrients (Terry 1999).

Site 4: Nukubuco Reef drop-off. Nukubuco Reef is approximately 4.5 km long and nearly 2 km wide, with a large seagrass bed between the back reef and lagoon. On the seaward side of the reef crest lies the reef face, with rapidly deepening waters where high proportions of clay occur (Schneider et al. 1995).

Site 5: Nadi Bay. Nadi Bay is situated between the Mamanuca and Yasawa groups of islands and the mainland on the western (leeward) side of Viti Levu. The fringing reef in Nadi Bay does not enclose the harbour and a few patch reefs are situated sporadically within the bay. These formations allow unobstructed circulation of oceanic water, but provide no protection from the cyclone winds and waves.

Sampling procedure. A total of 200 samples was collected from the 50 stations using a 0.1 m^2 Smith-McIntyre grab. At each station, 3 grab samples were taken for faunal analysis. Faunal samples were washed through a 1 mm sieve. Benthos retained on the sieve

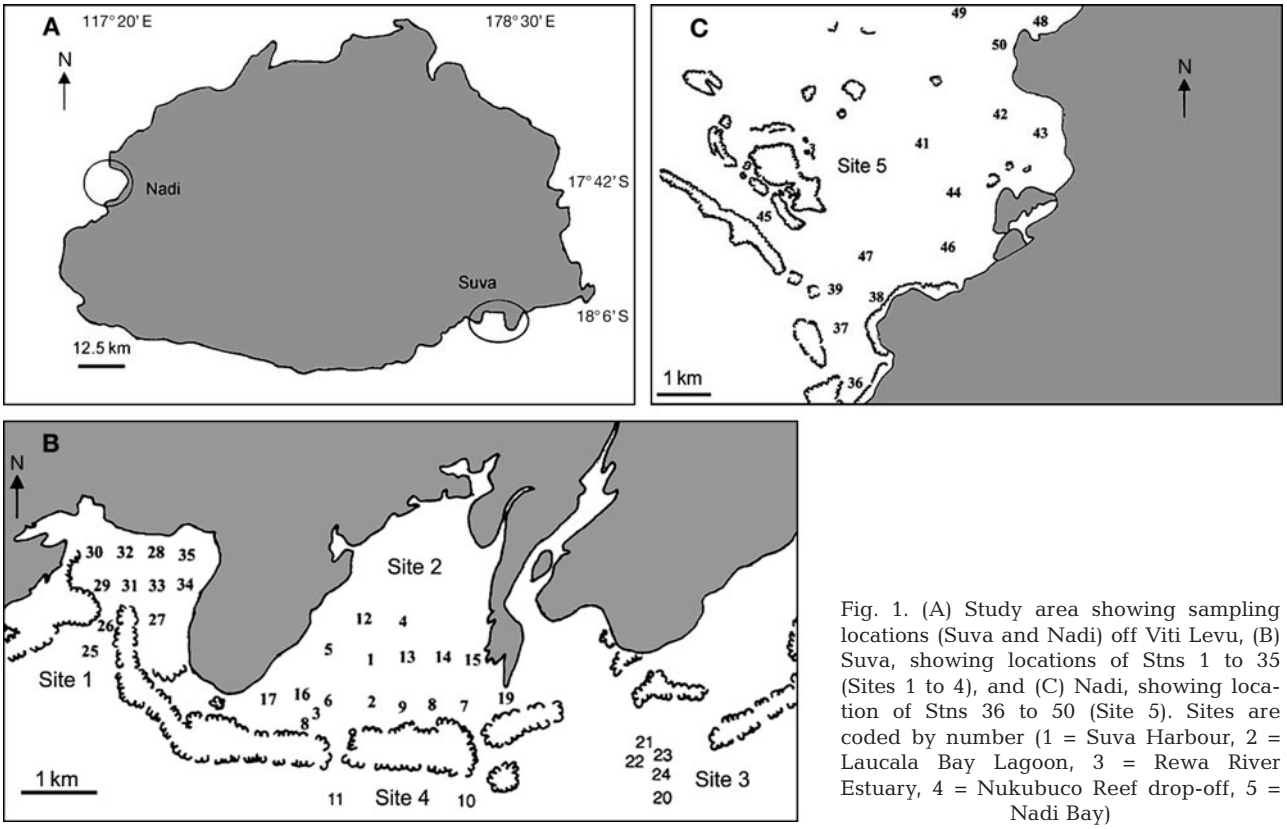

Fig. 1. (A) Study area showing sampling locations (Suva and Nadi) off Viti Levu, (B) Suva, showing locations of Stns 1 to 35 (Sites 1 to 4), and (C) Nadi, showing location of Stns 36 to 50 (Site 5). Sites are coded by number (1 = Suva Harbour, 2 = Laucala Bay Lagoon, 3 = Rewa River Estuary, 4 = Nukubuco Reef drop-off, 5 = Nadi Bay)

was fixed with 4% formaldehyde and stained with concentrated Rose Bengal. In the laboratory, the faunal samples were rinsed in tap water, the fauna picked out, sorted to major taxa and stored in 70% isopropanol. Identifications of benthos were carried out to the lowest taxonomic unit possible, followed by enumeration. Samples were deposited in the collections of Australian Museum (Australia), IRD (Institut de Recherche pour le Développement, New Caledonia) and Marine Studies Programme (Fiji).

A separate grab sample was collected at each station for sediment analysis. The sedimentary properties analysed included grain size, silt and clay fraction, organic matter content and carbonate/terrigenous material. Grain size fractions were obtained by dry sieving through a stack of sieves ranging from 2 to 0.063 mm pore sizes. The weight retained on each sieve was recorded as a percentage. Size analysis of naturally occurring fine sediments (silt/clay content) was achieved using the pipette method (Day 1965). This technique relies on the fact that particles in a dilute suspension settle through a column of water at velocities dependent upon their size (Folk 1974). Organic contents of the sediments were obtained by combustion of samples at high temperatures (550°C). The weight change on combustion measures the organic content, and presence of carbonate and terrigenous materials present were calculated from the basaltic content of the sediments. Sediment was added to 4% HCl then rinsed and washed through after 12 h. The fraction of sediment that dissolved was classified as carbonate material, and the remaining fraction as terrigenous.

Data analysis. Univariate and multivariate analyses of data were performed using the PRIMER (Plymouth Routines in Multivariate Ecological Research) suite of programmes (Clarke & Warwick 1994). Statistical analysis used was similar to that of Moyer et. al (2003).

Fauna data were entered into a square matrix (species × station) and a 4th-root transformation was performed to lessen the weighting of the dominant species and increase the weighting of rare species. A logarithmic transformation was used to normalize relative abundance data. A triangular matrix of similarity coefficients was constructed from sample pairwise similarities (Bray-Curtis coefficient); the matrix was subjected to clustering and ordination analyses. Clustering was by a hierarchical agglomerative method resulting in a dendrogram, while ordination was by non-metric multidimensional scaling (MDS). In the 2-dimensional ordinations generated by MDS analysis, highly similar stations appear closer together than stations with lower rank similarities.

Analyses of similarity (ANOSIM: Clarke & Green 1988) were used for testing statisitical significance of sample groupings. The test statistic *R* indicates some degree of discrimination between stations. When *R* differs significantly from 0 and tends towards 1, intra-site similarity is greater than inter-site similarity. SIMPER (non-metric similarity of percentages) analysis (Clarke & Warwick 2001) was performed to calculate the degree of similarity between sites. Species contributing most to the similarity and dissimilarity of the groups were identified by this test.

Diversity indices, including Margalef's species richness index (d), Pielou's evenness coefficient (J'), and the Shannon-Wiener diversity coefficient (H'), were calculated from pooled and untransformed faunal data sets. Although species richness is a natural measure of biodiversity, observed richness based on species counts over limited time periods often underestimates actual richness (Smith & van Belle 1984). Species accumulation and rarefaction curves were calculated with the EstimateS 5 programme (Colwell 1999), which computes randomised species accumulation curves. The relationships between patterns in multivariate community structure and combinations of environmental variables were examined using the BIO-ENV procedure (Clarke & Ainsworth 1993). This procedure calculates rank correlation between a similarity matrix derived from biotic data and matrices derived from various subsets of environmental variables, thereby defining suites of variables most closely correlated with the observed biotic structure. Range size (number of sites occupied by a single species) was calculated and species restricted to a single site were labelled 'uniques' (Schlacher et al. 1998).

