Shoreline Erosion on a Low Coral Island in Fiji - Causes and Consequences

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Abstract

Yanuca Island is a 50 Ha low emerged coral limestone island, located near the south west coast of mainland Fiji in the South Pacific. Developed on the island is an international resort complex. Local Fijian land owners and resort staff provide accounts of shoreline erosion on the island over recent years. An investigation into the processes responsible for this erosion found several influences were important. A comparison of air photos over the last 50 years indicates there has been significant evolution of the coastal geomorphology of Yanuca Island. In the 1980s, sand mining and vegetation clearance led to instability and narrowing of a coastal sand bar at the north end of the island. Along the south coast, current measurements show that there is a strong longshore drift, driven by the persistent southeast trade winds. This is responsible for the removal of beach deposits and the resulting exposure of underlying beachrock. The erosion problem is probably compounded by a reduction in the supply of biogenic sand from adjacent fringing reefs, due to over-fishing and degradation of the reef ecosystems. Tropical cyclones have also caused much coastal erosion in recent years. Finally, a causeway connecting to the eastern side of the island has a dam effect and influences the flow of currents around the island. Consequences of beach loss and sand mobility include sediment infilling and deterioration of adjacent lagoon conditions. Several management actions to alleviate coastal erosion problems on Yanuca Island are suggested.

Key words: coastal geomorphology, beach erosion, Fiji Islands

Introduction and Aims

Yanuca Island (pronounced "Ya-nu-tha" in the Fijian language) is a 50 hectare emerged coral limestone island lying in Cuvu Bay, immediately adjacent to the south west coast of Viti Levu, the main island of Fiji (Fig. 1). Separating the north and east coasts of Yanuca Island from the mainland is a narrow marine channel called the Yanuca Channel, which varies in width from 90 m to 250 m across. The traditional Fijian owners of Yanuca Island and the nearby reefs and lagoons live in the villages of Cuvu and Rukurukulevu opposite the island. Occupying Yanuca Island is an international tourist resort, the Shangri-La Fijian Resort, which has extensive building complexes and a golf course. Development of the resort began in 1966 after the construction of a causeway linking the island to the mainland (Fig. 2a). The resort is important for the local economy and a major employer of the people from Rukurukulevu, Cuvu and the surrounding area.

This paper presents an investigation into problems of shore erosion along the ocean coasts of Yanuca Island. The aims were to determine the processes responsible

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for coastline change and the consequences. The study began in 2001 after concern was raised by several groups about the loss of beaches over recent years. Anecdotal accounts from the villagers of Cuvu and Rukurukulevu provided oral evidence that within living memory the island beaches have degraded. According to some villagers, prior to resort development the beaches were stable. The management of the Fijian Resort was also concerned that beach erosion represents degradation of one of the main tourist attractions on Yanuca. Shoreline erosion was said to be gradually transforming the island's white sandy beaches into a less attractive stony coastal environment. From the resort's perspective, white sand beaches are preferable to rocky shores since they have more 'charm value' for tourists.

