EU EDF 8/9 – SOPAC Project Report 36:
Reducing Vulnerability of Pacific ACP States

TUVALU

TECHNICAL & COUNTRY MISSION REPORT – ASSESSMENT OF AGGREGATE SUPPLY, POND AND LAGOON WATER QUALITY & CAUSEWAY CONSTRUCTION ON FUNAFUTI AND VAITUPU ATOLLS

Fieldwork undertaken from 13th to 24th September 2004

Funafuti Lagoon, Tuvalu.

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Important Notice

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I would like to acknowledge the help and assistance of the Government of Tuvalu, particularly staff of the Public Works Department, Lands Division, Environment Division and Waste Management Section. Sincere thanks also to both TANGO and the Funafuti Kaupule particularly, the Kaupule President and Deputy President. I am also greatly indebted to Mr Semese Alefaio (Conservation / Milkfish Project Officer) who's assistance with gathering information and help with the field sampling programme was invaluable. Thanks also to Dr Tim Pickering of the University of the South Pacific for comments concerning milkfish aquaculture.

Many thanks also to the Vaitupu Kaupule President and Kaupule members for their warmth, generosity and assistance whilst on Vaitupu.

INTRODUCTION

This "fact finding" trip was undertaken within the SOPAC/EU EDF 8/9 Reducing Vulnerability of Pacific Islands States Project. The trip was a follow up to an earlier Multi-Stakeholder Consultation meeting (29th October 2003), where the following issues pertaining to Aggregates and Coastal Processes were identified. Otherwise, the trip was initiated to meet the EDF 8/9 project tasks for Tuvalu as outlined in the Work Plan (Task No.'s. TV 1.1.1; 1.1.2 and TV 1.2.4; 1.2.5; 1.2.6 [TV 3.5.2]).

- Assess present aggregates supply situation and investigate past monitoring procedures.
- Liaise with MNRE on a source of fill and capping material for the Waste Management Division's landfill.
- Liaise with Government / PWD on the proposed Funafuti borrow pit filling project.
- Liaise with Meteorological Office with regard to filling / raising low-lying areas where the facility is located (western side of airstrip).
- Assist with marine survey work in Funafuti lagoon.
- Collect aggregate samples for analysis of origin and suitability for construction and general-purpose use.
- Assess the location of the proposed Vaitupu lagoon passage causeway.
- Clarify project goals to Funafuti and Vaitupu stakeholders and define requests for assistance appropriate to the EDF Coastal Processes and Aggregates portfolio from stakeholders on both islands.

These previously identified issues and objectives were the principal starting point during all discussions and negotiations with stakeholders. Additional issues were, however, raised by the stakeholders (Table 1 gives a list of principal contacts) and were independently identified as priorities during this trip. It is also important to mention that casual community consultation was also undertaken during site visits and whilst these individual's names do not appear in Table 1, their opinions are reflected in the report.

EXECUTIVE SUMMARY

Before EDF 8/9 can assist with any of the identified issues pertaining to aggregate and fill utilisation on Funafuti the broader issue of aggregate supply must be addressed. There are only two viable, long-term options to this aggregate accessibility issue, (1) importation and (2) mine off-shore resources. All stakeholders recognise that imported aggregates will be prohibitively expensive yet there remains great resistance to exploiting the offshore resource. The resistance is prevalent through all levels of the community and is based largely on the perceived environmental damage that will ensue if offshore dredging is undertaken. This negative community opinion appears to have resulted due to a lack of sound scientific information outlining the real impacts and costs of dredging in comparison to the potential benefits. Stakeholders have requested that SOPAC provide technical assistance to support the delivery of a clear and objective information seminar to Government, the Kaupule (Island Council) and the wider community regarding the aggregate supply issue, and the potential of the off-shore resource to address the critical aggregate supply issue on Funafuti.

Among the additional issues identified were an overwhelming number of requests with regard to the suitability of the Fongafale borrow pits and Tafua pond for milkfish production. Milkfish aquaculture per se is neither within the author's sphere of expertise nor easily included into the EDF project primary objectives. However, taking into consideration stakeholder persistence, the apparent lack of expertise on hand in Tuvalu and the fact that significant funds and effort were about to be expended by TANGO (Tuvalu Association of Non Government Organisations) and the Funafuti Kaupule on a milkfish production project, the issue was addressed from the point of view of the overall ecological health, suitability and from a resource management perspective for the proposed milkfish production locations. Within these parameters, it appeared some oversights may be present in the current proposal and these have been explored in this report.

Discussion with the Vaitupu Island Kaupule was similarly dominated by their aspirations with regard to milkfish production and concerns over the gradual infilling of Vaitupu Lagoon. The issue of aggregate supply was raised during my meeting with the Kaupule but this did not appear to be considered a major issue during discussions or during the subsequent island tour. This is possibly due to Vaitupu's comparatively large terrestrial resources of sand, gravel and road-base supplies and far smaller requirements.

The site of the proposed Vaitupu Lagoon passage causeway was also visited and assessed and the options discussed with the Vaitupu Kaupule team.

Table 1. List of primary people involved during consultation process.

FUNAFUTI	POSITION
SOPAC	
Mr Quan Chung	SOPAC Marine Survey
Ms Litea Biukoto	SOPAC IKONOS Image Correct Ground Survey
Mr Steven Hays	SOPAC Research Vessel Captain.
Dr Arthur Webb	SOPAC Aggregates & Coastal Processes Adviser
Government	
Mr Afelee Pita	Permanent Secretary, MNRE (Ministry of Natural Resources & Environment), SOPAC National Representative
Mr Kolene	Lands and Survey Division, MNRE
Mr Faatasi Malolonga	Lands and Survey Division, MNRE
Ms Pepetua Latasi	Environment Officer/Climate Change Officer, MNRE
Mr Kelesoma Saloa	International Waters Project Coordinator
Ms Sussan Tupulanga	Waste Management Project Coordinator
Mr Vavao Soamanaia	Waste Management Officer
Mr Am Pelosa Tehulu	Deputy Director of Works & Energy, PWD (Public Work Department)
Mr Filipo Taulima	Director of Public Works, PWD
Mr Paani Laupepa	Assistant Secretary – Foreign Affairs, Office of the Prime Minister
Ms Kilateli Epu	Aerology Officer – Meteorology Office
NGOs	
Ms Annie Homasi	TANGO Coordinator
Mr Doods Abagajin	TANGO Project Officer
Ms Pasemata Sateko	EU-NZAID, In-Country Coordinator
Kaupule (Is. Council)	
Mr Talakatoa O'Brian	Secretary – Funafuti Kaupule (Island Council)
Mr Semese Alefaio	Conservation / Milkfish Project Officer – Funafuti Kaupule
Mr Solomona Lelemia	President – Funafuti Kaupule
Mr Mesako Usufono	Deputy President – Funafuti Kaupule

VAITUPU	POSITION
Kaupule (Is. Council)	
Mr Ioane Paulo	Secretary
Mr Semele Sio	President
Mr Silu Malanga	Treasurer
Mr Tui Tamafau	Community Planner
Mr Silo Tilito	Member
Mr Paneta Siaosi	Member
Mr Josua Pita	Member
Mr Viliane Panapa	Member
Government	
Mr Fietau Nemaia	Lands Clerk

WORK PLAN

This plan was necessarily mutable and evolved as the trip proceeded as our work schedule revolved around the movements and changing time table of the SOPAC research vessel.

DATE (September)	ACTIVITY
Monday, 13th	Arrive team – (Quan Chung, Litea Biukoto, Steven Hays, Arthur Webb) meet with Mr Afelee Pita, Permanent Secretary MNRE (SOPAC National Representative to discuss work plans whilst in Tuvalu. Also present were Mr Kolene and Mr Faatasi Malolonga both of the Lands and Survey Division MNRD. (Faatasi went on to become our primary contact).
Tuesday, 14th	Present draft work schedule to MNRD and discussed details of travel and other arrangement with Faatasi. Meeting with Environment Unit MNRD - Ms Pepetua Latasi – Environment Officer / Climate Change Officer.
Wednesday, 15th	Meetings with: International Waters Project Coordinator – Mr Kelesoma Saloa. Waste Management Project Coordinator – Ms Sussan Tupulanga. Deputy Director of Works & Energy PWD – Mr Am Pelosa Tehulu also made site visits with Am Pelosa to sand and gravel quarry sites, inspect PWD crushing facility, SOPAC pilot borrow pit fill site and coastal development sites. TANGO Coordinator – Ms Annie Homasi & Project Officer – Mr Doods Abagajin.
Thursday 16th	Meeting with Director of Public Works PWD – Mr Filipo Taulima. Site visits to Tafua pond, AusAID piggery, landfill and waste management facility and borrow pits with Waste Management Project Coordinator – Ms Sussan Tupulanga and Waste Management Officer – Mr Vavao Soamanaia.
Friday 17th	Meeting with Secretary of Funafuti Kaupule (Island Council) – Mr Talakatoa O'Brian. Meeting and site visits with Kaupule Conservation Officer / Milkfish Project Officer – Mr Semese Alefaio. Meeting with Funafuti Kaupule President and Deputy President.
Saturday, 18th	Joined research vessel for Funafuti lagoon survey and current meter deployment.
Sunday, 19th	Continued Funafuti lagoon survey and current meter deployment.
Monday, 20th	Travelled to Vaitupu Island aboard research vessel (10-hour trip). Meeting with Vaitupu Kaupule Secretary – Mr Ioane Paulo.
Tuesday, 21st	Meeting with Vaitupu Island Kaupule members and President – Mr Semele Sio to explain Project and GPS and bathymetric survey work. Accompanied by Kaupule on tour of island making site visits, sampling, discussing aggregate and other issues and undertaking GPS survey (Litea). Bathymetric survey completed – overnight return to Funafuti on research vessel.
Wednesday, 22nd	Meeting / debriefing session with Mr Afelee Pita, Permanent Secretary MNRE. Meeting with Assistant Secretary of Foreign Affairs – Mr Paani Laupepa, to discuss progress of US proposal to fill borrow pits. Site assessment and sampling in Tafua pond with Conservation / Milkfish Project Officer – Mr Semese Alefaio.
Thursday, 23rd	Return flight to Suva cancelled. Meeting with EU-NZAID In-Country Coordinator – Ms Pasemata Sateko. Meeting with Meteorology Office staff – Ms Kilateli Epu, Aerology Officer. Site visits to airstrip fore dune quarry area and new sports field.
Friday, 24th	Return to Suva.