RESULTS

Community properties

A total of 13 128 individuals and 230 species (Table 1) were recorded, comprising 89 species of polychaetes (38.7%), 84 species of crustaceans (36.5%), 50 species of molluscs (21.7%) and 7 species of echinoderms (3.1%). Distributional ranges of soft sediment taxa were compressed. No single species occurred in all 50 stations (Fig. 2) and 20% of the species were restricted to 1 station. Conversely 81 species (35%) were restricted to single sites ('uniques'), highlighting some degree of spot endemism in the community. The long 'tail' on the abundance-rank relationship suggests the presence of rare species (Fig. 3). Of these 81 'unique' species, 34.6% were molluscs, 32.1% polychaetes, 28.4% crustaceans and 4.9% were echinoderms. Cluster (Fig. 4A) and MDS (Fig. 4B) analysis of faunal data revealed 3

Table 1. List of species, total number of individuals collected and number of stations at which each species was found

Species identified	No. of ind. collected	No. of stations
Cossura sp.	1724	43
Notomastus sp. 2	765	38
Aglaophamus sp.	677	45
Ampelisca melanesiensis	665	31
Cymadusa sp.	492	32
Spionidae sp. 1	450	40
Piromis sp.	438	39
Aricidea sp.	423	39
Capitella sp.	395	39
Notomastus sp. 1	309	37
Ampharetidae sp.	267	38
Magelona sp.	265	31
Sternaspis sp.	251	27
Ancistrosyllis sp.	243	37
Wildus parathambaroo	214	21
Spionidae sp. 2	204	38
Paralacydonia sp.	182	26
Mactridae sp. 1	170	22
Mediomastus sp.	156	34
Scoloplos (S) sp.	135	23
Photis pirloti	130	18
Cerapus sp.	120	3
Pilargis sp.	119	28
Elasmopus sp.	118	16
Horstileanira sp.	112	34
Ostracoda sp. 3	111	12
Ostracoda sp. 1	109	14
Cumacea sp. 1	104	12
Tanaidacea sp. 1	98	13
Caulleriella sp. 2	89	23
Cirolana sp. 1	89	24
Cirriformia sp.	89	25
Tellina sp. 2	87	26
Harpacticoida sp.	83	19
Caulleriella sp.1	79	21
Tellina sp. 1	78	14
Leucothoe cf. *diemenensis*	75	17
Scoloplos sp.	75	22
Veneridae sp. 1	72	14
Terebellides sp.	67	20
Mesochaetopterus sp.	63	21
Thalassina sp. 1	63	21
Sabellidae	62	12
Monoliropus sp.	60	23
Glycera sp. 1	59	9
Lumbrinerides sp.	58	17
Unknown sp. 1	55	7
Elaphognathia sp. 1	57	18
Spionidae sp. 5	54	9
Amphipholis squamata	52	24
Ceratonereis sp.	48	16
Schistomeringos sp.	48	11
Spionidae sp. 4	46	14
Pagurus sp. 1	46	14
Tellina sp. 3	46	13
Scyphoproctus sp.	45	14
Lucinidae	44	18
Armandia sp.	42	8

Table 1 (continued)

Species identified	No. of ind. collected	No. of station
Photis kepapa	40	9
Loimia sp.	39	10
Cirolana sp. 2	39	12
Protella cf. *similis*	39	9
Cardiidae sp. 4	38	11
Macrophthalmus (*Venitus*) *latreillei*	35	18
Amphilocus sp.	35	10
Ophiactis savignyi	34	18
Maldanidae	33	12
Glycera sp. 2	32	9
Typhlocarcinops sp. 1	32	16
Goniada sp.	31	12
Spionidae sp. 6	31	7
Spionidae sp. 15	31	1
Cumacea sp. 2	31	6
Ostracoda sp. 2	32	12
Marphysa sp.	28	10
Spionidae sp. 7	30	3
Processa sp. 1	28	12
Diogenes sp. 1	28	13
Spionidae sp. 9	27	9
Spionidae sp. 11	27	3
Anthuridea	26	8
Macrophthalmus sp. 2	25	15
Paracaprella sp.	25	10
Polycirrus sp.	24	7
Onuphis sp.	23	2
Hexapus sp. 1	22	10
Macrophthalmus sp. 1	22	11
Macrophthalmus dentatus	22	11
Laonome sp.	21	10
Polynoidea sp.1	21	6
Anadara sp. 1	21	8
Sabellastarte sp.	20	8
Typhlocarcinus nudus	20	12
Gitana sp.	20	5
Bulla sp. 1	19	9
Nassarius concinnus	19	10
Harmothoe sp.	18	10
Phyllodocidae	18	11
Phyllodoce sp.	18	15
Pseudeurythoe sp.	17	6
Poecilochaetus sp.	17	8
Athanas nitescens	17	8
Cumacea sp. 3	17	6
Pseudoprotomima sp.	17	7
Leptosquilla schmeltzii	16	8
Leucothoe gaviata	16	8
Ophionereis variegate	16	11
Leptochela sp. 1	15	6
Alpheus sp. 1	15	8
Alpheus longichaelis	15	8
Alpheus chacei	15	6
Parambasia cf. *nui*	15	5
Syllis sp. 1	14	5
Syllis sp. 2	14	6
Unknown sp. 5	14	4
Typhlocarcinus sp. 1	14	16

Species identified	No.of ind. collected	No. of station
Syllidae	13	7
Tanaidacea sp. 2	13	6
Haplosyllis sp.	11	7
Bullidae sp. 2	11	7
Mussels	11	6
Natica sp. 1	11	9
Rissoidea	11	5
Genetyllis sp.	10	5
Trypanosyllis sp.	10	6
Spionidae sp. 3	10	6
Leander capensis	10	6
Periclemenes sp. 1	10	5
Nassarius venustus	10	4
Hesionella sp.	9	7
Spionidae sp. 10	9	6
Hexapus sexpes	9	5
Typhlocarcinus stephensis	9	6
Thalamita sp. 1	8	4
Spionidae sp. 13	7	2
Arcania quinquespionsa	7	4
Chloridina microphthalma	7	3
Socarnopsis sp.	7	4
Cominella sp. 1	7	4
Turbo sp. 2	7	3
Polyophthalmus sp.	6	2
Unknown sp. 4	6	2
Hexapus sp. 2	6	5
Amphithoe sp.	6	2
Eusiridae	6	4
Cardiidae sp. 1	6	3
Polynoidea sp. 2	5	6
Spionidae sp. 12	5	5
Thalamita sexlobata	5	2
Portunus (*Xiphonectus*) *hastatoides*	5	4
Portunus sp. 1	5	4
Oratosquillina gravieri	5	2
Cyclopoida sp.	5	3
Cardiidae sp. 2	5	3
Cerithium sp.	5	3
Turritella sp. 1	5	3
Vexillum sp. 1	5	2
Turridae sp. 1	5	5
Arabella sp.	4	3
Serpulidae	4	3
Spionidae sp. 8	4	1
Unknown sp. 6	4	1
Lybistes paucidentus	4	3
Podophthalmus vigil	4	3
Tetrias fisheri	4	4
Parapasiphae sp. 1	4	3
Callianassa sp. 1	4	1
Podoceruscrenulates	4	2
Mitre sp. 1	4	3
Mitre sp. 2	4	1
Turbo sp. 1	4	3
Eurythoe sp.	3	2
Owenia sp.	3	1
Scalibregmidae	3	3

Table 1 (continued)