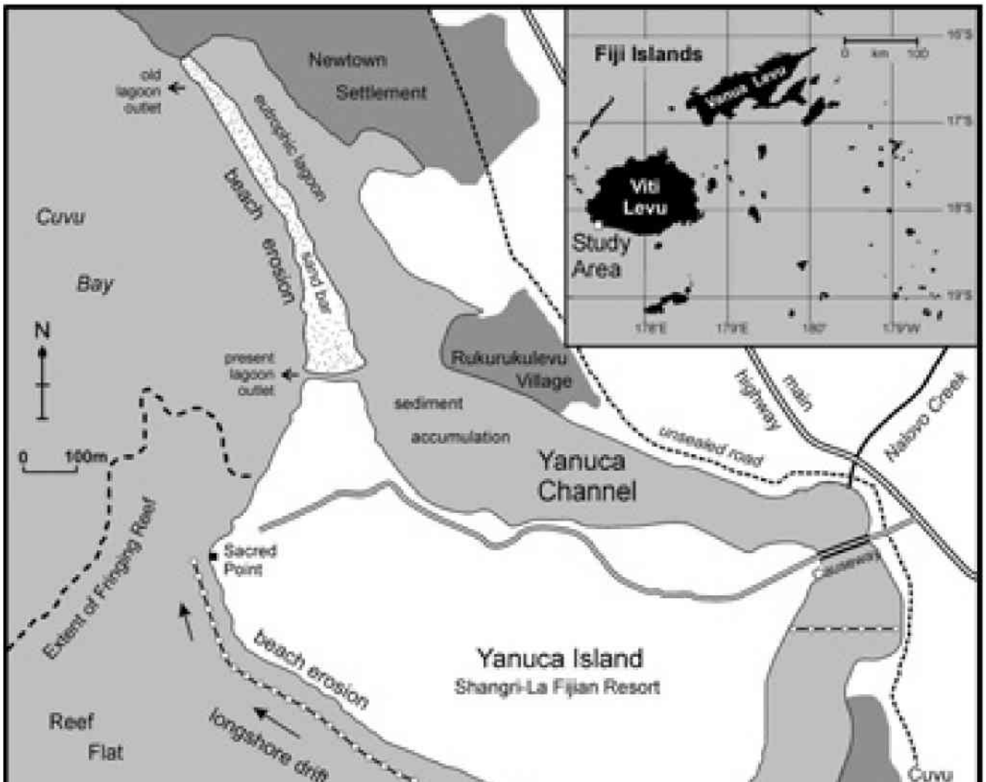

Fig. 1. Map of Yanuca Island in south west Fiji, and location of monitoring sites described in the text.

In order to fulfil the main aims of the study, the following objectives were undertaken. First, long term changes in the costal geomorphology of Yanuca Island were assessed from archive maps, air photographs and earlier reports, to determine whether coastal change is a recent or historical problem. Second, interviews were held with senior chiefs and land owners from Rukurukulevu and Cuvu villages about the causes of coastal change. The third task was to measure and compare current velocities along the ocean side coast of Yanuca Island and in Yanuca Channel. The fourth task was to examine the impact of the resort causeway across Yanuca Channel on current flow around the island.

Fig. 2. a. View of the Fijian Resort causeway linking the east coast of Yanuca Island with mainland Viti Levu. b. Southern entrance of Yanuca Channel seen from the causeway. c. Significant damming effect of the causeway in storm surge conditions during tropical cyclone Paula, March 2001.

Environmental characteristics of the study area

The geology of Yanuca Island is the Volivoloi Limestone. This has a variable composition of lithified calcareous sediments. The maximum elevation of Yanuca Island is approximately 5 m above mean sea level. The coast has a microtidal environment, with a spring tide range of approximately 2 m. On the west, south and east coasts of the island there are beaches composed of coralline reef materials. The ocean side of the island is fringed by living coral reefs. Yanuca Channel, separating Yanuca Island from the mainland, is a shallow marine lagoon (Fig. 2b), the floor of which is partially exposed at low tide. Along the exposed southern coast of the island, waves generally approach at an oblique angle to the shore from the south east. This is due to the year-round influence of the south east trade winds as the dominant force driving waves and currents across the fringing reef flat. Therefore, on both incoming and outgoing tides, longshore drift is always in the same direction, in a north west direction parallel to the coast (Fig. 1). The drift is stronger at high tide when there is less wave protection afforded by the fringing reefs. The south east trade winds are also the primary generating mechanism of a prevailing current flowing into Yanuca Channel at all phases of the tide, coming from the south entrance and exiting into Cuvu Bay.

Observations and Measurements

Historical coastal changes

Examination of historical reports and air photographs reveals that the coastline of northern end of Yanuca Island has not remained static but has changed substantially through time. Fig. 3 shows a pair of air photographs from 1951 and 2001, taken obliquely from a low altitude at approximately the same location over Cuvu Bay and viewing Yanuca Island in the same orientation. The 1951 photograph shows that a wide sand bar previously formed an approximately 400m long peninsular adjoining the north west point of the island. The bar is an elongated ridge of sand built by longshore drift and wave action. The bar sediments are composed of coralline materials, predominantly medium to coarse grain sands similar to the beaches elsewhere on Yanuca Island. In 1951 the sand bar was well vegetated with coconut trees and coastal shrubs. The presence of mature vegetation indicates that accretion was taking place and stable conditions had existed for some time. The position of the sand bar directed currents flowing through Yanuca Channel to exit into the central area of Cuvu Bay opposite Newtown settlement.

From a survey of later air photos at the South Pacific Applied Geoscience Commission (SOPAC) in the Fiji capital Suva, PRASAD (1992) reported that the beach front of the sand bar was eroding after 1979, with a maximum reduction in width of 40 m between 1979 and 1992. Anthropogenic influences were important in this erosion. During the mid-1980s sand was regularly removed from the bar to replenish beaches on Yanuca Island. Also, much of the vegetation growing on the bar was cleared. Attempts by the management of the Fijian Resort to control the ensuing erosion of the sand bar with vertical wooden piles and sand bag groynes proved ineffective (resort engineers, pers. comm.). The 2001 air photo (Fig. 3) now shows that the southern end of the sand bar has separated from Yanuca Island. According to local people, separation occurred by wave erosion during a tropical cyclone in the early 1990s.