PART 1 – FUNAFUTI ISLAND

1. Aggregate Supply Issues

The need for a reliable supply of aggregate to meet Funafuti's requirements with regard to the waste management landfill site, filling of low-lying areas on the east of Funafuti airstrip, filling of borrow pits and for use in road maintenance and general construction is clearly understood by all stakeholders at all levels. Funafuti presently has a critical shortage of such material, which in turn, serves to increase the destructive mining of beaches. Large development projects (e.g. airport and road sealing, government offices) and even some private individuals are importing building materials from overseas however, very few can afford this option.

The licensing of sand and aggregate suppliers is regulated by the Kaupule but does not appear to be strictly enforced and during my visit I was unable to obtain any records. Until recently the PWD was licensed to collect cobble (from the ocean side shoreline) to crush for gravel. Sand seems to have been largely supplied from land-based quarries. Both of these commodities were once stock piled at the PWD compound for use in public works and for sale to the public. At the time of this visit PWD's stock piles of rubble and general-purpose fill were nearly exhausted as, due to environmental concerns, the Kaupule has refused to continue to renew PWD's licence to collect aggregates. Otherwise, there was evidence of small amounts of beach gravel still being removed (by hand) from the ocean side beach head (particularly adjacent to the airstrip) and sand continues to be supplied from terrestrial extraction sites in the more rural north and south arms of Fongafale.

Figure 1. Fongafale waste collection site (old borrow pit) desperately requires capping material (some 2500 m^3 of general-purpose fill is presently required to cap the landfill to 0.4 m).

Stakeholders unanimously agreed that the importation of aggregates was the most desirable option to supply the capital's needs however, it was also agreed that this option would really only be appropriate for large overseas-funded capital works projects, due to the costs involved. Even if imported aggregates were made available at cost price (approximately AUD \$100 m^{-3}), many people simply couldn't afford them and would most likely continue to take aggregates from the beach and/or terrestrial quarries. It should also be noted that imported materials particularly soils and to a lesser extent sands, present a huge and unmanageable quarantine risk. Most stakeholders were aware that a potential supply of cheap aggregates were available offshore. However, they did not necessarily understand that this supply could address a range of Funafuti's fill, construction and general purpose requirements. Also as already discussed, there was a general resistance to the pursuit of this option due to environmental concerns.

The reticence to disturb the marine environment is understandable in view of current global temperature and sea-level change issues and the vulnerable nature of Funafuti atoll. However, many of the views concerning dredging do not seem to be based on a complete understanding of the realistic extent of impacts of sand mining activity. And it is likely that if appropriate, scientific information was available a more balanced community view of this issue may arise. It is also important to note that many of the problems locally perceived to be resulting from increased mean sea levels (e.g. increased erosion, localised flooding, waves over-topping fore-dunes, etc.) could be addressed by the reliable supply of cheap fill material (e.g. Figure 2). This would also aid in preventing mining of fore-dune systems, provide aggregates for infrastructure construction and erosion prevention structures could supply desperately needed material for applications such as the Funafuti landfill (Figure 1). In essence, whilst there will be some environmental costs of undertaking dredging, if the operation is well managed, the impacts should not be significant and these would be greatly outweighed by the net benefits to the Funafuti community.

In conclusion, it appears that in terms of quality, quantity and cost, a viable supply of aggregates is readily available to the people of Funafuti however, public and institutional opinion and concern regarding the mining of offshore aggregates has prevented the exploitation of this resource. Before any of the EDF Project goals pertaining to the use and supply of aggregates and fill in Funafuti can be addressed, a consensus of opinion must be reached by the Funafuti Government, the Kaupule and the wider community as to how they will obtain these materials. This decision-making process in turn must be based on sound and correct information regarding all of the options. In particular, the likely environmental effects of dredging should be clearly explained. Only once the issue of aggregate supply is determined can the EDF Programme provide further technical assistance in this area and this will be particularly important if offshore aggregate extraction is pursued.

Figure 2. Funafuti Meteorological Office, inundated with seawater during spring tide conditions (tides > 2.8 m), the western side of the airstrip requires some 7500 m^3 of fill to raise the surrounding area 0.3 m.

2. Potential Milkfish Production Sites on Funafuti

At the outset, it must be clarified that the author is not a aquaculturalist and this assessment of milkfish production sites on Funafuti was made (at the request of the Funafuti Kaupule) from the point of view of ecosystem health, function and resource management.

2.1 Tafua Pond – Funafuti

Tafua pond located at the north eastern end of the Funafuti airstrip (Figure 3) has been proposed by the Funafuti Kaupule in cooperation with TANGO as a potential site for environmental restoration and milkfish (*Chanos chanos*) production. Tafua pond is a relict of a far larger low-lying area, which was filled during the construction of the airstrip by US forces in 1942. The previously larger low-lying area is in turn thought to have been an ocean passage, which separated the "elbow" of Fongafale into two islets. Over time these Islets gradually joined as the passage became in-filled (due to natural processes) and eventually wave action built a continuous fore-dune system along the ocean side, leaving a protected low sandy basin on the leeward side. Sediment transported from the lagoon partially filled the basin and the lagoon shoreline prograded westwards leaving the low-lying areas like Tafua (Xue and Malolonga, 1995).

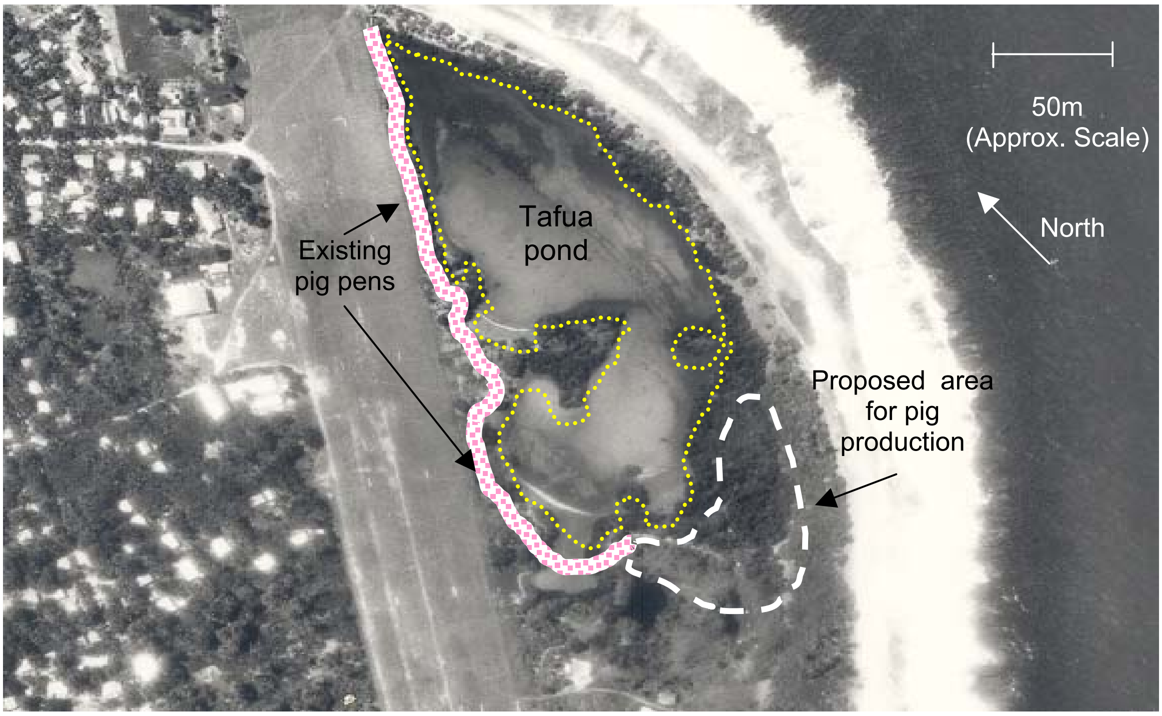

Figure 3. Tafua pond at the NE end of the Funafuti airstrip. Note this older air photo (1984) does not show the present extent of mangroves, but does give a clearer indication of the true pond boundary. Also note that water quality appears good (i.e. clear) with strips of thin white sand beaches on the western shorelines. (Source – SOPAC AP archives, 1984).

The present pond area is some 1.39 ha and it is separated from the ocean by a single fore-dune mostly comprised of boulders and cobble. This allows the ready infiltration of seawater in and out of the pond during the tidal cycle. Brackish groundwater also communicates with the pond from the surrounding land area and it is likely that significant amounts of fresh surface water enters the pond during heavy rainfall (due to the camber and proximity of the hard sealed airstrip). The pond appears marine dominated however, salinity probably fluctuates depending on tide, weather and rainfall. Much of the substratum of the pond is smooth flat limestone bedrock which slopes down consistently towards the north giving the pond an average depth of approximately 0.3 m in the south and 1.0 m in the north. The bedrock surface was covered to varying depths in a dark flocculent organic sediment.