Species identified	No. of ind. collected	No. of station
Spionidae sp. 21	3	3
Serolia sp. 2	3	1
Gitanopsis sp.	3	2
Cardiidae sp. 3	3	2
Marginella sp. 1	3	3
Myacea sp. 1	3	2
Natica sp. 2	3	3
Nematonereis sp.	2	2
Spionidae sp. 14	2	1
Spionidae sp. 18	2	2
Spionidae sp. 22	2	2
Unknown sp. 2	2	2
Unknown sp. 3	2	1
Portunus sp. 2	2	2
Paranamixis sp.	2	1
Nebalia sp.	2	1
Arcidae sp. 1	2	2
Arcidae sp. 2	2	2
Atys sp. 2	2	1
Bullidae sp. 3	2	1
Olividae sp. 2	2	2
Tellina sp. 4	2	1
Pectinidae sp. 1	2	1
Mytilidae sp. 1	2	1
Epitonidae sp.	2	1
Maretia planulata	2	1
Streptosyllis sp.	1	3
Spionidae sp. 16	1	1
Spionidae sp. 17	1	1
Spionidae sp. 19	1	1
Spionidae sp. 20	1	1
Spionidae sp. 23	1	1
Iphiculus spongiosus	1	1
Nursilia sp.	1	1
Parthenope (*Rhino-lambrus*) sp. 1	1	1
Thalamita sp. 2	1	1
Thalamita spinifera	1	1
Crangon sp. 1	1	1
Galathea sp. 1	1	1
Serolia sp. 1	1	1
Isopoda sp.	1	1
Sabidae sp.	1	1
Acteon sp. 1	1	1
Atys sp. 1	1	1
Collumbellidae sp. 1	1	1
Fasciolaridae sp. 1	1	1
Fasciolaridae sp. 2	1	1
Nassarius sp. 1	1	1
Pectinidae sp. 2	1	1
Pyramidellidae sp. 1	1	1
Pyramidellidae sp. 2	1	1
Solecurtidae	1	1
Cardiidae sp. 5	1	1
Clypeaster reticulatus	1	1
Fibularia ovulum	1	1
Echinoneus cyclostomus	1	1

distinct groupings. Sites 1 and 2 formed one cluster, Site 3 formed a second cluster and a third cluster comprised Sites 4 and 5. Principal component analysis (PCA) ordination of environmental variables superimposed on faunal data also showed 3 major clusters. Sites 1, 2 and 3 form one cluster, Site 4 forms a second cluster and Site 5 forms a third cluster (Fig. 5). A mean density of 273.5 ind. m^{-2} was recorded. Mean densities were similar in Sites 1 and 2 (609 to 781 m^{-2}), high in Sites 3 and 5 (1040.8 to 1548.6 m^{-2}) and lowest in Site 4 (226.6 m^{-2}). Average values for the taxa, numbers of species and individuals are presented in Table 2. Mean species diversity H' varied from 2.41 to 3.26. Species causing similarities and dissimilarities within and between sites are shown in Table 3.

Sampling effort was taken into account when comparing species richness. Differences in the richness and relative abundances of species in the communities sampled are shown by differences in the shapes of the species accumulation and rarefaction curves. Since the number of species in any community is finite, a species accumulation curve that reaches an asymptote indicates that no additional species are to be found. Projections from the species accumulation curves (Fig. 6) all extrapolate the total richness at the study site to over 250 species: 251 (Bootstrap), 277 (Jackknife 1) and 302 (Jackknife 2). Accumulation (Fig. 7) and rarefaction curves (Fig. 8) do not reach asymptotes, suggesting inadequate sampling. The more concave-downward the curve, the better sampled the community, confirming that Site 4 (Nukubuco Reef) was the most under-sampled.

Site 1: Suva Harbour

A total of 2010 individuals and 113 species at a mean density of 609 ind. m^{-2} were recorded in Site 1 (Table 2). Of the taxa collected, 14 (17.3%) were 'uniues'. Polychaetes were the dominant group comprising 49% (55) of the population, followed by crustaceans (31%, 35), molluscs (17%, 19) and echinoderms (3%, 4) (Table 4). Highest species counts were recorded at stations in close proximity to the shore and within the channel. Lowest abundances were recorded at stations outside the passages. Diversity measures in Site 1 (Table 5) showed that Stn 25 had the lowest species richness (d), while Stn 26 had the highest. Species diversity (H') was lowest at Stn 34 and greatest at Stn 26. Mean species diversity was 3.19. The ANOSIM of Site 1 (Table 6) showed no significant differences between Sites 2 and 5 (R = 0.242, p = 0.3% and R = 0.434, p = 0.1% respectively), but did not show significant difference between Sites 3 and 4 (R = 0.565, p = 0.2% and R = 0.828, p = 1.3%,

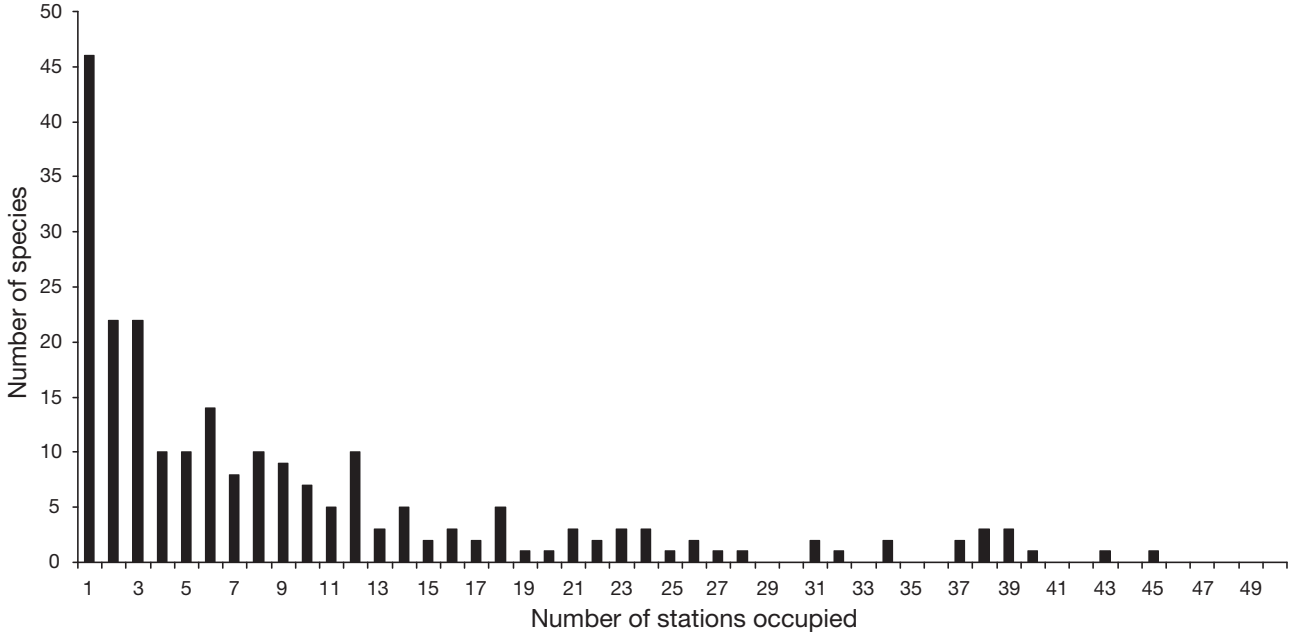

Fig. 2. Frequency distribution of species occurrences across stations. Range size is the number of stations occupied by a species out of a total of 50 stations

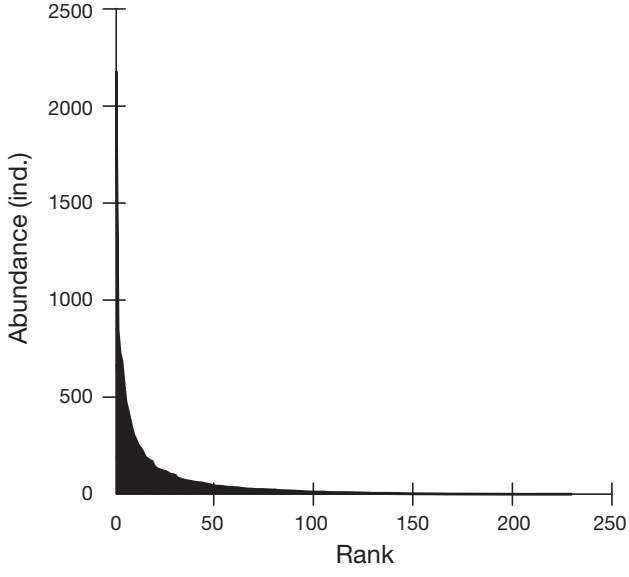

Fig. 3. Rank-abundance plot (log abundance [no. of individuals] against rank [species sequence]). Plot based on 230 species that are ranked so that the most common species are on the left

respectively). SIMPER analysis showed that at Site 1 the polychaetes *Aglaophamus* sp. and *Paralacydonia* sp. contributed most to within group similarity (16.9 and 10.6% respectively), along with *Piromis* sp.(9.9%), Spionidae sp. 1 (7.8%) and *Notomastus* sp. 2 (7.2%, Table 3).