Fig. 3. Oblique aerial photographs of Yanuca Island in 1951 and 2001. Note the degradation of the sand bar in the bottom left of the image, the loss of coastal forest on the sand bar, and the consequent relocation of the drainage outlet of Yanuca Channel into Cuvu Bay.

Reef sand supply

During interviews at Rukurukulevu and Cuvu villages, the people admitted that over-fishing on the fringing reefs has affected the biological community of reef ecosystems. This may have been a major factor in the loss of beach sand along the southern coast (THAMAN *et al.* 2001). This is because white sand beaches are almost exclusively composed of biogenic material derived from living reef organisms. Specifically, the bulk of the sand on Yanuca Island beaches comprises the calcareous remains of foraminiferans (tiny one celled invertebrate animals with calcareous tests), coralline algae (mainly *Halimeda* spp., which are common on the reef), pieces of broken coral and shell fragments, and the faecal materials of fish, such as parrotfishes and wrasses. These fishes bite off coral, ingest the living tissue and symbiotic algae, and excrete what remains as coral sand. Over-fishing of coral-ingesting fish, and the reduction in habitat for forams and coralline algae, contributes to beach loss by decreasing the supply of reef-derived carbonate sands.

Tropical cyclones and sea level rise

It should be remembered that accelerated coastal and beach erosion over the past three decades is a Pacific-wide phenomenon, throughout the high volcanic islands and the low-lying limestone and atoll islands of the Pacific. This is related to a combination of slowly rising sea levels due to global warming and an increase in the severity and frequency of extreme events such as tropical cyclones (NUNN 1994). Thus, shoreline erosion on Yanuca Island is partly linked to these regional impacts.

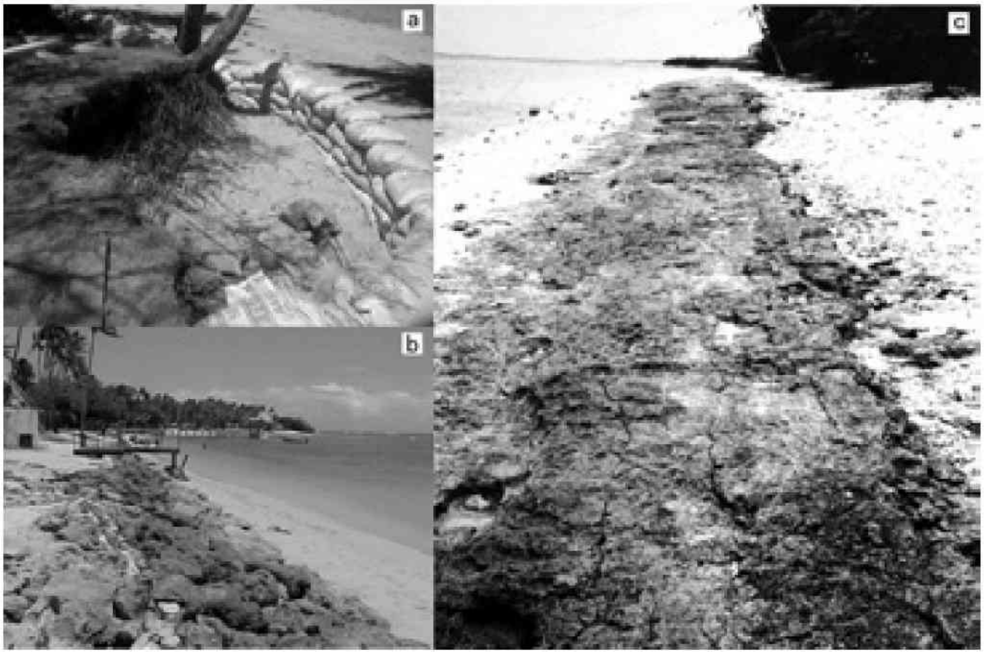

Fig. 4. Coastal erosion problems on Yanuca Island. a. Beach erosion along the south west coast caused by Cyclone Paula in March 2001. b. Seawall to prevent erosion on the north west coast. c. Extensive exposure of beachrock along the south coast, indicating removal of the overlying beach.

