A CASE HISTORY FROM TONGA: THE DEGRADATION OF FANGA'UTA LAGOON, TONGATA

Leon Zann
Great Barrier Reef Marine Park Authority

INTRODUCTION

The effects of urbanization, changing land use, pollution and overfishing are most apparent on coral reefs of the Third World nations of the South Pacific and South-East Asia. Australia, the only developed nation with significant areas of coral reefs, can learn much about anthropogenic effects on reefs from the misfortunes of others.

Fanga'uta Lagoon is a shallow, almost enclosed embayment in the northern coastline of Tongatapu Island, the main island of the Kingdom of Tonga in the South Pacific (Fig 1.). It was once the focus of the island; the ancient capital of M'ua lay on its western shore, and its waters provided shellfish and fish, particularly mullet.

The pressures on the island's meagre resources have intensified this century. During the past 80 years Tongatapu's population has grown eight fold, to about 60,000. Urbanization has been rapid; Nuku'alofa, the modern capital, has grown from 3,000 to 30,000 in 50 years (Crane, 1979).

Added pressure was placed on the lagoon's fisheries to 'meet the new urban demand for fresh fish. Traditional subsistence fishing techniques were replaced by more efficient monofilament gillnets, arrowhead fish fences, and a trawl fishery for penaeid prawns, and the use of explosives was common. The cichlid *Tilapia* has also been introduced, possibly competing with native species. The results of the increased fishing pressure has been dramatic; the lagoon fisheries virtually collapsed in the mid-1970s (W. Wilkinson, pers comm.).

Although commercial fishing was banned within the lagoon in 1975 the prohibition has never been strictly enforced. While the fish fences were removed from the lagoon, they were placed immediately outside the entrance where they continued to catch grey mullet migrating to and from the lagoon.

The general ecology was also greatly disturbed. Much of the lagoon has shoaled and the cover of mangroves, seagrasses and algae has increased. Water quality has declined; storm water drains and untreated sewage now discharge directly and indirectly into the lagoon. *E. coli* levels are high and typhus and other gastro-intestinal diseases are a major health problem in villages around the lagoon (Ludwig, 1979).

The following briefly summarizes the major findings of a joint study of the ecology, hydrography and fisheries of Fanga'uta Lagoon by the University of the South Pacific and the University of Hawaii, under the International Sea Grant Program, in 1981 (Zann, Kimmerer and Brock, 1982).