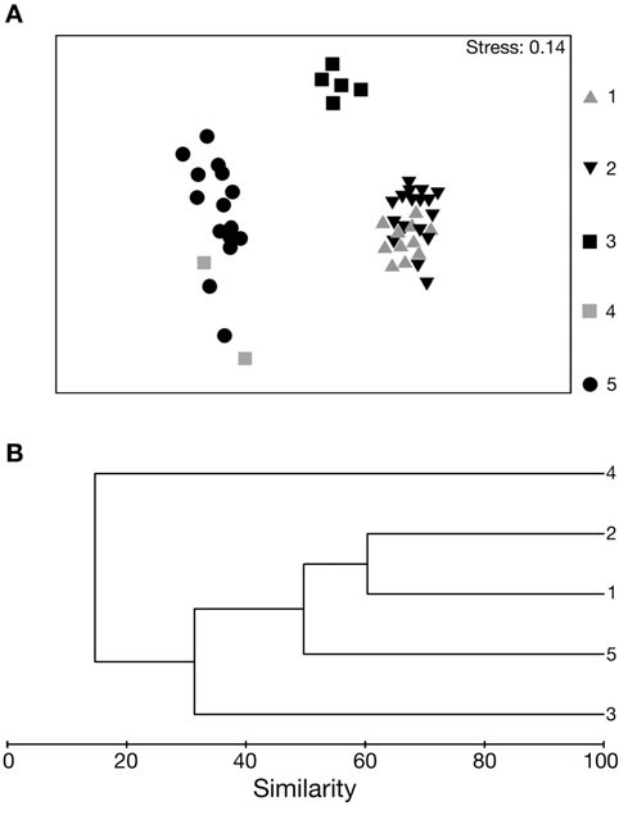

Fig. 4. (A) MDS plot and (B) dendrogram of all sites based on the Bray-Curtis similarity index. Sites are coded 1 to 5 (see Fig. 1)

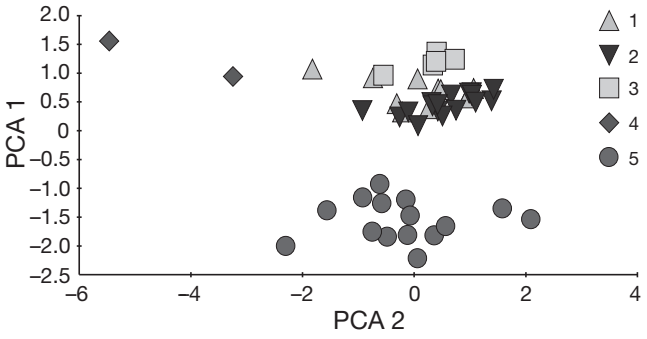

Fig. 5. PCA (principal component analysis) ordination of faunal data superimposed with environmental factors (depth, distance from reef and river, sand content) that contribute most to similarities in community structure between sites. Sites are coded 1 to 5 (see Fig. 1)

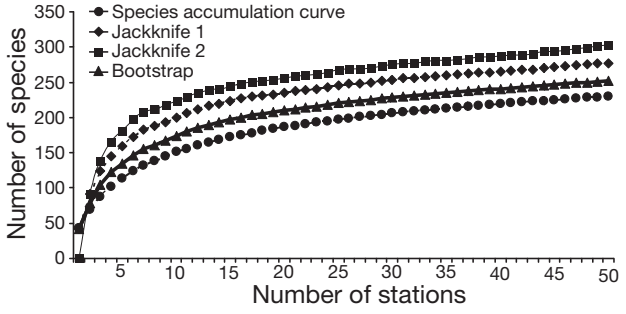

Fig. 6. Species accumulation curves based on EstimateS 5 (Colwell 1999)

Site 2: Laucala Bay Lagoon

A total of 3985 individuals belonging to 138 species at a mean density of 781 ind. m^{-2} was recorded in Site 2 (Table 2). Nineteen (23.5%) 'uniques' were recorded in this site. Crustaceans were the dominant group comprising 46% (63) of the population, followed by polychaetes (40%, 55), molluscs (12%, 17) and echinoderms (2%, 3) (Table 4). Stations closer to the shore had greater abundances than those further from shore. Lowest abundance was recorded in the middle of the lagoon. Stn 1 had the lowest species richness (*d*), while Stn 17 had the highest. Lowest species diversity (*H'*) was recorded at Stn 14 and greatest at Stn 17. Mean species diversity (*H'*) was 3.06. The ANOSIM of Site 2 (Table 6) showed no significant differences from Sites 1, 3 and 5 ($R = 0.242$, p = 0.3%; $R = 0.159$, p = 17.1% and $R = 0.434$, p = 0.1%, respectively), but did show a significant difference from Site 4 ($R = 0.828$, p = 1.3%). SIMPER analysis (Table 3) indicated that at Site 2 the polychaetes *Notomastus* sp. 2 and *Piromis* sp. made the largest contribution to the group similarities (11.4 and 10.1%, respectively), followed by Spionidae sp. 1 (8.4%), *Aricidea* sp. (8.3%), *Ampelisca melanesiensis* (7.2%) and *Notomastus* sp. 1 (6.1%).

Site 3: Rewa River Estuary

Seventy species and 2323 individuals were recorded at Site 3 (Table 2). The mean density was 1548.6 ind. m^{-2}. Polychaetes were the dominant taxa (55%, 39),

Table 2. Principal environmental and biological characteristics of the 5 sites (mean values for each site and for all stations). See Fig. 1 for sites; n = no. of stations

	Site					All sites
	1 (n = 11)	2 (n = 17)	3 (n = 5)	4 (n = 2)	5 (n = 15)	(n = 50)
Environmental parameters						
Depth (m)	45.4	18.9	29.4	168	22.5	31.08
Percent gravel (>1 mm)	6.29	1.49	0.58	57.3	6.87	14.51
Percent sand (0.125–1 mm)	31.89	29.74	6.90	35.30	38.19	28.40
Percent silt (0.63 µm)	43.29	50.18	79.72	6.17	46.26	45.12
Percent clay (<0.63 µm)	12.29	18.50	21.89	1.15	9.09	12.58
Organic content (%)	11.18	14.88	10.14	6.70	7.37	10.05
Biological parameters						
No. ind. m^{-2}	609	781	1548.6	226.6	1040.8	273.5
No. of species	42.27	49.17	36.4	16	49.46	44.66
Species diversity (*H'*)	3.19	3.06	2.41	2.48	3.26	3.06
Evenness (*J'*)	0.86	0.82	0.66	0.93	0.88	0.84
No. of polychaetes	5.0	3.23	7.6	8.5	4.47	1.78
No. of crustaceans	3.18	3.71	4.2	2.0	4.2	1.68
No. of molluscs	1.82	1.0	1.6	0	2.4	1.0
No. of echinoderms	0.27	0.17	0.6	0	0.33	0.14

Table 3. Species causing similarities within groups and dissimilarities between groups (Bray Curtis similarity indices). Species that contribute towards 50% of cumulative data (Cum. %) are listed in descending order of their percent contributions (Cont. %). Average similarities and dissimilarities (%) are given in parentheses. See Fig. 1 for site locations