Tropical cyclones have a major influence on the exposed Yanuca Island shores owing to the violent winds generating large waves and piling the sea against the coast.

Cyclones Bebe in 1972, Oscar 1983, Hettie 1987 and Paula 2001 are some examples that caused serious erosion and loss of beach sand on Yanuca Island, according to interviews with the staff of the Fijian Resort. Coastal flooding and erosion is also exacerbated by storm surge, especially if the surge coincides with the time of high tide. A storm surge is a temporary rise in sea level, normally caused by the very low atmospheric pressure close to the centre of tropical cyclones, although surges can also be caused by other low pressure systems. The low pressure causes the water level near a cyclone centre to rise, maybe more than a metre. Storm surges cause local submergence of coral reefs, which normally protect the coastline. Huge waves produced by the strong winds will then sweep ashore and cause damage to much greater heights reached by the surge alone. Such conditions were observed when violent winds during the passage of Tropical Cyclone Paula across south western Fiji waters in March 2001 generated large waves. Much sand was removed from the beaches along the southern shore of Yanuca Island during this event (Fig. 4a).

Current flow patterns

The objective here was to carry out direct measurements of current velocities in order to determine the strength of longshore drift along the south western (ocean) coast of Yanuca Island, where beach erosion is reported to be most significant. Drift velocities were then compared with current characteristics on the east side of the island through the entrance of Yanuca Channel in maximum tidal phases.

Longshore current velocity measurements were made at 30 m intervals along a transect at a distance of 20 m offshore during an incoming tide on 14th February 2001. Measurements started at Sacred Point at the western point of Yanuca Island, then continued south-eastwards for 540 m, as far as the end of the resort buildings. The device used was a MGP GeoPacs Ltd. hand-held current meter, connected to a wading rod and a digital logger. All measurements were taken at a constant depth of 30 cm over a 1-minute period. The number of propeller revolutions were converted to velocities in centimetres per second (cm s^{-1}) after field observations were completed, using a calibration chart provided. During observations, current velocities increased notably in swells. In response, several velocity measurements were taken at each survey point to record differences between swell and non-swell currents. Following this, flow velocities were then measured on the eastern side of the island across Yanuca Channel in a similar way. Readings were taken at 20 m increments along a west-to-east transect across the channel 117 m above the resort causeway. The results are summarised in Tables 1-3.

Table 1. Height and times of tides during field observations.

Date	Low tide		High tide		Low tide		High tide	
13th Feb. 2001	time height	04:53 0.4m	time height	10:57 1.6m	time height	17:13 0.4m	time height	23:32 1.7m
14th Feb. 2001	time height	05:11 0.4m	time height	11:32 1.7m	time height	18:05 0.4m	time height	24:00 1.7m

Source: Fiji Post

Note: Tide times are for Suva Harbour, approximately 150 km east of the study area

From examination of the current velocity measurements, the following points emerge. It is seen that there is a strong persistent longshore drift flowing in a north west direction parallel to the beachfront on the ocean side of Yanuca Island. This drift is not a tidal current, but is generated by the oblique angle of wave approach in the near-shore zone, driven by the force of the south east trade winds across the fringing reef surrounding the southern coast of the island. On an incoming tide, measured longshore drift velocities 20 m offshore ranged from 17 to 95 cm s^{-1} (average 48 cm s^{-1}). An earlier study by GAWEL and SEETO (1982) obtained broadly similar although slightly lower results, measuring a maximum drift velocity of 33 cm s^{-1}. These current velocities are sufficient to entrain and transport sand out of the beachfront zone and into Cuvu Bay. This process is therefore contributing to the current erosion of the beaches on the southern side of Yanuca Island.

Table 2. Current measurements along the south west coast of Yanuca Island

Measurement Point	Distance from Sacred Point along survey transect m	Velocity* cm s^{-1}
1	0	39
2	30	45
3	60	40
4	90	28
5	120	95
6	120	94
7	150	73
8	180	59
9	210	61
10	240	58
11	270	44
12	300	56
13	330	43
14	360	59
15	390	28
16	420	26
17	450	27
18	480	44
19	510	17
20	540	23
	mean	48

* average of 3 measurements at each measurement point

Table 3. Current measurements across Yanuca Channel

Measurement Point	Distance from Yanuca Island along survey transect m	Velocity* cm s^{-1}
1	20	68
2	40	28
3	60	26
4	80	28
5	100	29
6	120	35
7	140	37
8	160	24
	mean	34

* average of 4 readings at each measurement point

At times of swell, there was up to a 3-times increase in velocity at individual survey points. Maximum longshore drift will therefore be generated when the swell is strongest and waves driven against the coast are largest. This will occur either when the south east trades are strong or during tropical storms blowing from a southerly direction. There is also a strong current flowing on a rising tide along the east coast of Yanuca Island through the entrance of Yanuca Channel. Velocity varies across the channel, with a measured average of 34 cm s^{-1}.