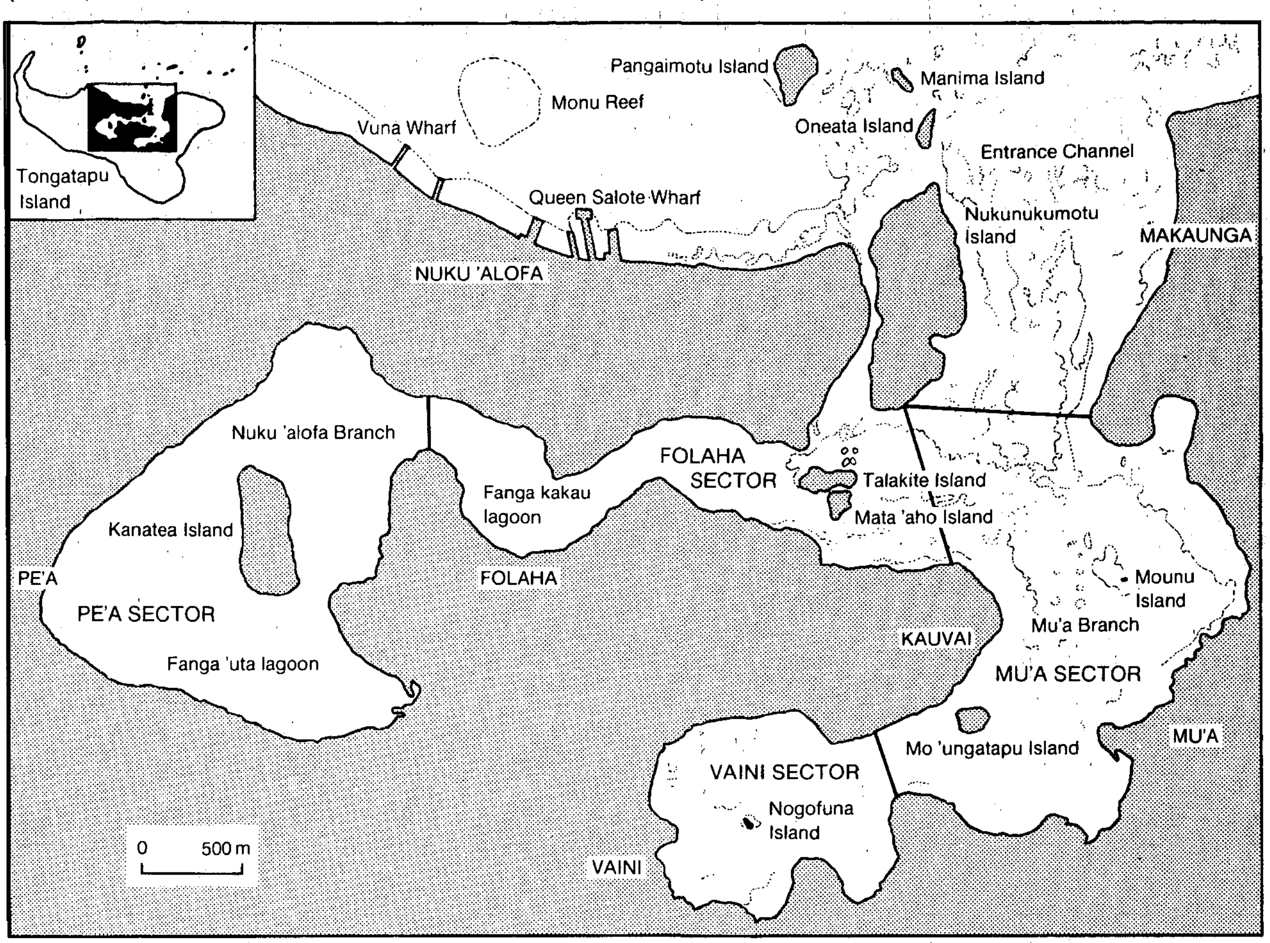

Figure 1. Fanga'uta Lagoon, Tongatapu

GEOMORPHOLOGY AND GEOGRAPHY

Tongatapu is an uplifted Pliocene/Quaternary coral reef. It lies on a geologically active zone along the edge of the Fijian and Pacific plates and has been progressively uplifted and tilted in very recent geologic time.

About 40km in length, the island is surrounded by fringing coral reefs. Platform reefs, some with sand cays, lie offshore on a submerged shelf on the northern side. The lagoon fills a bi-lobed depression in the centre of the island.

Fanga'uta Lagoon is about 27 sq.km in area, with a mean depth of 1.4m and a maximum of 6m. The two lobes (Nuku'alofa and Mu'a) are naturally divided into four sectors (Fig. 1), of which the Pe'a sector is the shallowest (mean depth 0.8m). The shallow areas are extremely turbid, as fine bottom sediments are resuspended in moderate winds.

The main opening consists of a wide intertidal reef flat (+0.2m to -1.0m datum), bissected by a channel (5.6m deep). The southern end of this subdivides into several channels which feed the two major branches.

The lagoon's watershed of 80 sq. km supports a human population of about 40,000. In Nuku'alofa which lies along the low northern and western shores of the lagoon urban planning has been minimal. Most sewage discharges into the ocean although the hospital discharges untreated sewage directly into the shallow Pe'a sector of Fanga'uta lagoon. Dissolved wastes from domestic septic pits enter the lagoon via groundwater, or directly during floods. Wastes from an industrial estate (warehouses, paint factory, light manufacturing etc.) and the island's diesel power station, which has a cooling main to the lagoon, are potential sources of pollution. Some leakage of fuel oil from the power station was seen during this study.

About 99% of Tongatapu has been cleared for cultivation, mainly of copra, taro 'and bananas and about 40% of farmers regularly use chemical fertilizers, 23% use insecticides and 26% use fungicides (Crane, 1979). Although the island lacks streams, agricultural chemicals may also enter the lagoon via the groundwater..

Although commercial fishing is prohibited in the 'lagoon, subsistence fisheries are still permitted. Major techniques include gillnetting, line and spearfishing, fish drives, crab trapping, and gleaning and wading for invertebrates. About 90 outrigger canoes (paopoa) and 40 punts and skiffs were based in the lagoon in 1981 (Zann, 1982).

