Status of coral reefs on the main volcanic islands of American Samoa:

a resurvey of long term monitoring sites (benthic communities, fish communities, and key macroinvertebrates)

Amanave, Tutuila (photo: A.Green)

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EXECUTIVE SUMMARY ... 4
Coral Communities ... 4
Reef Fish Communities ... 8
Key Macroinvertebrates ... 10
Marine Protected Areas ... 11
Long Term Monitoring ... 12
INTRODUCTION ... 13
Large Scale Disturbances ... 13
Crown-of-thorns starfish ... 13
Hurricanes ... 14
Mass Coral Bleaching ... 15
Human Impacts ... 16
Fishing ... 16
Water Quality ... 20
Long Term Monitoring and Survey Objectives ... 21
METHODS ... 23
Description of Study Area ... 23
Samoan Archipelago ... 23
Reef and Habitat types ... 24
Location of Study Sites ... 24
Baseline Survey Design ... 27
Reef Fish Communities ... 28
Benthic Communities ... 30
Key Macroinvertebrates (Giant Clams and Crown-of-Thorns Starfish) ... 30
Resurvey Design ... 30
Reef Fish Communities, Benthic Communities, Key Macroinvertebrates ... 31
Large, Vulnerable Fish Species ... 31
Fish Recruitment ... 31
Fish Species Lists ... 32
Coral Bleaching ... 32
RESULTS ... 33
Benthic Communities ... 33
General Trends: Reef Slopes ... 33
General Trends: Ofu Lagoon ... 36
Reef Fish Communities ... 37
General Trends: Reef Slopes ... 37
General Trends: Ofu Lagoon ... 42
Key Macroinvertebrates ... 44
Giant Clams ... 44
Crown-of-Thorns Starfish ... 45
DISCUSSION ... 46
Recovery from Large Scale Disturbances on Tutuila and Aunu'u ... 46
Chronic Impacts of Crown-of-thorns Starfish in the Manu'a Islands ... 52
Human Impacts ... 54
Fishing ... 54

Water Quality 60
Mass Recruitment of Surgeonfish *(pala'ia)* 63
Mass Coral Bleaching 67
Marine Protected Areas 69
Monitoring Recommendations 73
ACKNOWLEDGEMENTS 77
REFERENCES 78
LIST OF FIGURES 83
LIST OF TABLES 84
LIST OF APPENDICES 85
LIST OF ACRONYMS 86

EXECUTIVE SUMMARY

Coral Communities

The coral reefs of the five main volcanic islands of American Samoa have experienced a series of large scale disturbances over the last few decades. The effects of these disturbances have been most severe on the main island of Tutuila and nearby Aunu'u.

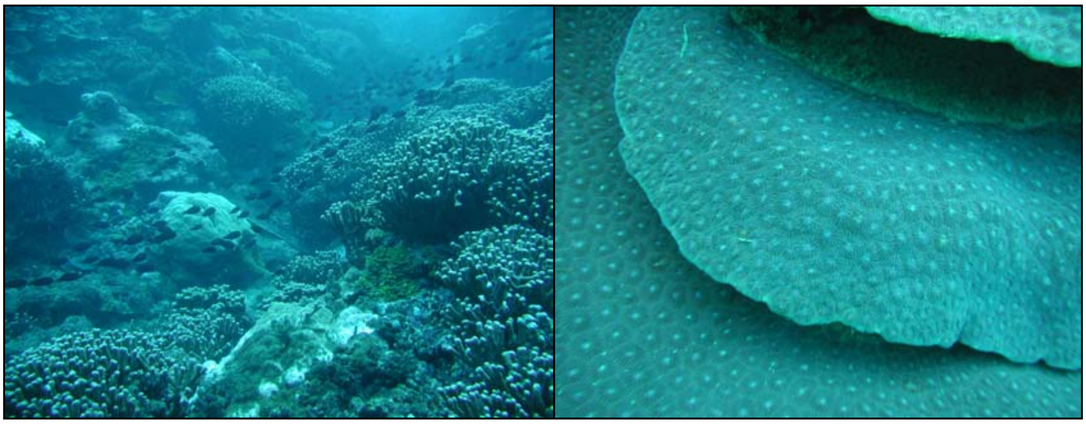
In the late 1970s, the lush coral communities on Tutuila and Aunu'u were devastated by a major COTS outbreak. Recovery was well underway by the early 1990s, when the reefs were devastated again by two severe hurricanes. By the mid 1990s, recovery was underway again, despite a mass coral bleaching event in 1994.