Site	Species	Cont. (%)	Cum. (%)
1: Suva Harbour			
(Average similarity: 42.56)			
	Aglaophamus sp.	16.99	16.99
	Paralacydonia sp.	10.65	27.64
	Piromis sp.	9.95	37.59
	Spionidae sp. 1	7.78	45.37
	Notomastus sp. 2	7.17	52.54
2: Laucala Bay			
(Average similarity: 32.97)			
	Notomastus sp. 2	11.36	11.36
	Piromis sp.	10.08	21.44
	Spionidae sp. 1	8.44	29.87
	Aricidea sp.	8.29	38.17
	Ampelisca melanesiensis	7.20	45.37
	Notomastus sp. 1	6.14	51.51
3: Rewa River			
(Average similarity: 34.40)			
	Cossura sp.	27.81	27.81
	Capitella sp.	11.74	39.55
	Aglaophamus sp.	11.20	50.74
4: Fore-Reef			
(Average similarity: 47.06)			
	Wildus parathambaroo	21.88	21.88
	Ampelisca melanesiensis	21.88	43.75
	Notomastus sp. 2	15.63	59.38
5: Nadi Bay			
(Average similarity: 23.96)			
	Cymadusa sp.	13.31	13.31
	Horstileanira sp.	8.51	21.83
	Magelona sp.	7.58	29.41
	Spionidae sp. 1	6.16	35.57
	Spionidae sp. 2	5.38	40.95
	Ampelisca melanesiensis	4.45	45.40
	Thalassina sp. *1*	4.30	49.70
	Sternaspis sp.	3.58	53.28
1 & 2: Suva Harbour & Laucala Bay			
(Average dissimilarity = 69.47)			
	Notomastus sp. 2	8.31	8.31
	Ampelisca melanesiensis	5.06	13.37
	Aglaophamus sp.	4.72	18.09
	Paralacydonia sp.	4.31	22.40
	Cossura sp.	4.24	26.63
	Spionidae sp. 1	4.12	30.76
	Notomastus sp. 1	3.09	33.85
	Capitella sp.	2.92	36.76
	Piromis sp.	2.83	39.60
	Aricidea sp.	2.83	42.42
	Cymadusa sp.	2.32	44.74
	Ampharetidae sp.	2.12	46.86
	Spionidae sp. 2	2.04	48.90
	Ancistrosyllis sp.	2.00	50.90
1 & 3: Suva Harbour & Rewa River			
(Average dissimilarity = 75.73)			
	Cossura sp.	30.14	30.14
	Cerapus sp.	6.11	36.25
	Notomastus sp. 2	4.63	40.88
	Capitella sp.	4.27	45.15
	Aricidea sp.	3.67	48.82
	Paralacydonia sp.	2.80	51.62
2 & 3: Laucala Bay & Rewa River			
(Average dissimilarity = 74.27)			
	Cossura sp. 0	29.46	29.46
	Notomastus sp. 2	6.60	36.06
	Cerapus sp.	5.81	41.87
	Capitella sp.	3.58	45.45
	Aricidea sp.	3.57	49.02
	Aglaophamus sp.	3.08	52.10
2 & 4: Laucala Bay & Fore-Reef			
(Average dissimilarity = 78.57)			
	Aglaophamus sp	6.51	6.51
	Paralacydonia sp.	5.91	12.43
	Piromis sp.	5.56	17.98
	Spionidae sp. 1	5.12	23.10
	Ampelisca melanesiensis	4.67	27.77
	Cossura sp.	4.31	32.08
	Wildus parathambaroo	4.11	36.19
	Aricidea sp.	4.05	40.23
	Ampharetidae sp.	2.79	43.03
	Spionidae sp. 2	2.52	45.55
	Anthuridea	2.38	47.93
	Notomastus sp. 2	2.34	50.28
1 & 4: Suva Harbour & Fore-Reef			
(Average dissimilarity = 77.57)			
	Notomastus sp. 2	10.09	10.09
	Ampelisca melanesiensis	6.21	16.30
	Piromis sp.	5.15	21.45
	Spionidae sp. 1	4.68	26.13
	Aricidea sp.	4.19	30.32
	Notomastus sp. 1	4.14	34.46
	Capitella sp.	3.78	38.25
	Wildus parathambaroo	3.42	41.67
	Cossura sp.	2.92	44.59
	Cymadusa sp.	2.84	47.44
	Ancistrosyllis sp.	2.39	49.83
	Anthuridea	2.07	51.89
3 & 4: Rewa River & Fore-Reef			
(Average dissimilarity = 86.65)			
	Cossura sp.	32.16	32.16
	Cerapus sp.	6.90	39.06
	Capitella sp.	5.75	44.81
	Notomastus sp. 2	5.35	50.16
1 & 5: Suva Harbour & Nadi Bay			
(Average dissimilarity = 80.80)			
	Aglaophamus sp.	6.33	6.33
	Cymadusa sp.	4.37	10.69
	Cossura sp.	4.30	15.00
	Paralacydonia sp.	4.24	19.24
	Ampelisca melanesiensis	3.61	22.85
	Piromis sp.	3.58	26.42

Table 3 (continued)

Site	Species	Cont. (%)	Cum. (%)
	Spionidae sp. 1	3.56	29.99
	Aricidea sp.	2.80	32.78
	Magelona sp.	2.52	35.31
	Notomastus sp. 2	2.46	37.77
	Sternaspis sp.	2.34	40.10
	Ampharetidae sp.	2.29	42.39
	Thalassina sp. 1	1.66	44.05
	Spionidae sp. 2	1.63	45.68
	Mactridae sp. 1	1.56	47.25
	Horstileanira sp.	1.53	48.78
	Capitella sp.	1.36	50.14
2 & 5: Laucala Bay & Nadi Bay			
(Average dissimilarity = 78.69)			
	Notomastus sp. 2	7.42	7.42
	Ampelisca melanesiensis	5.66	13.08
	Cymadusa sp.	4.20	17.27
	Cossura sp.	3.52	20.80
	Piromis sp.	3.36	24.16
	Spionidae sp. 1	3.08	27.24
	Aglaophamus sp.	3.06	30.30
	Aricidea sp.	3.02	33.32
	Notomastus sp. 1	2.90	36.22
	Capitella sp.	2.69	38.92
	Magelona sp.	2.63	41.54
	Wildus parathambaroo	2.08	43.63
	Ampharetidae sp.	2.01	45.64
	Sternaspis sp.	1.88	47.52
	Ancistrosyllis sp.	1.82	49.35
	Thalassina sp. 1	1.58	50.93
3 & 5: Rewa River & Nadi Bay			
(Average dissimilarity = 83.96)			
	Cossura sp.	26.67	26.67
	Cerapus sp.	5.27	31.93
	Notomastus sp. 2	4.53	36.46
	Aglaophamus sp.	4.24	40.70
	Capitella sp.	3.74	44.44
	Aricidea sp.	3.00	47.44
	Cymadusa sp.	2.84	50.28
4 & 5: Fore-Reef & Nadi Bay			
(Average dissimilarity = 84.86)			
	Cymadusa sp.	6.03	6.03
	Ampelisca melanesiensis	6.01	12.04
	Magelona sp.	3.48	15.52
	Wildus parathambaroo	3.48	19.00
	Spionidae sp. 1	3.26	22.26
	Aglaophamus sp.	3.22	25.49
	Cossura sp.	3.12	28.61
	Horstileanira sp.	2.64	31.25
	Sternaspis sp.	2.60	33.85
	Thalassina sp. 1	2.54	36.39
	Notomastus sp. 2	2.53	38.92
	Anthuridea	2.28	41.20
	Spionidae sp. 2	2.02	43.22
	Ampharetidae sp.	1.92	45.14
	Tanaidacea sp. 1	1.63	46.77
	Capitella sp.	1.58	48.35
	Elasmopus sp.	1.57	49.92
	Piromis sp.	1.57	51.49

followed by crustaceans (30%, 21), molluscs (11%, 7) and echinoderms (4%, 3). Of the species collected, 7.4% were 'uniques'. Low species counts were recorded at this site. Stn 23 had the lowest species richness (d) and species diversity (H'), and Stn 20 had the highest d and H' (Table 5). Mean H' was 2.41. The ANOSIM of Site 3 (Table 6) showed significant difference from Sites 1 and 4 (R = 0.565, p = 0.2% and R = 0.691, p = 4.8%), but no significant differences from Sites 2 and 5 (R = 0.645, p = 2.9% and R = 0.181, p = 9.6%, respectively). SIMPER analysis showed that at Site 3 the polychaetes *Cossura* sp., *Capitella* sp. and *Aglaophamus* sp. made the largest contribution to group similarity (27.8, 11.7 and 11.2%, respectively, Table 3).

Site 4: Nukubuco Reef drop-off

A total of 21 species and 136 individuals were recorded at Site 4. The mean density was 226.6 ind. m^{-2}. Polychaeta was the dominant taxonomic group (81%, 17), followed by crustaceans (19%, 4). No other groups or 'uniques' were recorded in this Site (Table 2). The lowest species count was recorded at Site 4. Abundances increased from east to west. Low d and H' were recorded at Stn 10, and greatest d and H' occurred at Stn 11 (Table 5). Mean species diversity was 2.48. ANOSIM results (Table 6) showed significant differences from all other sites (Site 1: R = 0.828, p = 1.3%; Site 2: R = 0.645, p = 2.9%; Site 3: R = 0.691, p = 4.8% and Site 5: R = 0.563, p = 1.5%). SIMPER analysis showed the Amphipods (Crustacea) *Wildus parathambaroo* and *Ampelisca melanesiensis* contributing the highest proportions to within group similarity (21.9% each), followed by the polychaete *Notomastus* sp. 2 (15.6%, Table 3).