ECOLOGY

Coral dominates the benthos of the ocean (northern) entrance to the lagoon but rapidly declines in diversity and abundance along the channel (Zann, 1982). Only one species (Porites sp.) persists into the relatively well flushed Mu'a sector and none are found in the other sectors (Fig.2). Large areas of dead Acropora, some partially standing, and extensive rubble banks at the subtidal lagoon (southern) end of the entrance indicates that a large scale, and relatively recent disturbance has occurred. Because there has been little or no subsequent recolonization of Acropora in this area the problem appears to be a chronic one.

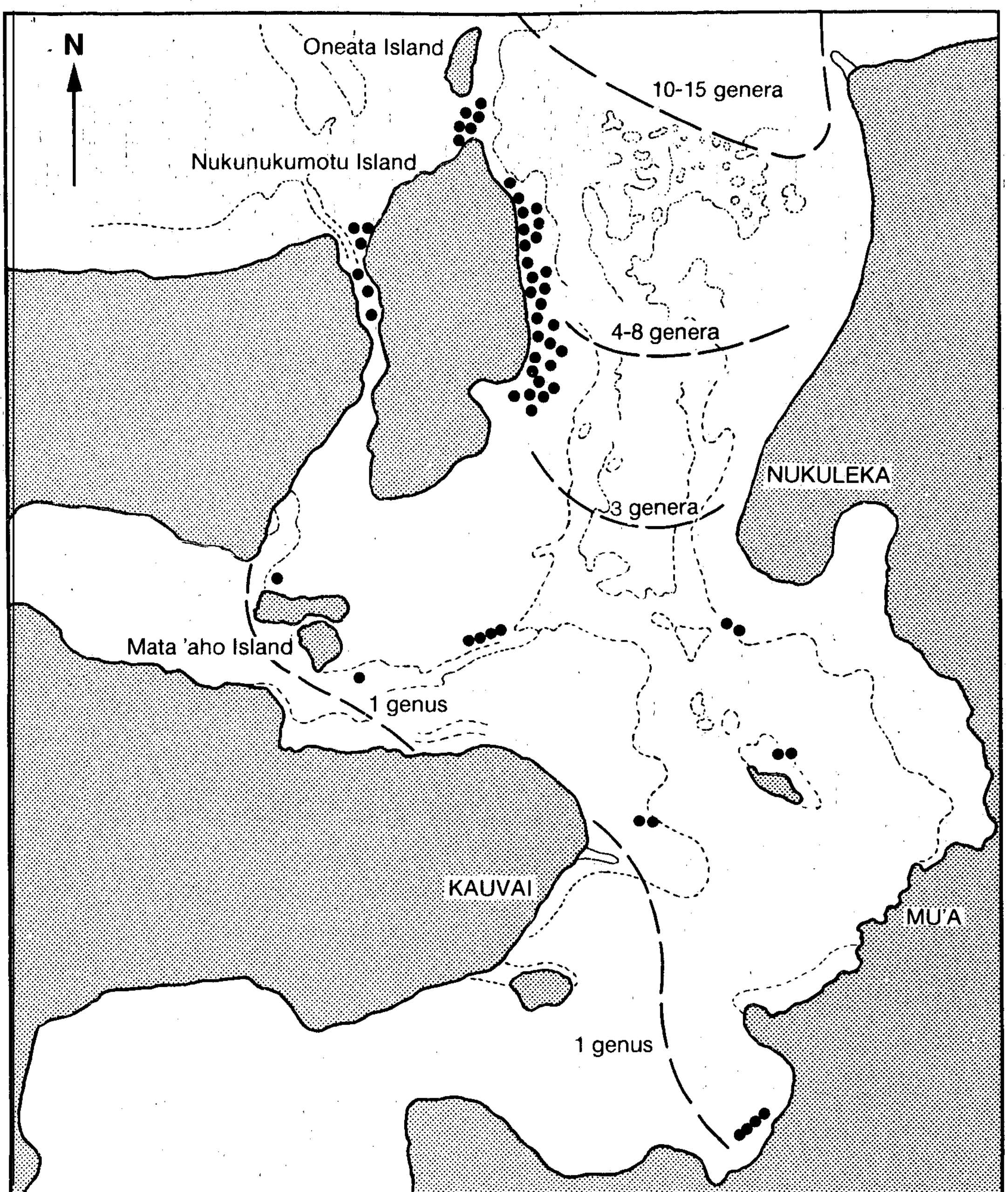

Figure 2. Genera of stony coral at dive sites, Fanga'uta Lagoon

The coral mortality has extended intertidally. Hundreds of large (2-3m diameter) Porites and faviid microatolls are, present on the reef flat surrounding Nukunukumoto Islet at the ocean entrance to the lagoon. Their general state of preservation also suggests a relatively recent time of death (decades or 'centuries ago), while their higher elevation (30-40cm) than living Porites microatolls in the vicinity indicates a sea level change was the cause of death. A major earthquake earlier this century is known to have caused some uplifting in Nuku'alofa (S. Tonganilava, pers. comm.).

The calcareous alga Halimeda discoidea dominates intertidal reef flats at the southern entrance. The seagrasses Halophilia ovalis and Halodule pinifoliosa are abundant on the reef flats and extend into the lagoon, particularly into the Vaini sector. Algae, dominated by Caulerpa spp., extend subtidally, but decrease with depth. Brock (1982) estimated the average wet biomass of seagrasses and algae in the lagoon was 562 g/m2 (wet weight) (Table 1). The total benthic production of seagrasses and algae was estimated to be 2,723 tonnes C/year.

The fauna of Fanga'uta is relatively diverse: 32 species of cnidarians, over 40 species of molluscs, 14 species of crustaceans, 18 species of echinoderms (Zann, 1982) and 96 species for fish (Brock, 1982).

HYDROGRAPHY AND CIRCULATION

The lagoonal circulation is driven predominantly by tides (Kimmerer, 1982). The ocean tidal range of about lm drives a current of up to 2.6 knots in the main channel and because the channel is constricted and shallow, the lagoonal tides lag behind the ocean and are of lower amplitude (eg. Nuku'alofa branch 0.13m range, lagging 3-4 hrs).