Mangrove stands (*Rhizophora stylosa*) dominate the perimeter of the pond and appear to have spread and become significantly denser since 1984 (Figure 3). Mangroves now border about 90% of Tafua's shoreline and have formed tall dense thickets more than 40 m wide on the SE banks. Large amounts of dark organic sediment have also accumulated within the root zones of these mangrove stands and none of the previous white sand shoreline (evident in Figure 3) is now exposed.

The elderly population of Funafuti remember a time when their children played in Tafua's clean protected waters and milkfish were commonly harvested, this "evocative" view of the pond appears to account for a considerable amount of the community motivation to clean up the pond and re-establish it as a milkfish resource. However, in recent years Tafua has undergone considerable physiochemical and ecological change, as it has become increasingly used to accept and assimilate effluent from a growing number of pig pens built on its shoreline. Differing views exist as to this particular use of the pond, some suggesting it was an unplanned process and alternatively, it was an intended aquaculture project, where pig effluent enhances the nutrient status to increase primary production and consequently the biomass of food species (Tilapia - *Oreochromis mossambicus*). However, tilapia are not eaten in Tuvalu and tilapia from Tafua are considered particularly unacceptable as these fish are grown with pig effluent. There was also no evidence that tilapia are used as pig food, in fact people were surprised when this was suggested. As such, if the relocation of pig pens and the introduction of tilapia to Tafua was a conscious aquaculture effort, there seems to have been a complete neglect of the environmental, ecological and social implications of these actions.

The 1984 airphoto (Figure 3) shows the pond water to be clear with strips of white sandy beaches. The substrate was also light coloured and mangrove cover was far sparser indicating a comparatively clean environment to that which exists today. The 1984 airphoto also shows far fewer pig pens located near the shores of the pond and it appears there has been a gradual increase in the number of pig pens during the years since. Presently the entire western shoreline is utilised for pig production, the AusAID intensive piggery also utilises the pond for dissolved and solid waste assimilation (Figure 4) and the Kaupule has plans to place hundreds more pens on the southern fringe of the pond. Effluent and solids drain either directly into the pond or through the highly-permeable substrate to mix with the pond waters, and it is evident that this has greatly increased the nutrient status of Tafua and phytoplankton blooms were apparent in the western shallows (Figure 4). Increased phytoplankton combined with faecal matter from tilapia, the shedding of organic matter from the mangroves and solid wastes from the pigs has formed a dark flocculent organic sediment. This overlays much of the substratum and is trapped to greater depths within the mangrove stands. These sediments are comparatively rich in nutrients (see Attachment 2) and would also recycle nutrients back to the water column (Webb 2003). The mangroves surrounding Tafua are an additional indication of the more recent nutrient status of the pond, as they are unusually luxuriant and are obviously growing at an accelerated rate.

The elevated nutrient status of the pond per se may not be an obstacle to milkfish production and indeed intensive milkfish aquaculture requires continual nutrient addition to maintain productivity. However, the balance between enhanced productivity and complete collapse (fish kills due to elevated ammonium concentrations, anoxia, etc.) of the pond ecosystem if too much additional nutrient enters the system needs to be carefully managed. This is of particular importance in light of the planned expansion of pig production on Tafua's shores. An incidental issue is the amount of enriched waters which are moving out of the pond, through the fore-dune and on to the ocean-side reefs adjacent to Tafua. Presently, no obvious signs of perturbation are evident and it is probable that in this high-energy environment problems may not arise due to dilution and flushing. Nonetheless, considering the expansion plans and the known intolerance of coral reef systems to increased nutrient supply (Mosley and Aalbersberg, 2002) monitoring of the reef is recommended.

Assuming the present (and future) level of effluent contamination is compatible with milkfish production, two obstacles remain concerning milkfish aquaculture in Tafua; (1) the presence of tilapia and (2) attitudes regarding the consumption of fish grown with pig effluent. Irrespective of the apparent abundance of food in Tafua, milkfish do not compete well with tilapia and the tilapia will require controlling before stocking the pond with milkfish fry (*pers. comm.* Pickering 2004). Local sources of fry are available but the seasonal variability and their accessibility needs to be defined so that tilapia control corresponds to the introduction of the milkfish fry. This will allow the milkfish to grow to a reasonable size before encountering significant completion from the tilapia. The second point and possibly one of the most important pertains to the cultural perceptions regarding the consumption of any fish grown with faecal matter and effluent. This concept is abhorrent in many Polynesian cultures and there needs to be no doubt about the community's acceptance of this product before significant energy and finances are devoted to the Tafua project.

Figure 4. Tafua pond (clockwise from top left) – Continuous row of pig pens on Tafua's western shore; AusAID piggery effluent treatment pond which overflows to Tafua; the proximity of pens to the pond on the north-western shoreline; and phytoplankton blooming on western side (green hazy tinge to the water colour).

Tafua pond will not in the foreseeable future satisfy the less tangible aspirations of the community in terms of its previous aesthetics, use for recreation or as a traditionally managed (minimum intervention) milkfish resource. However, with more stringent modern and costly management techniques it is likely that the pond could produce a sustainable harvest of milkfish (*pers. comm.* Pickering 2004). It is highly recommended that an aquaculture specialist is brought in to consider the viability of the project and develop and produce management and production recommendations. If the Tafua project goes ahead, it will require a considerable amount of labour and money to establish and will have significant on-going maintenance costs. It is important that the Kaupule understands that Tafua can no longer be successfully managed for milkfish aquaculture in a traditional (low intervention), manner. As such, the community must be willing to adsorb these costs through the price of the fish produced (or the Kaupule will need to subsidise the price of the product). This leads to the final question concerning the cultural acceptance of milkfish grown in these circumstances and the willingness of the community to pay for such a product.

2.2 Borrow Pits – Funafuti

The borrow pits of Fongafale have also been earmarked by TANGO and the Kaupule as possible alternative locations for milkfish production and most of these were also visited during the author's trip.

Some of the borrow pits have or are being used as disposal sites for domestic waste and these are considered no further due to the obvious conflict in use type. Otherwise, none of the other borrow pits seen appeared suitable for milkfish aquaculture. These pits dry out completely or become very shallow (10-20 cm) during low tides some with only a few small deeper holes available as a refuge for fish, these were small (probably less than 5 % of the pit area) and were all infested with tilapia (Figure 5). The water in such shallow pools may heat considerably during clear weather and temperatures above 32^{0}C may cause stress in milkfish (*pers. comm*. Pickering 2004). To ensure adequate water remained in the pits these areas will either require sealing (so that water does not escape at low tide) or earthworks to deepen them. Both options would be very costly and even if this was undertaken the presence of tilapia will again require consistent management and on-going control measures if milkfish production is to succeed.

Figure 5. A borrow pit being considered as an alternative milkfish production site.

3. Conclusions / Recommendations – Funafuti

3.1 Aggregate Supply Issue

SOPAC has already undertaken an assessment of the near-shore aggregate resources in the central Fongafale area (Smith 1995) and undertook a successful pilot dredging project in 1992. As such, there is little doubt that offshore resources can supply much of the aggregate needs of Funafuti well into the future and at a reasonable price to consumers (particularly if capital costs for equipment were provided by a donor organisation/nation). SPREP (South Pacific Regional Environmental Programme) also undertook a consecutive assessment of the ecological impacts on lagoon communities before, during and after the completion of SOPAC's pilot dredging project (Kaly and Jones 1994). It concluded that there were no significant environmental impacts associated with that project. It is also interesting to note that the borrow pit filled with aggregates during the pilot project, now supports dense vegetation (including taro and bananas), it is no longer vulnerable to flooding and is generally perceived by stakeholders to be a successful venture.

Many stakeholders however, were not aware of the full implications and outcome of these earlier reports and work, and this lack of clear information concerning off-shore sand extraction no doubt exacerbates the negative perception regarding exploitation of lagoon sediments. It was agreed that little progress could be achieved in the EU EDF 8/9 Project task areas (TV 1.2.4, 1.2.5 and 1.2.6), unless the Government, the Kaupule and the broader community reached a consensus as to how aggregates can be supplied on Funafuti. To assist and facilitate stakeholder discussion on this issue it is recommended that SOPAC is involved in delivering information seminars to the Government and Kaupule. Both stakeholders have also indicated that open community discussions would greatly assist progress, particularly if SOPAC can provide an "impartial expert" to assist in clarifying the options and technical and environmental issues during consultations.

Figure 6. Present extent of PWD's aggregate stock pile.

The EU EDF 8/9 programme is well placed to provide information explaining the potential of off-shore aggregate extraction and it is recommended that an information seminar be drafted using resources and reports previously compiled by SOPAC and other organisations. This information combined with case studies from other island nations undertaking the exploitation of their offshore resources should present a clear picture to stakeholders. Similarly, the Funafuti lagoon water current and bathymetric data presently being collected by the EU EDF8/9 survey team can be used to better describe the environment where dredging may take place, and will assist in describing sediment transport mechanisms and likely plume and transport effects. Concepts in sound resource management practices including environmental monitoring and ongoing assessment could also be introduced. This will assure stakeholders that "safety nets" can be put in place to detect and prevent significant environmental impacts. SOPAC may also provide assistance to Government to undertake a plan of action based on the outcome of these meetings, particularly if there is community consensus to pursue lagoon sediment extraction.