Most of the reefs on Tutuila and Aunu'u have continued to show a rapid recovery over the last few years, and now comprise lush coral communities. The reefs on Aunu'u (see below) and the north side of Tutuila (eg Vatia), are in particularly good condition and are quite spectacular. These results demonstrate that most of the reefs on these islands are healthy and resilient to large scale disturbances.

Coral communities at Aunu'u (photos: L. Basch, NPAS)

Unfortunately, some of the reefs on Tutuila are not in good condition, probably due to poor water quality. For example, sites that receive high sediment loads (eg Fagasa, Fagafue, Faga'alu), tend to have lower coral cover than elsewhere around the island, and comprise distinctive coral communities dominated by species that can tolerate high sediment loads (eg *Porites* and *Diploastrea*: see below).

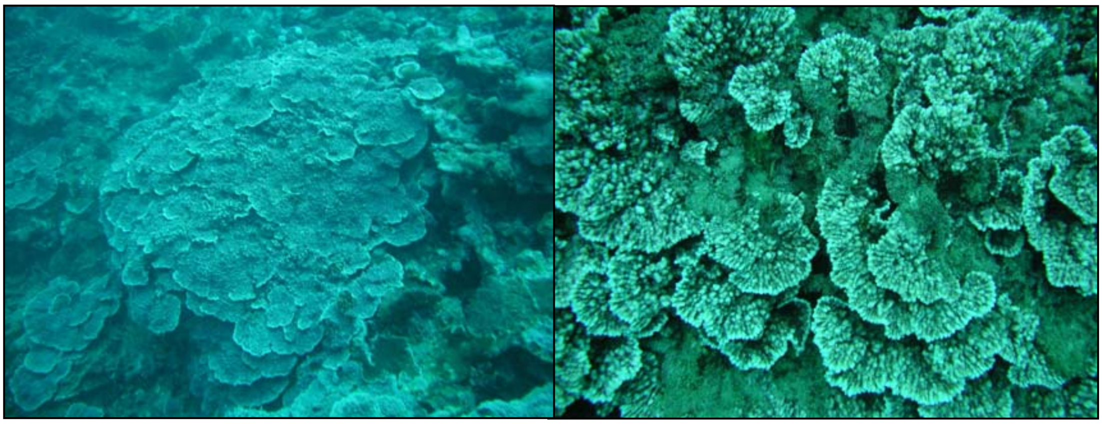
Even the reefs in Pago Pago Harbour are showing signs of improvement, probably due to improved water quality. In particular, good coral recruitment has been recorded at some sites for the first time in decades. This includes species that are particularly sensitive to poor water quality (eg *Acropora* species), which have been absent or rare in the Harbour since the 1950s.



Coral community at Fagasa dominated by *Porites* colonies (left), and large *Diploastrea* colony (12m diam.) at Faga'alu (photos: L. Basch, NPAS)

Despite recent improvements, there are still problems with water quality in the Harbour (eg chronic fuel spills), and the reefs remain in the worst condition of all the reefs in the Territory. Unfortunately, the lush coral communities described in the Harbour early last century have not been seen for decades.

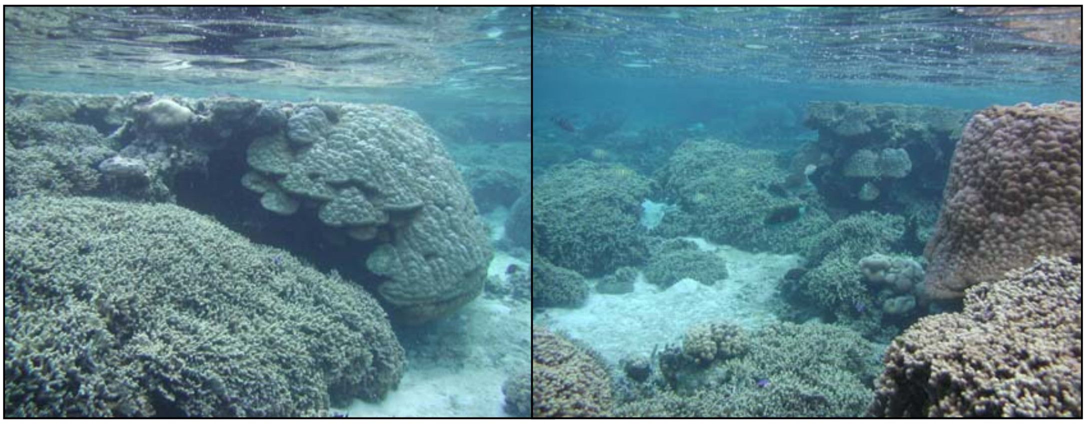
Despite these problems, the reefs in the Harbour are quite important, because they support habitats and species otherwise unique to Samoa. A good example is the coral community at Faga'alu, which is dominated by large massive and foliaceus colonies of *Diploastrea*, *Oxypora*, and *Merulina* and *Lobophyllia* (see below).