As there are no rivers or streams on the island, freshwater input into the lagoon occurs from the groundwater lens, and direct rainfall. An average input is ca. $2.6 \times 10^3\ m^3$/day, of which 85% enters through diffuse 'subsurface springs and 15% from solution channels on the shore.

From models of the freshwater input and tides, the residence time of water in the lagoon was estimated to be 23 days. Mixing on each tidal excursion is only about 12%; most of the water entering on the flood tide leaves on the following ebb tide without mixing.

WATER CHEMISTRY

Kimmerer (1982) found that nutrient levels in the surrounding ocean were low while those in the groundwater were high (Table 2). Nitrate and silica levels were much higher than normal but phosphate was not abnormally high. Nutrient levels in the lagoon were much lower (Table 3) indicating that it is very rapidly taken up by plants.

Kimmerer's mass balance model of total nitrogen and dissolved silica fluxes indicates that the biological processes dominating the four sectors are quite distinctive. The deep, clear, but relatively poorly flushed Vaini sector is largely dominated by benthic processes as illustrated by algae and seagrasses; the very shallow and very poorly flushed Pe'a sector is dominated by both plankton and detrital processes; and the better flushed Folaha and Mu'a sectors closer to the entrance are more dominated by planktonic processes (table 4).

DISCUSSION

Because Fanga'uta Lagoon is a complex semi-estuarine system with a constricted entrance to the sea and consequent long residence times, it has been particularly prone to natural and human 'disturbances. The combination, of the changes in' depth and circulation following the geological uplift of the northern coastline of Tongatapu Island, the introduction of new fishing technologies and high urban demand for fish, and the high input of nutrients from urban and rural developments has seriously disturbed the ecology of the lagoon.

Increased nutrient levels have probably had a significant effect. Some nutrients enter the lagoon directly from the hospital sewage outfall, storm drains from Nuku'alofa, and from surface runoff during heavy rain, but the majority probably enter via the groundwater. Nitrate levels in the groundwater are extremely high; although phosphates are relatively low. Benthic algae, seagrass and mangroves have therefore proliferated in the clearer areas of the lagoon although in the turbid Pe'a sector the system is 'dominated by decomposers and plankton.