3.2 Milkfish Production

Funafuti borrow pits are not recommended as a viable option for milkfish aquaculture. It is likely however, that Tafua pond could be utilised for milkfish aquaculture but it's success will be dependent on several factors:

- Community acceptance of the product.
- Specialist establishment and management assistance.
- Kaupule's willingness / ability to continue the management regime.
- Consideration of the impact of placing more pig pens in the vicinity of the pond.

On a general note, it must also be understood that Tafua has changed significantly over the last 20-30 years and cannot easily be restored to its former "pristine state". Even if all the pig pens were removed, the pond's recovery could take many years and for the foreseeable future it will always be dominated by tilapia. Also, if the pigs were moved, where would they go, and wherever they go, a second pollution problem is likely to ensue. It should also be acknowledged that, even in its current state, Tafua performs an important community function by accepting and assimilating effluent from the numerous resident pigs. It processes much of this waste into tilapia biomass which is a greatly under-utilised resource as tilapia are an excellent source of protein and could easily be used for pig food rather than purchasing expensive feeds from overseas. Similarly, the mangroves which grow luxuriantly around the perimeter of the pond (Figure 7) could be sustainably harvested as a pole and/or a fire wood resource.

Figure 7. Dense mangrove stands (Rhizophora stylosa) lining the shore of Tafua pond.

PART 2 – VAITUPU ISLAND

Four issues were discussed during the meeting with Vaitupu Kaupule and were the main focus of our subsequent island tour and site visits:

- Consideration of a road base supply.
- Assessment of the Kaupule's identified milkfish production sites.
- Consideration of issues pertaining to water quality and in-filling of Vaitupu Lagoon.
- Consideration of a bridge / causeway over Tefota and Aua Opeti Passage.

1. Assessment of Aggregate Supply

Vaitupu has a comparatively large land area, is slightly more elevated above mean sea level (*ca* 0.5 m) and has a far smaller population than Funafuti. These factors determine that there is less pressure on land and marine resources to supply the needs of the Vaitupu community. As such, it is not surprising that during discussions with the Vaitupu Kaupule the issue of aggregate supply did not rank particularly highly and other than a single question concerning a source of road base, there was little concern about aggregates for construction purposes. Some houses were however, built of imported (Fijian) cement blocks but the reasoning behind their choice was related to the quality of these blocks in comparison to the locally-made product, rather than a lack of aggregate.

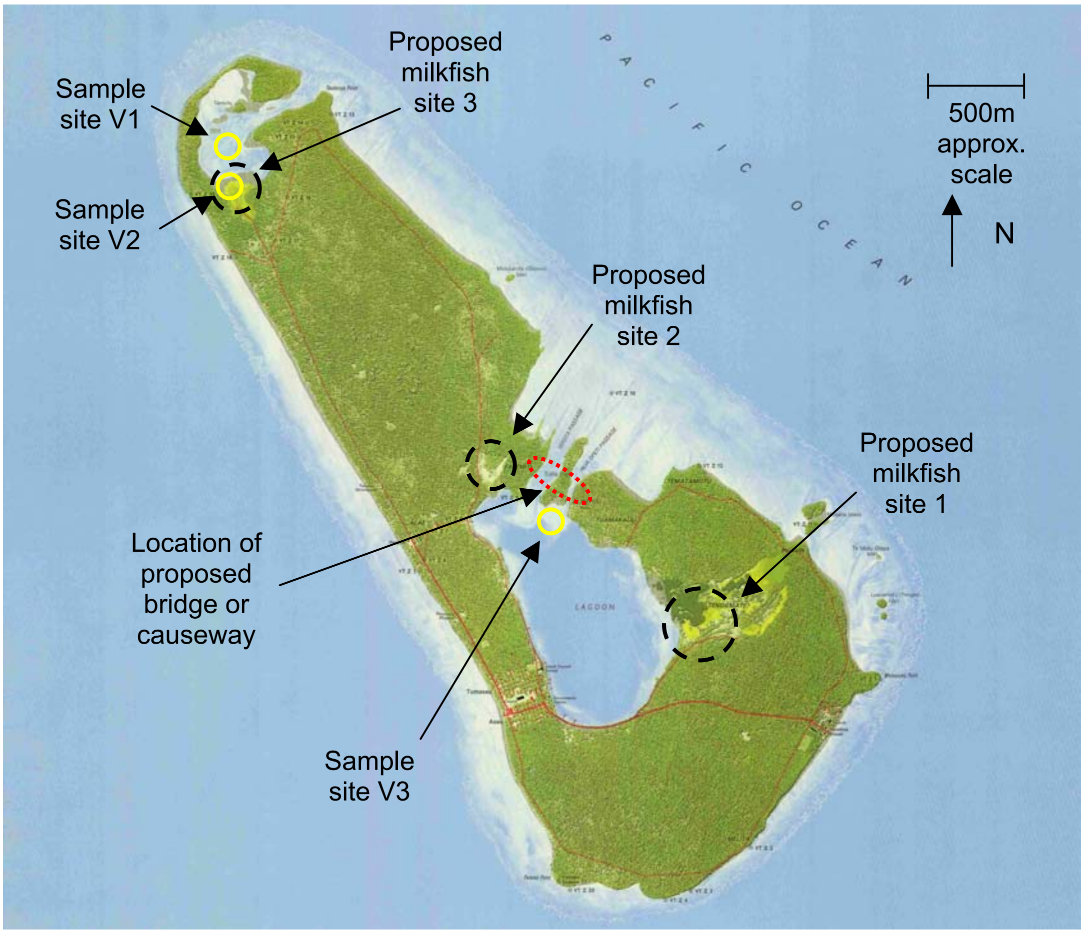

Figure 8. Vaitupu Island showing sand sample locations and the Kaupule's proposed sites for milkfish production and a bridge or causeway over the Tefota / Aua Opeti Passage. (Source – Vaitupu Is. 1:10 000 Topographic, Department of Overseas Survey, UK. 1974).

Aggregates are collected mostly with shovel and bag by individuals and by tractor and trailer by the Kaupule. There seems little control over this process but at the present rates of consumption there seems few significant negative impacts. The beach is favoured as a gravel and sand collection site for private interests and larger-scale sand collection (by the Kaupule) has taken place at swamp taro pit spoil mounds (Figure 9). Some of these pits are many hundreds of square metres in area and over 1 m deep and the resulting spoil mounds are large. At present rates of consumption these will likely supply the community's needs for some years to come and their removal does not present significant environmental issues. Visual field analysis of these sands showed they were chiefly composed of coral and foraminiferal fragments, and were well sorted with a grain size predominantly less than 1.5 mm. These sands whilst useful for construction (concrete) do not form a good road base material as they do not readily compact and harden.

Figure 9. The spoil piles on the edge of large swamp taro pits (dug in pre-European times) are used as a sand resource.

Fine Halimeda(lagoon-dwelling calcareous algae)-derived basin deposits are a preferred road base material in atoll environments as these readily compact to form an excellent hard cap over softer substrates and are usually in abundant supply on atolls with larger lagoons. Vaitupu does not have an extensive lagoon and none of the sediments sampled were predominantly Halimeda in origin. Of the sites sampled, Site V2 (Figure 8) may have some potential for road base purposes as this material had a significant fraction of 4-16 mm gravel (approximately 40% – Figure 15), which may produce a more durable road surface. Otherwise, finer lagoon muds may be available in Vaitupu Lagoon however, the Kaupule is unwilling to risk the potential environmental damage which could be caused by dredging.

Sample site V2 (Figure 8) also corresponds to a proposed milkfish production site (No. 3 – Figure 8). Since milkfish production will require the digging of ponds in these intertidal sand flats, if this activity goes ahead, it could also generate a large amount of general purpose fill and road base which could be stockpiled and utilised by the Kaupule. These intertidal flats were comparatively extensive, were not vegetated nor were they extensively utilised by burrowing infauna (Figure 10). As such, from the sites assessed this area represented the least environmentally sensitive for both pond construction and road-base extraction.

Figure 10. Proposed milkfish production Site (3) in the northern lagoon area. Sediments from this area could also be used as a road base material and may be readily available if ponds are dug for milkfish production.

2. Milkfish Issues on Vaitupu

During our meeting with the Vaitupu Kaupule, milkfish production dominated the discussions. The Kaupule has designated 3 sites for potential production, two of which (sites 1 and 2) have previously been used for this purpose (see Figure 8). Tilapia have not been introduced to Vaitupu and this alone makes any such venture significantly easier. The environment is comparatively unperturbed and cultural issues such as those pertaining to the consumption of fish from Tafua pond do not exist. Milkfish already utilise the protected environments of both the northern and main lagoons of Vaitupu and this wild population maintains a supply of fry which could be utilised to stock production ponds.

The Vaitupu community wishes to pursue this venture as: (1) milkfish are a favoured eating species; (2) ponds can supply fresh fish during periods of bad weather when reef and ocean fishing is difficult; and (3) a potential income generation option (Funafuti market). This last point is of particular importance as the price of copra (previously the main source of income) is no longer subsidised. As such, it is not economic for farmers to continue copra production leaving very few income-generating options to outer island families. The second and third points are also consistent with the EDF Programme goals of reducing vulnerability of small island states and communities.

2.1 Decline in Vaitupu Lagoon water quality and milkfish abundance

Elderly members of the Kaupule indicated that milkfish were far more abundant in Vaitupu Lagoon in earlier times and the Kaupule felt that issues of water quality, over-fishing and infilling of the lagoon have contributed to the decline in milkfish and general productivity of the lagoon. Water quality does appear to have changed as living coral outcrops were present in the lagoon in earlier times (evident in 1984 airphotos) however it was reported that these have now disappeared or are dead. The lagoon waters were turbid at the time of our visit and this appeared to be mostly related to the re-suspension of sediment fines as the water had a typical milky appearance. Another factor which contributes to water quality change is the proximity of the main Vaitupu settlement to the lagoon (on the SW shoreline). It is likely that effluent from pit toilets, pig pens and other wastewater from the village contributes a significant nutrient load to the lagoon as contaminated subterranean water moves through the island. The impact these inputs may have on the overall "health" and ecology of the lagoon are in turn dependent on oceanic flushing regimes. There is only one ocean entrance into the lagoon divided into 2 shallow passages (Figure 11) and oceanic flushing is probably not sufficient to maintain the former water quality conditions with the more recent pressures of nutrient loads and environmental change.