Site 5: Nadi Bay

A total of 170 species of benthic fauna and 4684 individuals were recorded at Site 5 (Table 2), with 42 (52%) of the species being 'uniques'. The mean density was 1040.8 ind. m^{-2}. Polychaetes were the dominant group (39%, 66) followed by crustaceans (37%, 63). Molluscs and echinoderms made up the remaining 21% (36) and 3% (5) of the population, respectively (Table 4). Greatest species counts were recorded at this site, with highest numbers occurring at stations furthest from the shore. Diversity measures (Table 5) indicated low species richness (d) and diversity (H') at Stn 39. Greatest d and H' were recorded at Stn 40. A mean species diversity of 3.26 was recorded. The ANOSIM (Table 6) indicated no significant difference

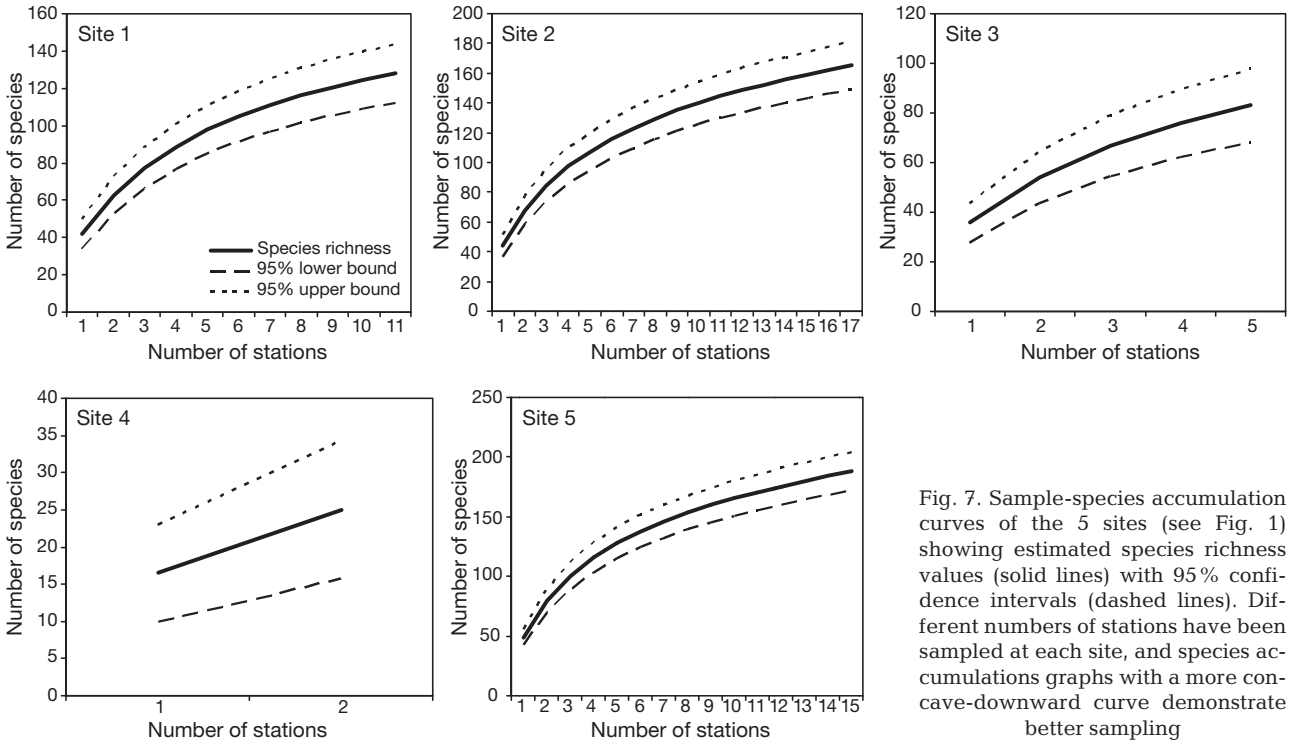

Fig. 7. Sample-species accumulation curves of the 5 sites (see Fig. 1) showing estimated species richness values (solid lines) with 95% confidence intervals (dashed lines). Different numbers of stations have been sampled at each site, and species accumulations graphs with a more concave-downward curve demonstrate better sampling

from Sites 1 (R = 0.434, p = 0.1%), 2 (R = 0.321, p = 0.1%) and 3 (R = 0.181, p = 9.6%), but did show significant difference from Site 4 (R = 0.563, p = 1.5%). SIMPER analysis (Table 3) revealed that largest contribution to within group similarity was made by the crustacean *Cymadusa* sp. (13.3%), followed by the polychaetes *Horstileanira* sp. (8.5%) and *Magelona* sp. (7.6%).

Environmental factors

Site 1: Suva Harbour

Across all stations sampled at this site, the predominant grain size was 63 µm (Fig. 9, Table 2). Stations situated within the reef passage at Site 1 had an abundance of poorly sorted, silty particles. The greatest amount of silt recorded at this site was 83.5%, while the lowest was 46.9%. Water depth increased from the north (close to the shore) to the reef. The deepest station was 113 m and the shallowest was 14 m. Carbonate content increased with depth. The highest percentage of carbonate content was 81.8%, while the lowest value was 25.0%. Greatest organic content was recorded at stations closest to the shore and just inside the channel. Values ranged from 5.7 to 15.2%. BIO-ENV analysis revealed that depth, distance from the reef and shoreline, and carbonate content had the greatest correlation (0.552) with the faunal composition.

Site 2: Laucala Bay Lagoon

The commonest grain size fraction was 63 µm (Fig. 9, Table 2). The middle of Laucala Bay lagoon (Site 2) contained poorly sorted sediment, while closer to shore there was a change to moderately sorted sediment. Clay sediment was predominant at 53.0% of the stations located on either side of the channel, and silty sediment was found at the remaining stations in the middle of the lagoon and within the channel. The highest percentage of silt recorded at this site was 68.7%, and the highest percentage of clay was 57.5%. The stations closer to shore were shallower than those located close to the barrier reef. The deepest station at this site was 41 m and the shallowest 13 m. Grain size and carbonate content were directly related to depth measurements. The carbonate values fell between 87.2 and 21.3%. Stations sampled in the centre of the lagoon contained large percentages of organic matter, ranging between 5.8% and 27.7%. Water depth and mean grain size had the highest correlation (0.348) with faunal composition at Site 2 (BIO-ENV analysis).

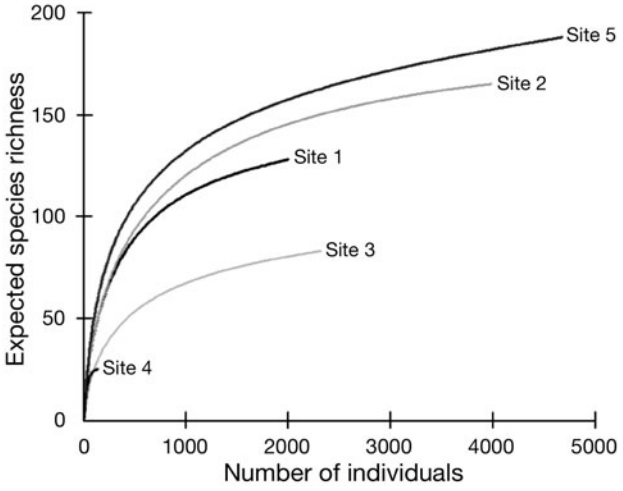

Fig. 8. Rarefaction curves for benthic fauna in the 5 sites (see Fig. 1) around Viti Levu indicating sites where sufficient individuals have been sampled in a community to determine species diversity

Site 3: Rewa River Estuary

The dominant grain size fraction at Site 3 (Rewa River Estuary) was 63 µm (Fig. 9, Table 2), and there were moderate amounts of sorted silty sediment. The highest percentage of silt was 77.8%. Depth increased at stations further away from the shore, with the greatest at 40 m and the shallowest at 24 m. Terrigenous content and organic matter were high at the majority of stations. Terrigenous content ranged from 24.5 to 87.4% while organic content varied from 6.77 to 10.5%. The sediment parameter skewness, with a correlation value of 0.663 best explained the faunal patterns at this site (BIO-ENV analysis).

Site 4: Nukubuco Reef drop-off

The Fore-Reef site situated close to the barrier reef platform contained large percentages of very coarse particles (> 1 mm) that were well sorted (Fig. 9, Table 2). Site 4 sediment largely comprised clay; the highest amount was 82.4%. The deepest stations were sampled at this site (213 and 123 m), and depth increased westwards. Carbonate content followed a similar trend, and values of 96.7 and 93.3% were recorded. The organic content was greatest at the deeper station (7.1%). BIO-ENV analysis was not possible at this site due to the small number of stations sampled.