The shallow entrance of the lagoon has shifted from being a coral-dominated system to an algal/seagrass dominated system. The shift is at least partially natural. The death of intertidal microatolls at the entrance to the lagoon is attributed to recent, geological uplift, while the virtual extinction of Acropora in subtidal areas may be due to changes in the lagoon's hydrography, and possibly the effects of increased nutrient levels on an already stressed system.

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TABLE 1
Wet we-ight in grams of the most common seagrass and algal species' collected from $150 cm^2$ random grab samples from each of the major sectors of Fanga'uta Lagoon (all depths, combined) (from Zann, Kimmerer and Brock, 1982)

Species	Wet Weight (g/m^2)		
	Nuku'alofa Sector	Folaha Sector	Mu'a Sector
Seagrasses			
Halophilia ovalis	113	33	13
Halodule pinifoliosa	113	140	193
Algae			
Caulerpa serrulata		293	
C. ramosa	80		240
C. ashmeadii	0.7		320
Cladophora sp.			53
Chlorodesmis spp.	93		
Halimeda discoidea		207	147
Gracilaria sp.			7

TABLE 2
Nutrient concentrations in groundwater (from Zann, Kimmerer and Brock,, 1982)

Nutrient	Concentration, g-at 1^{-1}	
	Mean	95% C.L.
Nitrate	78	57-99
Ammonium	<0.5	--
Phosphate	0.6	0.25-0.95
Silica	310	240-380

NOTE: Means and 95% confidence limits of the mean, (N-16)

TABLE 3
Summary statistics for water chemistry variables in Fanga'uta Lagoon sectors (from Zann, Kimmerer and Brock, 1982)

Variable	Sector: Pe'a	Folaha	Vaini	Mu'a
Nitrate	0.11±0.06(6)	0.11±0.08(3)	0.97±0.5(3)	0.4±0.3(5)
Ammonium	0.7±0.4(6)	0.5±0.01(3)	0.05±0.07(3)	0.7±0.3(5)
Phosphate	0.08±0.04(6)	0.5±0.004(3)	0.04±0.01(3)	0.09±0.08(5)
Silica	91±19(6)	48±3(3)	39±11(3)	17±4(5)
Dissolved organic nitrogen	23±3(5)	16±0.5(3)	11±3(3)	10±2(5)
Particulate nitrogen	10±1(3)	6±1(2)	4±3(3)	3.0±0.2(2)
Total nitrogen	34±4(3)	21±4(2)	17±4(3)	13±2(3)
Particulate inorganic carbon	3.3±1.7(3)	6.5±2(2)	5±2.5(3)	4.5±1.3(3)
Organic C:N ratio	12±1(3)	7±0.3(2)	9.2±0.8(3)	13±2(3)
Chlorophyll mg m^{-3}	1.8±0.9(6)	1.7±0.3(2)	1.9±1.6(3)	1.2±0.6(5)
%plant carbon	11±6(3)	17±(1)	26±5(3)	18±5(3)

NOTE: Mean ± standard deviation (N). All values in g-at l^{-1} unless otherwise noted.

TABLE 4
Material flux model for total nitrogen and dissolved silica (from Zann, Kimmerer and Brock, 1982).

	Pe'a Sector	Folaha Sector	Vaini Sector	Mu'a Sector
	Total Nitrogen			
Input in groundwater	8.0	1.3	6.6	4.7
Flux with adjacent sector	-6.0	6.0	-1.9	1.9
Flux to ocean	0	-6.2	0	-5.9
Uptake (net loss to benthos)	-2.0	-1.1	-4.7	-0.4
Sector area (km^2)	8.8	4.9	3.8	9.7,
Uptake per unit area (mmoles $m^{-2}d^{-1}$)	0.2	0.2	1.2	0.1
	Dissolved Silica			
Input in groundwater	31.0	6.0	26.0	18.0
Flux with adjacent sector	-20.0	20.0	-11.0	11.0
Flux to ocean	0.0	-22.0	0.0	-18.0
Uptake (net loss to benthos)	-11.0	-4.0	-15.0	-11.0
Sector area (km^2)	8.8	4.9	3.8	9.7
Uptake per unit area (mmoles $M^{-2}d^{-1}$)	1.3	0.8	3.9	1.1

NOTE: Fluxes are in Kmoles d^{-1} and are positive for flux into the sector.