Figure 11. Water clarity in this 2004 IKONOS image of Vaitupu Lagoon is comparable to that of the 1984 airphotos and there is no indication of the lagoon becoming shallower particularly in the northern entrance area (the only significant source of transport into the lagoon). These mobile sand shoals at the entrance appear to have been surprisingly stable with few differences apparent between the 1984 and 2004 images. The absence of live coral is however evident in the northern area of the lagoon.

Figure 11 shows that large channels to the lagoon existed in fairly recent times at the SE corner and at the NE point of the lagoon. These intertidal areas are now separated from the main lagoon by causeways, which allow only limited marine water to move into the low-lying channel areas at high tide. Dense mangrove stands (*Rhizophora stylosa*) and ironwood thicket (*Pemphis acidula*) dominate the southern low-lying area and in earlier times (presumably before the causeway was built) it was valued by the community as a milkfish fry refuge area. The northern relict channel represents a similar habitat and likely preformed a similar function however, the vegetation is presently dominated by ironwood as marine flushing is possibly inadequate to support mangroves. When open, these intertidal flats may also have performed a significant biochemical "cleansing" function of the lagoon waters (nutrients being removed by benthic algae and macrophytes during high tide) and elsewhere similar environments are known to be the sites of high productivity and drive important food-chains (Webb, 2003).

The changes in water quality and ecology within Vaitupu lagoon could partially be a natural result of ongoing in-filling processes which are gradually restricting the amount of marine flushing and exchange between the ocean and lagoon. Over the years sediment has moved from the outside reef flat to the lagoon gradually choking and closing the passages. This process is confirmed by the composition of sediment sample V3 (Figure 14) as these sediments are mainly composed of Forams (*Baculogypsina spp.*) which are associated with reef flat environments, not enclosed lagoons. This gradual infilling has reduced flushing regimes and the negative effect of this on water quality has been greatly magnified by more recent human activity (nutrient loading and the isolation of the main lagoon from ecologically-important intertidal areas). As a consequence the lagoon has experienced a slow decline in water quality leading to the death of corals and possibly the decline in species such as milkfish.

2.2 Assessment of Milkfish Production Sites

As discussed milkfish are known to tolerate conditions of significant nutrient enrichment (e.g. Tafua pond) as such, it seems unlikely that there are any water quality issues preventing milkfish aquaculture at any of the proposed sites on Vaitupu. Furthermore, there is no tilapia on Vaitupu, there is a known milkfish fry resource for stocking purposes and there is a ready market for the sale of milkfish locally and on Funafuti. There is also a large work force on Vaitupu with limited income options and these factors combined suggest that a milkfish production venture on Vaitupu should be comparatively successful. The largest obstacle was the lack of expert advice to assist the Kaupule to initiate and run such a venture.

The level of management and infrastructure required would depend on the level of production the Kaupule is interested in pursuing. A low-intensity operation is recommended, as this requires minimum costs, infrastructure and inputs. Also, intensive aquaculture can lead to subsequent environmental problems of pond effluent disposal and nutrient enrichment of neighbouring environments. It is highly recommended that the Kaupule seek the advice and assistance of a milkfish aquaculturalist to assist in the final site selection and design of ponds and the implementation of a management regime.

3. Assessment of the proposed causeway over the Tefota / Aua Opeti Passage

The Vaitupu Kaupule has proposed building a causeway or bridge over the Tefota and Aua Opeti Passage of Vaitupu Lagoon (Figures 8 and 11). As discussed above, maintaining and possibly enhancing the tidal flushing of Vaitupu Lagoon is of great importance if the health and ecology of the lagoon is to be preserved. As such, any obstruction of tidal flow in and out of the lagoon is not recommended. During the site visit various configurations of the proposed causeway or bridge were discussed and assessed (see Figure 12).

The Kaupule is experienced with causeway building and this option (Option 3 – Figure 12) is attractive as both materials and technical skills are locally available and the cost of this type of structure is comparatively low. However, it is strongly recommended that the Kaupule does not pursue a causeway option, as this will reduce water flow into the lagoon. As such, if the Kaupule wishes to pursue this project the only appropriate structure would be a pylon and platform bridge over both channels (Option 1 – Figure 12). Care should be taken so that bridge ramparts do not extend out into the intertidal areas of the passages (often done to reduce cost by shortening the span of the bridge platform (Option 2 – Figure 12), as ramparts will affect flow through the passages during high tide and often cause erosion of passage shorelines.

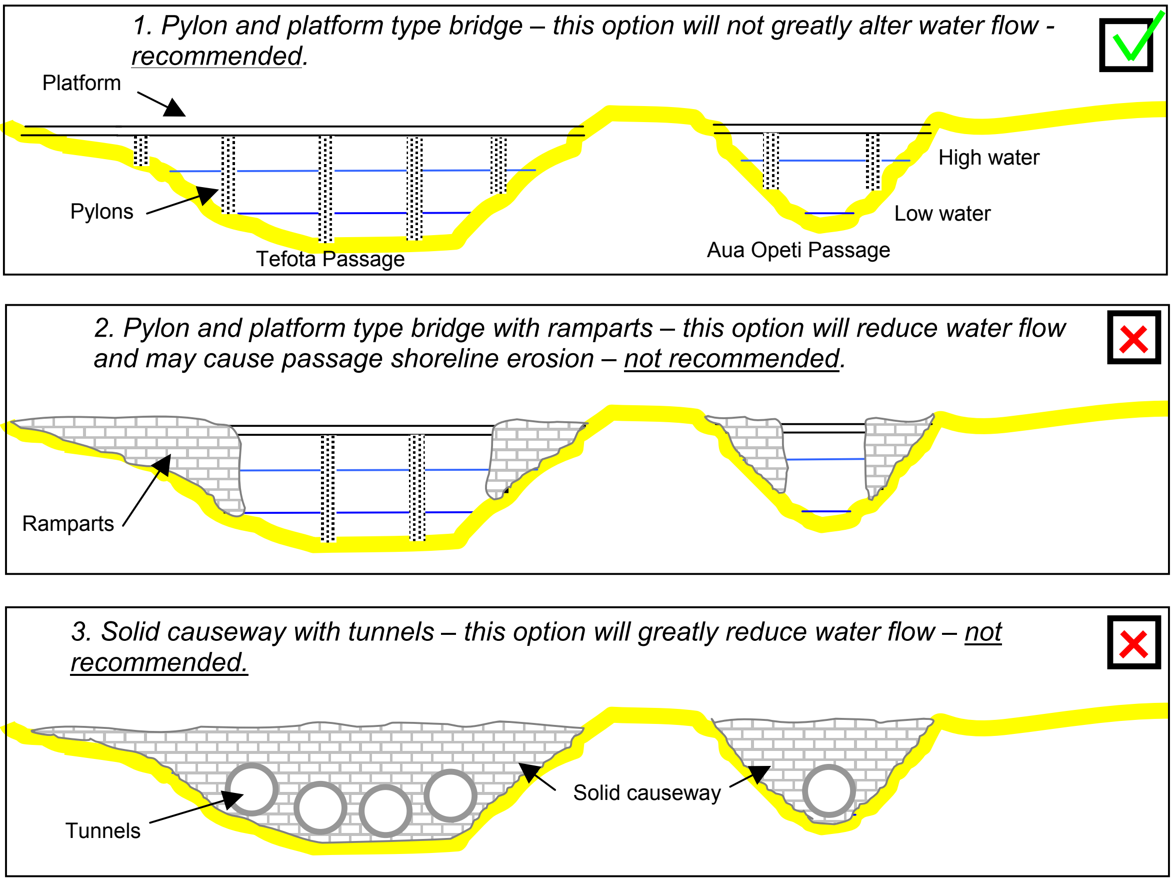

Figure 12. Conceptual diagram's of causeway / bridge options for Tefota / Aua Opeti Passage, only option 1 should be considered if this project goes ahead.

4. Conclusions/Recommendations –-Vaitupu

4.1 Aggregate Supply

In general aggregates were not deemed by the Vaitupu Kaupule to be in short supply. Of the sites inspected and sampled, Site V2 (milkfish pond Site 3 – see Figure 8) may have potential as a supply of road base. Selection of this area is based on the sediment type, the less-sensitive nature of the environment and the potential to combine fill-extraction activities with the proposed excavation of milkfish ponds.

It should be noted that this recommendation is based on the analysis of surface samples and observation only and does not constitute a comprehensive assessment of the resource. Rather, it is intended to provide an appropriate level of advice for the modest aggregate requirements of the Viatupu community.

4.2 Vaitupu Lagoon

The three main factors that appear to affect water quality and therefore the ecology of Vaitupu Lagoon are:

- flushing regimes;
- nutrient enrichment; and
- causeways blocking flow and organism movement into and out of intertidal mangrove / ironwood swamp areas.