Evidence for shoreline erosion by longshore drift are the exposures of beachrock along the southern coast of Yanuca Island (Fig. 4c). Beachrock exposures are characterised by surfaces which are scalloped and pitted by solution. Beachrock is a type of calcarenite limestone, i.e. it is a calcareous sandstone which formed beneath the surface of the beach through the compaction and cementation of the calcareous materials that comprise the beach deposits. Since beachrock lithifies within a beach profile, its exposure at the surface is proof that large quantities of overlying beach materials have been removed.

Influence of the causeway

The 94 m long concrete causeway across Yanuca Channel was constructed in the mid-1960s to link the east coast of Yanuca Island with the Fiji mainland. The causeway has an 'Irish crossing' design, with a level access road built across 57 concrete culverts (Fig. 2a). There is a single open span in the centre of the causeway, in addition to the culverts, to allow the through-put of water. The causeway was built across the narrowest part of the channel, but land reclamation at each end has further reduced the channel width, increasing the constriction. Visual reconnaissance during this study indicated that the causeway design impedes water flow around the north side of Yanuca Island, so the damming effect of the structure was estimated as follows. Because the causeway structure blocks part of the channel, the dam area is equivalent to the cross-sectional area of the causeway, minus the surface area of the 'gaps' which allow water to flow through, i.e. the circular culverts and the central rectangular span. If the gaps in the structure were sufficient to accommodate the entire channel flow, then the water level on both sides of the structure should be equal. It follows that any observed difference in water level on either side of the causeway indicates the dam effect. At high tide on 14th February 2001, water level was measured simultaneously on opposite sides of the causeway at 45 equally spaced locations along its length. The average difference in water level on opposite sides was 12 cm. This equates to a causeway dam effect of approximately 20% of channel flow at high tide.

However, Fig. 2c illustrates that the causeway dam effect is much more significant in tropical cyclones and storm surge conditions. These conditions occurred with the passage of Tropical Cyclone Paula across south western Fiji waters in March 2001, generating storm surge, large waves and swells (FIJI METEOROLOGICAL SERVICES 2001). The impact of the causeway dam effect in these extreme conditions is to hold back the strongest currents that should be generated around the north coast of Yanuca Island. The high surge waters are then forced to escape around the south coast of the island. This has the effect of increasing longhore drift along the south coast of Yanuca Island (PRASAD 1992), thus increasing the potential for erosion of the southern beaches.

Consequences of Beach Erosion

There have been several important consequences of the historical and continuing problems of coastal erosion around Yanuca Island. First, the instability of the sand bar on the north side of the island has caused a shift in the position of the exit of Yanuca Channel into Cuvu Bay. The present outlet formed in 1992 when the sand bar was separated from Yanuca Island by wave erosion during a tropical cyclone. Prior to this, the channel exit was located at the north end of the sand bar, in the mid-section of Cuvu Bay. As mentioned earlier, factors leading to the new cut were narrowing of the sand bar in the 1980s, exacerbated by sand mining and the removal of coastal vegetation which previously had a stabilising role.

The altered channel configuration has caused the old exit at the north end of the sand bar to fill in. The sand bar now joins the mainland as a peninsular, blocking the drainage of water out of the north end of Yanuca Channel into Cuvu Bay. Also, since the sand bar is now mostly devegetated, its sediments are highly mobile. As a result, the blocked lagoon 'cul-de-sac', enclosed behind the sand bar, now efficiently traps beach materials that are washed over the bar by large waves during storms. A severe algal bloom witnessed in the blocked cul-de-sac during the Fiji hot season in early 2000 indicates that stagnation, pollution and eutrophication are a problem there.

Second, the channel on the north side of Yanuca Island opposite Rukurukulevu village is also rapidly infilling with sediments. Earlier, PRASAD (1992) observed that "the floor [of the channel] is generally clean with evidence of scouring". However, local people now report that the lagoon has become shallower, and the water generally dirtier, than before the sand bar and the channel exit adjusted to their present configuration. Evidence for sedimentation is found in the results of cores collected by the author (TERRY and THAMAN 2001), which indicate that there are now thick deposits of sands (>130 cm) on the lagoon floor.