Site 5: Nadi Bay

Stations at Site 5 contained predominantly fine-grained (63 µm) particles (Fig. 9, Table 2). Poorly sorted and silty sediment was most common, reaching a maximum value of 81.0%. Stations were in general shallower than those on the eastern side of the island. The deepest station was at 39 m, while the shallowest station was at 10 m. Stations sampled within the bay were shallower, and depth increased away from the shore-line. Carbonate content was directly related to depth measurements, while high organic content was recorded at stations closer to the shore. The values for carbonate content were between 98.4 and 27.2%, while organic content ranged from 4.6 to 11.0%. The subset of environmental variables which best 'explained' the faunal patterns included distance from river, organic content and mean grain size (correlation value: 0.560, BIO-ENV)

DISCUSSION

Community structure

The Viti Levu (Fiji) soft sediment fauna was characterised by high biodiversity and large numbers of individuals, the exception being Site 3 (Rewa River Estuary), suggesting an unstable environment. Direct comparison of soft bottom community biodiversity of Viti Levu with those reported from previous studies conducted in the South Pacific is difficult because of the differences in methodology and habitats investigated. The total of 230 species collected in this study was higher than those recorded at the Great Astrolabe Reef, Fiji by Newell & Clavier (1997) (207 taxa) and Schlacher et al (1998) (211 taxa), and along the Great

Table 4. Biological characteristics of the 5 sites (see Fig. 1)

Site	Total no.			No. of species				Total no.
	Stations	Samples	Individuals	Polychaeta	Crustacea	Mollusca	Echinodermata	of spp.
1	11	33	2010	55	35	20	3	113
2	17	51	3985	55	63	17	3	138
3	5	15	2323	38	21	8	3	70
4	2	6	136	17	4	0	0	21
5	15	45	4684	67	63	36	5	171

Barrier Reef, Australia (154 taxa) by Riddle (1988). Frouin & Hutchings (2001), however, collected 315 taxa in Tahitian lagoons and Chardy et al. (1988) recorded 311 taxa in New Caledonian lagoons. We found faunal den-sities of 226 to 1548 ind. m^{-2}. Densities of 3115 to 43 690 ind. m^{-2} (using a 0.5 mm sieve) were recorded on the central Great Barrier Reef (Riddle 1988), 41 to 220 ind. m^{-2} in New Caledonia (Chardy et al. 1988) and 22 to 868 ('large') and 670 to 20 818 ('small') ind. m^{-2} in Tahiti (Frouin & Hutchings 2001). Similar values of 870 to 10 260 ind. m^{-2} were measured in Hawaii (DeFelice & Parrish 2001) and in French Polynesia (496 to 4866 ind. m^{-2}; Thomassin et al. 1982). These figures fall within the range given by Alongi (1989) for the southern Pacific (307 to 16 750 ind. m^{-2}). Neither the species accumulation curves nor the Jackknife 1 and 2 nor bootstrap estimates reached asymptotes, indicating insufficient sampling in our program. A solution would be to increase sampling intensity, but Schlacher et al (1998) and Ellingsen (2002) both agree that with increasing sample size, rare species are continuously added, but those with low abundance would have a low probability of being recorded. Hence, an asymptote would not be reached. On the contrary however, increased sampling and research in invertebrate fauna would highlight more rare and endemic species in Fiji, as shown in New Caledonia. The wealth of inventory and systematic work conducted on the New Caledonian fauna in recent years has revealed high levels of regional endemicity and it is likely a similar trend would be observed in Fiji were a similar research intensity applied.

Common species were widely spatially distributed in Vitl Levu, while species of low abundance had compressed range sizes (Table 1), as shown previously by Schlacher et al (1998) and Ellingsen (2002). This generally observed pattern can be explained by inadequate sampling, which underestimates range sizes. Polychaetes were the most common taxonomic group and had the highest proportion of widely distributed species followed by crustaceans and molluscs. Echinoderms were more restricted in their distributions across the 5 sites. The 'uniques' comprised a significant fraction of the benthos recorded (35%). Similar proportions were found by Schlacher et al. (1998) in the Great

Table 5. Diversity indices for all 50 stations in 5 sites (see Fig. 1). N: total number of individuals, S: total number of species (richness), *H'*: Shannon-Weiner diversity index, *J'*: Pielou's evenness index, *d*: Margalef's richness index

Stn	Site	N	S	*J'*	*H'*	*d*
25	1	104	25	0.89	2.86	5.17
26	1	272	70	0.89	3.78	12.31
27	1	241	39	0.89	3.28	6.93
28	1	171	41	0.87	3.21	7.58
29	1	165	43	0.88	3.31	8.23
30	1	116	33	0.88	3.09	6.73
31	1	181	48	0.87	3.34	8.85
32	1	136	40	0.86	3.15	7.73
33	1	205	48	0.86	3.32	8.64
34	1	225	38	0.77	2.76	6.46
35	1	194	40	0.82	3.02	7.40
1	2	34	15	0.86	2.39	4.25
2	2	116	28	0.82	2.74	5.68
3	2	142	48	0.93	3.59	9.48
4	2	382	51	0.76	2.99	8.24
5	2	277	59	0.83	3.38	10.14
6	2	208	45	0.86	3.27	8.24
7	2	189	54	0.81	3.19	9.54
8	2	269	50	0.84	3.29	8.58
9	2	120	30	0.84	2.82	5.85
12	2	327	46	0.78	2.94	7.43
13	2	251	33	0.67	2.31	5.61
14	2	139	21	0.74	2.29	4.26
15	2	216	38	0.83	3.02	6.88
16	2	317	64	0.86	3.59	10.94
17	2	450	81	0.87	3.82	12.77
18	2	187	42	0.86	3.22	7.84
19	2	361	50	0.83	3.21	7.98
20	3	50	51	0.79	3.10	8.19
21	3	33	35	0.78	2.73	5.65
22	3	38	38	0.79	2.86	6.42
23	3	23	22	0.17	0.53	3.17
24	3	35	36	0.79	2.82	6.04
10	4	8	7	0.90	1.87	1.87
11	4	25	25	0.96	3.10	5.28
36	5	64	64	0.77	3.21	9.43
37	5	70	71	0.89	3.82	12.65
38	5	27	27	0.89	2.93	5.14
39	5	16	16	0.93	2.58	3.47
40	5	108	107	0.83	3.87	14.70
41	5	61	65	0.89	3.65	11.01
42	5	28	29	0.87	2.90	6.09
43	5	28	29	0.89	2.97	5.66
44	5	17	17	0.95	2.69	3.83
45	5	80	82	0.86	3.78	13.16
46	5	32	32	0.89	3.09	6.42
47	5	92	95	0.87	3.92	14.20
48	5	29	29	0.82	2.76	5.92
49	5	52	54	0.94	3.70	10.46
50	5	26	25	0.92	3.01	5.63

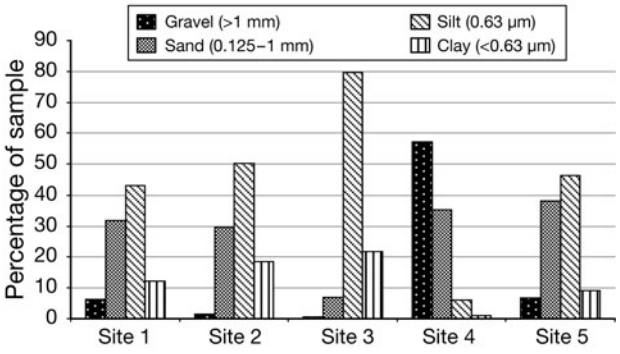

Fig. 9. Relative distributions of sediment particle sizes of gravel, sand, silt or clay at 5 sites (see Fig. 1); bars are averages of stations within sites

Table 6. One-way analysis of similarity (ANOSIM) for all 5 sites. Sample statistic (Global *R*): 0.343

Site location (Site no.)	*R* statistic	Significance level %	Significant difference	Possible permutations	Actual permutations	No. obs.
Suva Harbour (1), Laucala Bay (2)	0.242	0.3	No	21 474 180	999	2
Suva Harbour (1), Rewa River (3)	0.565	0.2	No	4368	999	1
Suva Harbour (1), Fore-Reef (4)	0.828	1.3	No	78	78	1
Suva Harbour (1), Nadi Bay (5)	0.434	0.1	Yes	7 726 160	999	0
Laucala Bay (2), Rewa River (3)	0.159	17.1	No	26 334	999	170
Laucala Bay (2), Fore-Reef (4)	0.645	2.9	No	171	171	5
Laucala Bay (2), Nadi Bay (5)	0.321	0.1	Yes	565 722 720	999	0
Rewa River (3), Fore-Reef (4)	0.691	4.8	No	21	21	1
Rewa River (3), Nadi Bay (5)	0.181	9.6	No	15 504	999	95
Fore-Reef (4), Nadi Bay (5)	0.563	1.5	No	136	136	2

Astrolabe Reef lagoon (Fiji, 42%), by Ellingsen (2001, 2002) off Norway (39%) and Bouchet et al (2002) off new Caledonia (32%), suggesting that high spatial heterogeneity in community structure is a feature of coral reef environments.