As discussed the infilling of Vaitupu Lagoon appears to be an ongoing and natural process which is gradually reducing tidal flushing of the lagoon. To ensure this process is not accelerated it is recommended that the shorelines, particularly those within and adjacent to the passages are protected from disturbance. The Kaupule may also consider mining sands for local construction purposes from the transient shoal at the lagoon entrance (Sample Site V3 – Figure 8). This will assist in slowing the infilling process, and in keeping the passage unobstructed, thereby enhance lagoon flushing. These clean, well-sorted foraminiferal sands are also suitable for construction purposes and low impact removal (by hand) is unlikely to have negative environmental impacts.

The only way to address nutrient loading into Vaitupu Lagoon is to have an effective wastewater collection and disposal system. To this end it is recommended that houses should have sound (not leaking) septic tank systems which are serviced regularly. The percentage of homes using septic tanks was not assessed, but anecdotal evidence suggests many homes are using simple pit systems and septic tanks are not strictly maintained. Both the issue of effluent disposal and wastewater collection requires considerable attention on Vaitupu and it is recommended that the Kaupule seek Government assistance in this regard.

The causeways across both the north and south eastern channel areas should be either removed or large sections replaced with a pier and platform bridge structure. This will allow less restricted water flow into these areas and in time the recovery of their ecological function and importance to the lagoon ecosystem.

It is stressed that the combination of these factors interact and intensify the overall reduction in health of Vaitupu Lagoon and whilst addressing any one of these issues will assist in slowing the decline. Only a coordinated effort to address all three issues, is likely to improve water quality towards its former state.

4.3 Milkfish Production

Vaitupu appears well placed to undertake a low-intensity milkfish production venture:

- It has a relatively clean, unpolluted environment.
- Tilapia are not present.
- The community is enthusiastic and is in great need of income-generating projects.
- A source of milkfish fry is readily available.
- Vaitupu has the best access to the Funafuti market of any of the outer islands.

Of the three locations proposed by the Kaupule Site 3 is recommended as the other two locations perform important ecological functions for Vaitupu Lagoon (particularly if the causeways were removed). They are also vegetated and are home to numerous burrowing infauna (crustaceans, molluscs, etc.) and are already used as a food source by the Vaitupu community. Site 3 is comparatively barren and is more extensive in area, it also appears to have the potential to double as a source of road base which could be taken from the spoil heaps during pond excavation.

It is strongly recommended that expert assistance is sought to confirm the site selection in terms of suitability for milkfish aquaculture and assist in the design and management of the venture.

4.4 Inter-island Milkfish Production

TANGO has attracted funds to establish a milkfish aquaculture venture in Tafua pond, Funafuti. As discussed in this report, there are issues pertaining to milkfish production in Tafua, which disqualify this area from a non-intensive traditionally-managed approach. There are also cultural questions regarding the appropriateness of any food production in Tafua.

As such, it is recommended that TANGO considers Vaitupu as a possible recipient of assistance with regard to milkfish production, particularly if TANGO acquires the services of an aquaculture expert. Milkfish production in Vaitupu can be undertaken as a more traditional, lower-intensity operation and its probability of long term success (sustainability) is consequently far greater. It is also obvious that many of the negative factors surrounding the Tafua proposal are not issues in Vaitupu. On a broader note, the creation of income-generating activities and food security on the outer islands are important issues and correspond well with EDF 8/9 Programme goals regarding the reduction of vulnerability of small island communities.

4.5 Causeway over Tefota / Aua Opeti Passage

It is important that the Vaitupu Kaupuli consider the environmental impact of building causeways in Tefota or Aua Opeti Passages, as any solid structure built in these passages will reduce water flow into and out of Vaitupu Lagoon. Reduced lagoon flushing will in turn speed the decline in health of the lagoon and will affect fisheries to an even greater extent.

It is also important to understand that whilst it is recommended that the existing causeways over the relic channels in the lagoon be removed (Figure 11), the removal of these causeways will increase the water volume of the lagoon and as a result, the velocity and volume of water which will move through Tefota or Aua Opeti Passages. As such, the maintenance of unrestricted flow through the channels with be of even greater importance.

Furthermore, new causeway structures over Tefota and Aua Opeti Passages are not recommended. Assuming this option is rejected, two other alternatives are advisable to the Vaitupu community:

1. Leave the passage as it is and improve, and use, the western side roadway to gain access to the northern end of the island.

2. Approach Government or seek outside assistance to build a pylon and platform bridge over the passage. It is strongly recommended however, that the design of any bridge should satisfy the environmental considerations outlined in this report (see Figure 12).

ATTACHMENT 1 – SEDIMENT SAMPLE COMPOSITION AND GRAIN-SIZE ANALYSIS

Overview

Eleven sand samples (8 from Funafuti and 3 from Vaitupu) were collected for grain size and composition analysis. Sampling was opportunistic in nature (deep-water samples being taken randomly during routine dives) and is intended as a preliminary guide rather than an intensive resource assessment. No drilling or deeper sample acquisition was attempted and all samples were scooped by hand from the upper 15 cm.

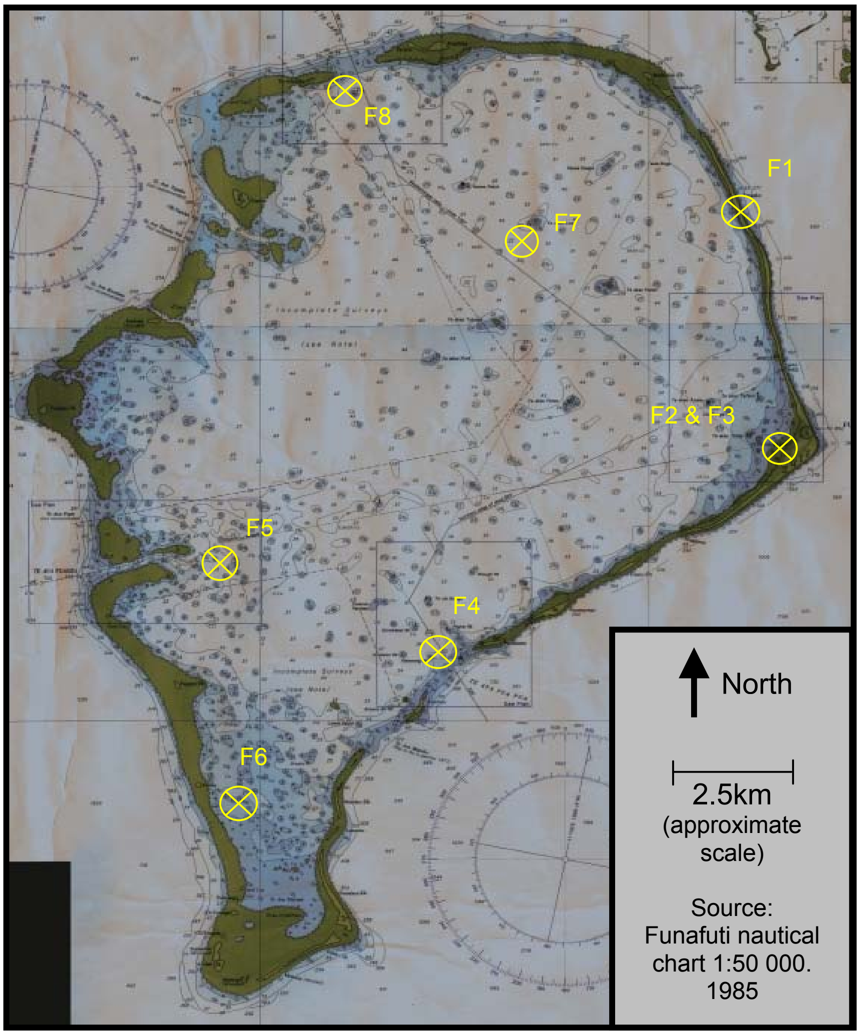

Figure 13. Funafuti sand sample locations (Figure 8 for Vaitupu sample locations).

Sediment sample composition analysis

Shallow lagoon and terrestrial sediment from Funafuti and Vaitupu all showed a predominance of Foraminiferal tests (40-60%). These were composed mostly of species from the genus *Baculogypsina, Marginopora, Amphistegina* and *Calcarina*. Otherwise, *Halimeda* (calcareous algae) greatly dominated the composition of deeper-lagoon samples (see Figure 14). The composition of these samples is consistent with other studies of the Funafuti Lagoon environment (e.g. Smith 1995; Collen and Garton 2004) and similarly highlights the importance of sediment production by both Forams and Halimeda as well as corals. Sediments composed of coral debris and foraminiferal tests (calcite) are more durable for construction purposes, whereas Halimeda-derived particles (aragonite), are physically soft and are more susceptible to chemical weathering

(Collen and Garton 2004). Fine-grained *Halimeda*-derived sediments are nevertheless useful for road building purposes as they form a hard, durable surface when compacted.

Table 2. Funafuti sediment sample collection information (see Figures 8 and 13 for Vaitupu and Funafuti sample locations, respectively).