Finally, related to these problems of erosion and sedimentation is an observed deterioration in the health of marine ecosystems in Yanuca Channel. A survey of marine biodiversity along several transects across the channel by THAMAN *et al.* (2001) reveal 1) death and disappearance of coral species, 2) increasing rarity of seaweeds and seagrasses and 3) impoverishment in the numbers of finfish, shellfish, crustaceans and other invertebrate wildlife.

Conclusions

This study has examined the factors responsible for problems of coastal erosion around Yanuca Island in south west Fiji. The main conclusions of the investigation can be summarised as follows. First, coastal erosion on the island is not a recent problem. Since the 1980s, there has been erosion of the sand bar on the north coast. This is probably in part related to Pacific-wide problems of rising sea levels and increasing tropical cyclone severity and frequency. However, the influence of humans in clearing coastal vegetation and sand mining were also important. The erosion of the sand bar has resulted in major changes to the coastal geomorphology. Principally, sand eroded from the bar has blocked an old exit of the Yanuca Channel into Cuvu Bay, and a new exit has been cut adjacent to the island. The enclosed northern end of the lagoon has become eutrophic and is accumulating sediments washed over the sand bar in storms.

Second, along the south coast of Yanuca Island, shoreline erosion is caused by the strong longshore drift, which is generated by the persistent south east trade winds. Evidence for the loss of beaches are the common outcrops of beachrock. Exacerbating the erosion are a possible reduction in the supply of new sand materials due to over fishing and degradation of the fringing reef, and the impact of recent tropical cyclones which have caused much damage.

Finally, the resort causeway on the east coast of Yanuca Island has a dam effect which restricts normal current flow through Yanuca Channel at high tide and especially in storm surge events. This is likely to increase the strength of the longshore drift along the south coast of the island, and therefore worsen the risk of shoreline erosion.

Some consequences of shoreline erosion and increased sand mobility are sediment accumulation and deteriorating health in the Yanuca Channel lagoon. Possible actions that may be taken to address the coastal erosion problem include: 1) Rehabilitation of the coastal forests previously growing on the sand bar to stabilise the coastal geomorphology. 2) Prohibiting over-fishing on the fringing reefs and designating the offshore area of Yanuca Island as a marine protected area or reserve. This should in time regenerate the reef ecosystem and ensure a continuing supply of biogenic sands to replenish the beaches on the island. 3) Replacing the causeway across Yanuca Channel with an alternative structure, such as a bridge, to reduce the dam effect at high tide and during tropical cyclones and surges. If current flow can be improved around the east and north sides of the island, then this may reduce the erosion potential of longshore drift along the south coast of Yanuca Island.

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References

FIJI METEOROLOGICAL SERVICE. 2001. Monthly Weather Summary, March 2001. FMS, Nadi Airport, Fiji. 6pp.

GAWEL, M. and SEETO, J. 1982. Limited marine investigations at the Fijian Hotel, Yanuca Island. Institute of Marine Resources, The University of the South Pacific, Suva, Fiji

NUNN, P. D. 1994. Oceanic Islands, Blackwells, Oxford, UK.

PRASAD S. 1992. Coastal geological study of Yanuca and Cuvu Harbour, Fiji. Unpublished B.App.Sc. dissertation, Department of Applied Geology, Queensland University of Technology, 1992 (113pp.).

TERRY, J.P. and THAMAN, R.R. 2001. Investigation of Current Flow, Sedimentation and Health of the Marine Ecosystem in Yanuca Channel, Shangri-La Fijian Resort, Cuvu, Sigatoka. Report prepared for the Foundation for the Peoples of the South Pacific (Suva). Institute of Applied Sciences, Technical Report No. 2001/6, University of the South Pacific, Suva, Fiji.

THAMAN, R.R., TAWAKE, A., THAMAN, B. and NIUKULA, J. 2001 Change over time and current status of the coastline, reef and biological organisms in Yanuca Channel: preliminary findings. In: Investigation of Current Flow, Sedimentation and Health of the Marine Ecosystem in Yanuca Channel, Shangri-La Fijian Resort, Cuvu, Sigatoka. (TERRY, J. P. and THAMAN, R. R.), 29-44, Report prepared for the Foundation for the Peoples of the South Pacific (Suva). Institute of Applied Sciences, Technical Report No. 2001/6, University of the South Pacific, Suva, Fiji.