Diversity and abundance increased from west to east across the study sites. Species diversity and richness were greatest at Site 5 (west of Viti Levu), and along the coast to the southeast of the island, species diversity and richness decreased. The number of 'uniques' correlated with species richness. Site 5 had the greatest species richness (49.5) and proportion of 'uniques' (52%). The fore-reef area (Site 4) had lowest species richness (16) and no 'uniques'. Likewise low species richness was found in Site 3 (36.4), and 7.4% of the fauna were 'uniques'. These 2 sites are subjected to regular high wave action and large salinity fluctuations. Gray (2002) reported that low species richness occurs in habitats subjected to constantly fluctuating environmental conditions. Ellingsen (2001) also reported that sites with a low proportion of restricted-range species also had low species richness.

Community structure at the 5 sites shows some similarities. In the MDS ordination (Fig. 3), 3 distinct clusters can be seen. The fauna at Site 5 is characterised by high diversity and resembles biologically accommodated communities found in stable environments (Shin & Thompson 1982). Sites 1 and 2 both had very high number of individuals and high diversity. A previous study at these 2 locations similarly found Site 1 more diverse than Site 2 (Corless 1995). Sites 3 and 4 had very low numbers of individuals and low diversities. Khan et al (2004) reported that in a healthy environment, the Shannon diversity index is usually high (2.5 to 3.5). The values for Sites 3 and 4 are lower, suggesting unstable environments. The distinct clusters on the MDS ordination (Fig. 3) are most likely due to the presence and absence of species from the sites. SIMPER analysis (Tables 2) shows species that caused most similarity within sites.

Factors influencing community structure

Granulometric analyses showed slight variations among sites, but the general trends are apparent (Fig. 9). Sediment compositions among Sites 1, 2 and 5 were very similar. Great importance has been placed on soft bottom sediments and sediment grain size as key factor in determining community differences (McIntyre 1969, Driscoll 1975, Hily et al. 1992, Snelgrove & Butman 1994, Frouin 2000). The difference in species richness and diversity between Sites 1, 2 and 5 suggests that sediment grain size did not affect infaunal community structure. The presence of heterogenous faunal communities among stations and sites of similar sediment type is not congruent with a concept of distinct associations between benthic community and sediment types. However the markedly lower species diversity in Site 3 fits the general observation that silt may be a more difficult sediment to colonise and coarser sediments are able to support more life (Gray 1974, Shin & Thompson, 1982).

The fluctuation in available organic matter is thought to be one of the principal causes of faunal change in near-shore benthic environments (Pearson & Rosenberg 1978, Gee & Warwick 1985, Linton & Taghon 2000). However, we found no clear correlation between benthic community structure and organic content. Greater organic contents were recorded at Sites 1, 2 and 3, which may be due to the influence of the Rewa River and the mangroves found along these study sites. Hansen et al. (1992) have reported that detrital particles from seagrass and mangroves may serve as a source of organic matter in lagoons. The degree of lagoon closure, nutrient input rates, mixing rates within the lagoon and the residence time of lagoonal waters at Sites 1, 2 and 3 may be related to the high levels of organic content recorded here. The lack of a barrier reef at Site 5, and the location of Site 4 outside the barrier reef likely

increases nutrient flushing rate, resulting in low organic content.

BIO-ENV showed that depth, distance from reef and river, and sand content (0.397) were most closely related to community structure. Studies have shown (Hutchings & Wells 1993, Glover et al. 2002) that factors like current energy, productivity and terrigenous input become important with increasing depth in determining benthic communities. The clusters formed in the PCA plot (Fig. 4) show 3 groupings. The close proximity of Site 3 to 1 and 2 in the cluster is most probably due to the influence of the Rewa River and tidal regimes experienced by these 3 sites on the southeastern side of the island. This could also explain the distinct separation of Site 5 (which is situated on the western side of the island) from those situated on the southeastern coast. The results show weak relationships between some of the environmental variables and faunal composition. Schlacher et al. (1998) and Frouin & Hutchings (2001) also found no clear relationship between faunal assemblage and environmental variables in a similar coral lagoon, suggesting factors other than those recorded might be influencing community structure. Ellingsen (2002) suggests that in any given locality, a number of interacting factors will be involved in determining its community structure. Vroom et al. (2005) found geological and oceanographic features (distance from reef, islands) lead to spatially variable environmental regimes (water flow, turbidity, temperature). This variability could explain the biological heterogeneity found among the sites.

Local oceanic conditions have been suggested to play a role in observed diversity gradients (Moyer et al. 2003). Site 1 (Suva Harbour) is a shallow embayment with an estuarine-type circulation (Corless 1995). High diversity recorded here could be a result of maximum tidal flushing experienced in this area. Site 2 (Laucala Bay Lagoon) is a large area which lies between the Suva peninsula and Rewa Delta. The bay is protected by coral reefs, which are exposed at low tides, allowing seawater to enter over the reef twice daily during high tide (Naidu et al.1991). Two narrow reef passages on either side of the bay also provide limited circulation. Site 5, which was the most diverse, has a fringing reef that does not enclose the bay and has sporadic patch reefs. These formations allow unobstructed circulation of oceanic water. Although not investigated in this study, the tidal current regime of lagoons around Fiji could help determine if changes in the current in an area would lead to changes in community structure.

Run offs, sewer outfalls, and rivers are likely to increase nutrient availability and sedimentation, which can lead to decreased diversity (Frouin 2000, Moyer et al. 2003). The presence of a sewage outfall in Laucala Bay Lagoon is likely to increase nutrient availability (Naidu et al. 1991, Corless 1995). We found higher levels of organic matter and lower benthic diversity closest to the outfall. Water quality, turbidity, salinity and temperature may play roles in determining community structure. Unfortunately, due to time and economic constraints these parameters could not be recorded for all sites. However, results that were collected show highest salinity and temperature at Site 1 and highest turbidity at Site 3.

CONCLUSION

Benthic communities in the sites around the Fiji lagoons are rich and diverse; species numbers and abundances are within the ranges observed in Australia, New Caledonia and Tahiti. Benthic communities showed spatial variability in abundance and taxonomic richness. The number of 'uniques' were comparable to those found in similar studies, suggesting a degree of 'spot endemism'. The suggestion of Roberts et al. (2002) that biodiversity decreases eastward across the Pacific was not supported, possibly because of inadequate sampling intensity and extent in the past. Fiji has been identified by the scientific community as having significant components of 'Outstanding Universal Value' in its tropical coastal, marine and small island biodiversity; further studies have been recommended to ascertain which components are of World Heritage value (The Hanoi Statement, 2002, available at: http://whc.unesco.org/uploads/events/documents/event-501-1.pdf)

Stations with similar environmental variables did not always have the same community structure. As in other studies (Schlacher et al 1998, Ellingsen 2002, Fonseca & Netto 2006), no single, well-defined relationship was observed between environmental factors and biotic assemblages. It would appear that in any given location a number of different interacting biological and physical factors are involved in determining the distribution and abundance of benthos (Snelgrove & Butman 1994, Frouin 2000, Ellingsen 2002. Further research on other environmental variables (chlorophyll *a*, salinity, temperature, turbidity) is needed in attempting to discern strong relationships between community structure and environment.

With increasing population, urban development and mounting anthropogenic pressures in coastal areas of Fiji, there is an increasing need to understand the mechanisms influencing biodiversity, and to develop conservation strategies. Site 3 had low diversity and dominance of a single species, indicative of a perturbed (organically enriched) environment. Pearson & Rosenberg (1978) and Lee et al. (2006) found that initial organic enrichment results in higher diversity val-

ues, followed subsequently by decreases as organic enrichment continually increases. The lagoons are a vital economic asset to the Fiji islanders and maintaining the biodiversity of the benthic fauna is a crucial part of maintaining this asset. In order to accurately gauge the biodiversity of benthic fauna in Fiji and to maintain native levels of biological diversity, more regular surveys and studies are needed and the results incorporated into a monitoring program to assess the effects of the changing environment.

Acknowledgements. This study was made possible by funding from the French Embassy (Suva, Fiji). We thank P. Newell, B. Richer de Forges, colleagues at IRD (Noumea, New Caledonia) and from the RV 'Alis'. Many thanks also go to T. Schlacher, J. Seeto, and P. Hutchings for their assistance in identification of fauna and data analysis.

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Editorial responsibility: Matthias Seaman, Oldendorf/Luhe, Germany

Submitted: September 3, 2007; Accepted: June 19, 2008
Proofs received from author(s): October 27, 2008