Location description ***Vaitupu***	***Date***	***Position***	***Sample #***	***Notes***
Vaitupu Northern lagoon / Temotu Islet. Lagoon basin	21/09/04	178 40 00 7 27 45.00	V1	Basin deposit subtidal 30 cm deep
Vaitupu Northern lagoon / Temotu Islet. Sthn. Lagoon flats	21/09/04	178 40 00 7 27 55.00	V2	Intertidal flats proposed milkfish pond
Vaitupu Bar deposit Vaitupu lagoon / Tofia Islet Sthn. extremity	21/09/04	178 39 40.55 7 27 29.50	V3	Sand bar deposit – infilling from ocean transport

Location description ***Funafuti***	***Date***	***Position***	***Sample #***	***Notes***
Funafuti Nth. Tengako terrestrial deposit	16/09/04	179 11 31.308 8 27 53.532	F1	0.5 m deep homogenous sand deposit – undisturbed horizon / midpoint through island – sand mine
Funafuti Subtidal near-shore deposit Vaiaku Langi Hotel	15/09/04	179 11 40.992 8 31 21.468	F2	2 m depth sand flats Halimeda meadows close by
Funafuti Beach deposit Vaiaku Langi Hotel	15/09/04	179 11 41.64 8 31 21.468	F3	Mean sea level beach deposit
Funafuti Doppler position 3 Funamanu Islet / Te Ava Puapua Passage	19/09/04	179 07 30.6506 08 33 49.8054	F4	Approximate depth 25 m
Funafuti Doppler Position 2 Vasafua Islet / Te Ava Fuagea Passage	18/09/04	179 04 45.4076 08 32 18.9435	F5	Approximate depth 25 m
Funafuti Southern lagoon / West off Luamotu	05/10/04	179 09 49.11 8 60 94.80	F6	Approximate depth 6 m
Funafuti Northern lagoon / North off Te Akau Loa reef	04/10/04	179 14 24.14 8 46 66.06	F7	Approximate depth 10 m
Funafuti Northern lagoon / South off Te Afuaaliku reef	23/10/04	179 11 40.17 8 43 19.95	F8	Approximate depth 16 m

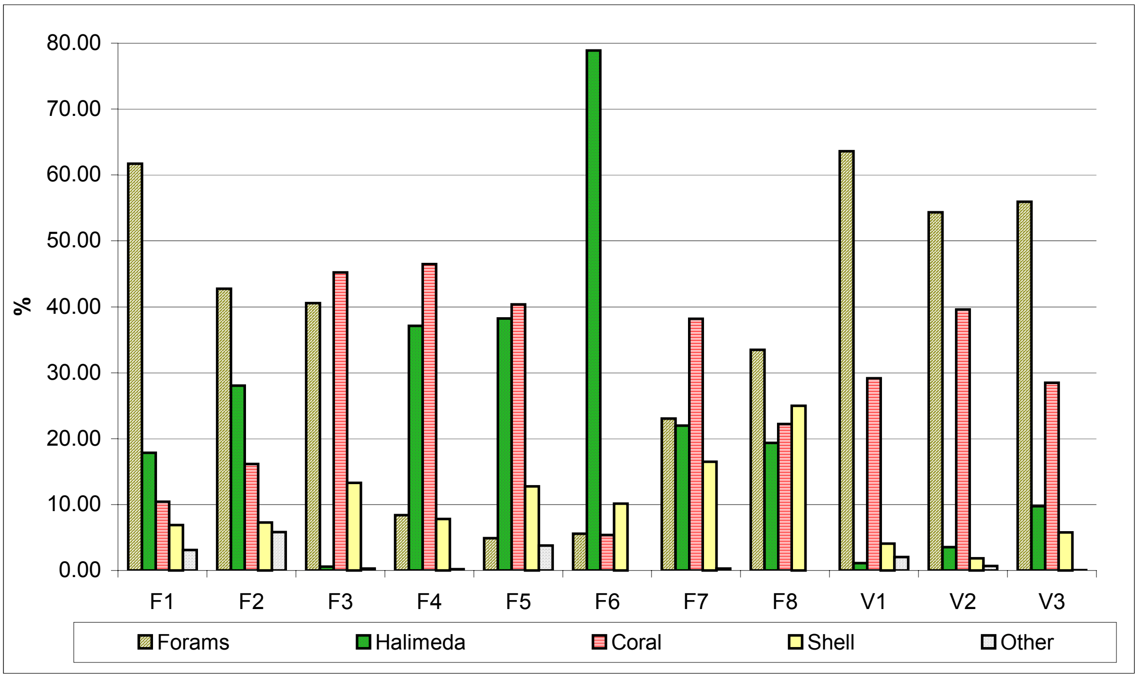

Figure 14. Comparative composition of Tuvalu sediment samples. Note the contribution of Forams in all shallow water environments F1, F2, F3, V1, V2 and V3 and Halimeda in the deeper water environments F4, F5 and F6 samples (see Figures 8 and 13 and Tables 2 and 3 for site and composition details).

Table 3. Percentage breakdown of main sediment components (note that in Figure 14 Foram species are grouped together).

	F1	F2	F3	F4	F5	F6	F7	F8	V1	V2	V3
Baculogypsina	15.49	11.42	7.15	0.00	0.00	0.00	0.00	6.22	41.62	28.74	37.09
Marginopra	22.13	7.49	11.81	0.85	0.67	1.76	2.11	2.68	16.91	19.63	9.59
Amphistegina	14.57	5.18	16.98	7.14	4.08	3.35	13.56	6.28	5.07	4.81	9.24
Calcarina	9.53	18.66	4.64	0.42	0.14	0.47	7.36	18.28	0.00	1.14	0.00
Halimeda	17.86	28.03	0.60	37.10	38.24	78.89	21.97	19.35	1.11	3.56	9.76
Coral	10.42	16.14	45.24	46.48	40.36	5.40	38.18	22.21	29.15	39.59	28.49
Shell	6.89	7.27	13.28	7.82	12.76	10.13	16.51	24.98	4.09	1.82	5.78
Other	3.11	5.81	0.30	0.19	3.76	0.00	0.30	0.00	2.05	0.70	0.06

Sediment sample grain-size analysis – Funafuti.

Figures 14 and 15 show that the existing sand resources in Funafuti (land F1 and beach deposits F3) have comparatively low percentages of Halimeda and at least 60 % of these sands are composed of granules between 0.25 and 1.4 mm ∅. This indicates that as well as being logistically easier to obtain, they are also of comparatively good quality for construction purposes. Deeper-channel deposits F4 and F5 contained a large Halimeda component (>35 %) and also contained a greater percentage of coarse material (2-4 mm ∅ – >35 %). F6 sands from the protected depositional environment of the southern lagoon area, contained a comparatively large percentage (>60 %) of fines (<0.125 mm ∅) and were almost entirely Halimeda-derived. Whilst this excludes F6 sands for construction purposes they would likely form an excellent road base material when compacted. The remaining samples F2, F7 and F8 are comparable to beach and land deposits in grain size (approximately 60 % laying between 0.25 and 1.4 mm ∅) but had higher percentages of Halimeda (20-25 %). F2, F7 and F8 are also comparable to the offshore deposits Smith (1995) identified as an adequate resource for exploitation by the Funafuti community for general building and fill purposes.

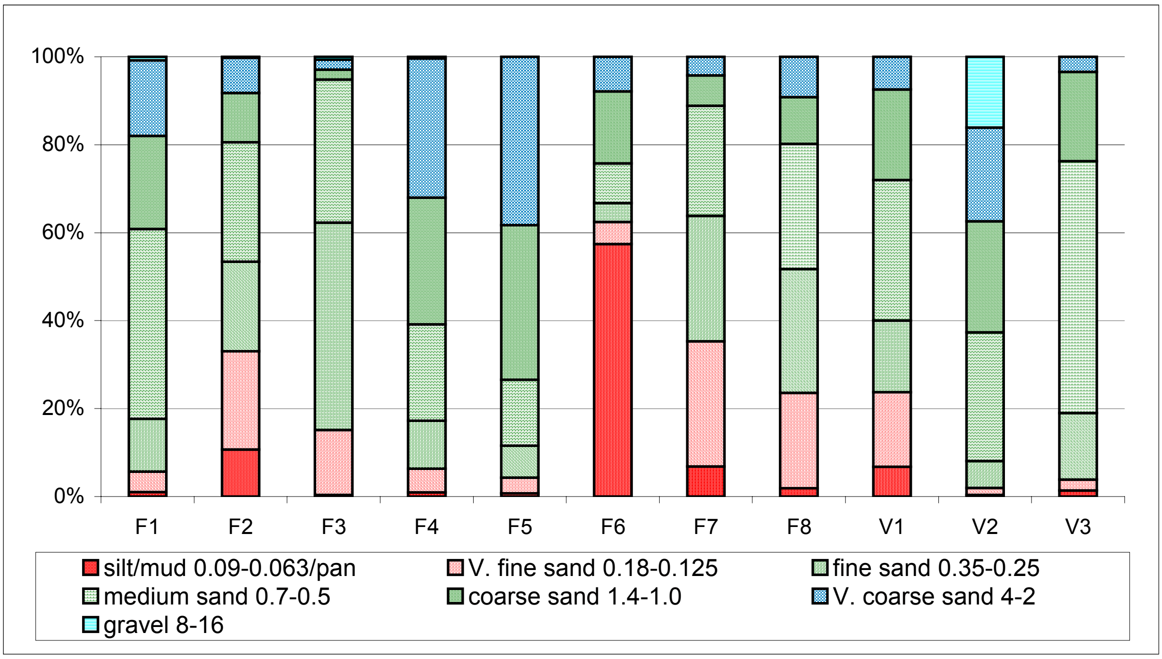

Figure 15. Sediment sample grain-size analysis.

Sediment sample grain-size analysis – Vaitupu

Of the three samples obtained in Vaitupu the components of sample V2 show a significant fraction (approximately 40 %) of coarse sand and gravel particles (2-16 mm ∅). As such, this material may be a suitable alternative for the Vaitupu Island community to consider as a road base rather than the well-sorted, non-compacting sands which are currently used. As mentioned earlier this area is also under consideration for aquaculture pond excavation and the spoil from this activity may double to supply the Vaitupu community road-base needs.

ATTACHMENT 2 – TAFUA POND SEDIMENT NITROGEN, LEAD AND COPPER ANALYSIS

Overview

Seven 100-g sediment samples were taken from Tafua pond, Funafuti at the request of the Funafuti Kaupule (Island Council) and in cooperation with TANGO (Tuvalu Association of Non Government Organisations) and the IWP (International Waters Project). These samples were taken from the western side as the sediments of the eastern side could not be sampled successfully due to bedrock underlying a few centimetres of extremely flocculent organic detritus. A seventh sediment sample was also collected and analysed as a control. The control sediments were collected from a comparatively undisturbed area on the leeside of the fore-dune between the pond and the ocean (Site 7, Figure 16).

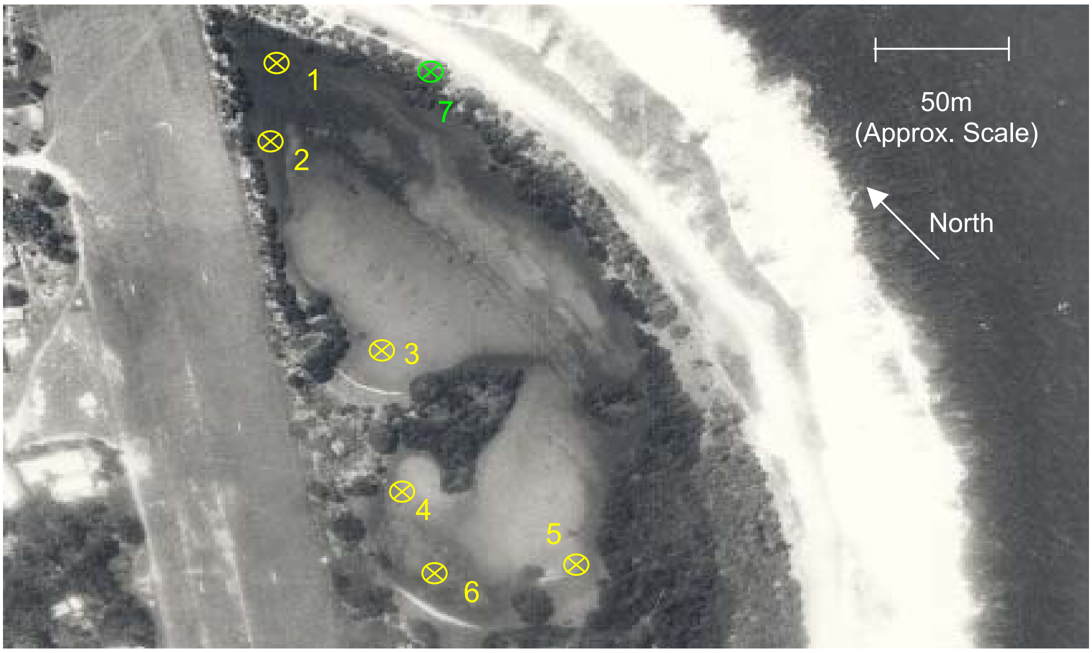

Figure 16. Tafua pond sediment sample locations.

Groundwater is no longer used for human consumption on Fongafale as it is often brackish but also because of the known risks of bacterial, metal and nutrient contamination. The IWP indicated that concentrations of both copper (Cu) and lead (Pb) have been found to be of concern in groundwater samples elsewhere on Fongafale and the Tafua samples were analysed for the presence of both metals (elevated concentrations of Cu and Pb is presumably related to ordinance haphazardly dumped and buried by the US forces in the early 1940's). It is important to consider the level of contamination of Tafua as it is possible that persistent metals may transfer up the food chain due to bioaccumulation in food species (milkfish) and become a human health issue. This is also an important consideration if tilapia are to be used as a pig food as a similar accumulation could occur.

Total nitrogen was also analysed, as in brackish and marine systems the availability of nitrogen usually limits primary production (algal growth). Sediment-nutrient concentrations in turn can give an indication of the level of nitrogen enrichment in shallow systems as much of the organic matter produced and added to the system settles in the sediments. Once this material enters the sediment environment, redox (anoxic / oxic) reactions act to recycle and return the nitrogen to the water column for subsequent use by primary producers (nitrification, ammonification), or nitrogen may also be removed from the system by sedimentary processes (denitrification). Due to these processes and other factors (tide, rainfall, loading, weather, etc.) water column nitrogen concentrations may vary considerably in such a small water body over short time intervals and the storage of nitrogen in the sediments gives an overall indication of enrichment particularly when compared with the control sediments.

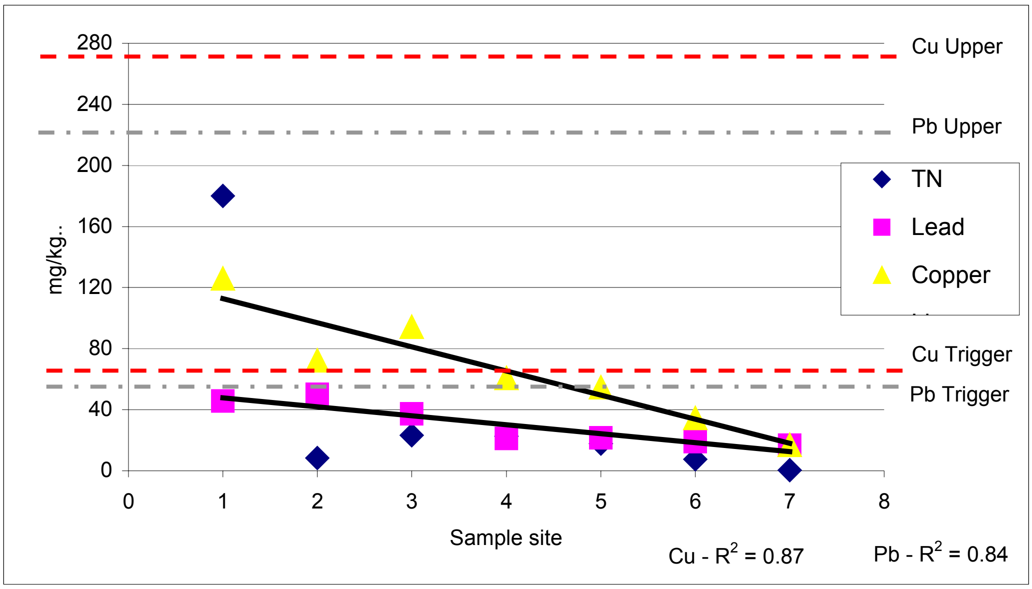

Figure 17. Total nitrogen (TN), lead (Pb) and copper (Cu) concentrations in 6 sites and the control sediment of Tafua pond. Dashed lines indicate the ANZECC (2000) "trigger" and "high" concentration limit recommendations of Cu and Pb in sediments.

Table 4. Total Nitrogen, Cu and Pb analyses results.

Site		1	2	3	4	5	6	7 (Ctrl)
TN	mg kg^{-1}	180	8.3	23.2	22.7	17.9	7.6	0.5
Lead (Pb)	mg kg^{-1}	45.7	50	37.3	21.2	21.6	19	16.7
Copper (Cu)	mg kg^{-1}	125.7	72.2	94.1	60.6	54.4	34.4	16.8

Total Nitrogen Concentrations

All sites particularly Site 1 appear to have elevated TN concentrations in comparison to the control sands however, these concentrations are still considerably lower than those common in relatively clean shallow sandy marine sediments in Australian systems (931-309 mg kg^{-1} – Webb, 2003). In light of the TN concentrations in comparison with the control sands (and other observations already discussed) the pond ecosystem could not be considered "pristine". However the level of nitrogen contamination is relatively low and the sedimentary and other uptake processes (algae, mangroves, etc.) appear to be able to process and/or remove the present degree of nitrogen loading. Tilapia are abundant in the pond and it appears the present degree of nutrient loading has stimulated their growth rather than disrupting it.'

However, caution should be exercised in expanding pig production on Tafua's shores, as the pond may quickly reach the limit of its assimilative capacity (i.e. it will no longer be able to process all of the additional nutrients and the system may "crash" resulting in water conditions which are too polluted to support fish). It is recommended that harvesting of the tilapia (pig food) and mangroves (building, firewood, etc.) be undertaken, as these activities will assist in producing a net movement of nutrients out of the pond.

Metal Contamination

Both Cu and Pb had consistently higher concentrations in comparison to the control sediments. The concentrations of Pb remained at or below the ANZECC (2000) trigger value (50 mg kg^{-1}) and as such, does not appear to represent an immediate problem. However, regular monitoring is recommended particularly since fish may bioaccumulate metals in their tissues. Copper concentrations are significantly higher than the trigger value (65 mg kg^{-1}) at Sites 1 and 3, however in marine systems copper can be bound strongly by sulphide in sediment redox layers and as such, is not necessarily bioavailable. Since Tafua pond is marine dominated, Cu is also not likely to be an immediate contamination problem.

As a useful safe guard and indicator of the potential for metal bioaccumulation during milkfish production, it is recommended that tissue from the tilapia currently living in the pond are sampled and analysed. This would be a useful guide and it would also be advisable that any such preliminary sampling and analysis include a broader suite of contaminants.

Of some concern is the apparent trend of increasing contamination of metals from the south to the northern point of the pond (Figure 17). This possibly indicates a source of contamination in the northern area of the pond or adjacent groundwater areas. This pattern may also be related to the predominance of the easterly wind direction as the dominant trade winds may act to accumulate detritus in the north-eastern point where it has collected and formed a more contaminated zone within the pond (note that nitrogen concentrations are also far higher at this location). This pattern could also be related to the comparative ease of access to the pond foreshore at this location and the larger amount of solid waste, which has been dumped there as a result. And finally, the north-eastern point is also the deepest part of the pond and as such, may also naturally accumulate a greater percentage of detritus.

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