Distinctive coral community at Faga'alu (photos: L. Basch, NPAS)

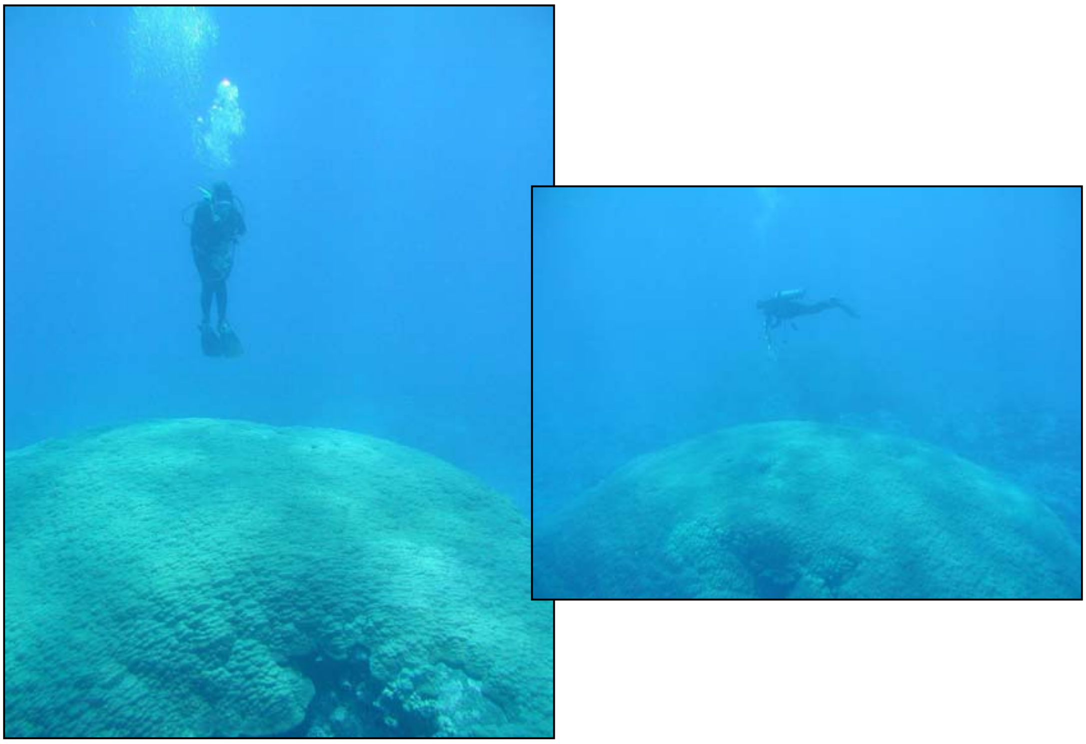
A different pattern is apparent in the Manu'a Islands. These reefs were devastated by Hurricane Tusi in 1987, but escaped damage from the major COTS outbreak in the late 1970s and the most recent hurricanes. By the mid 1990s, they had largely recovered from the effects of Hurricane Tusi, and most were in good condition. Unfortunately, there has been a decline in the coral communities on the reef slope on Ofu and Olosega over the last few years, probably due chronic COTS predation.

In contrast, the coral communities in Ofu Lagoon have not declined, and remain in good condition. However these reefs are dominated by large *Porites* and *Millepora* colonies (see below), which are characteristic of remanent coral communities after COTS predation. These communities remain among the most spectacular in the Territory.



Coral communities in Ofu Lagoon (photos: L. Basch, NPAS)

The reefs of Tau are in good condition, and coral cover has increased over the last few years. Some of these reefs are particularly important, because they support some of the largest coral colonies recorded in Samoa (see below). These colonies are rare, have high conservation value, and should be protected.

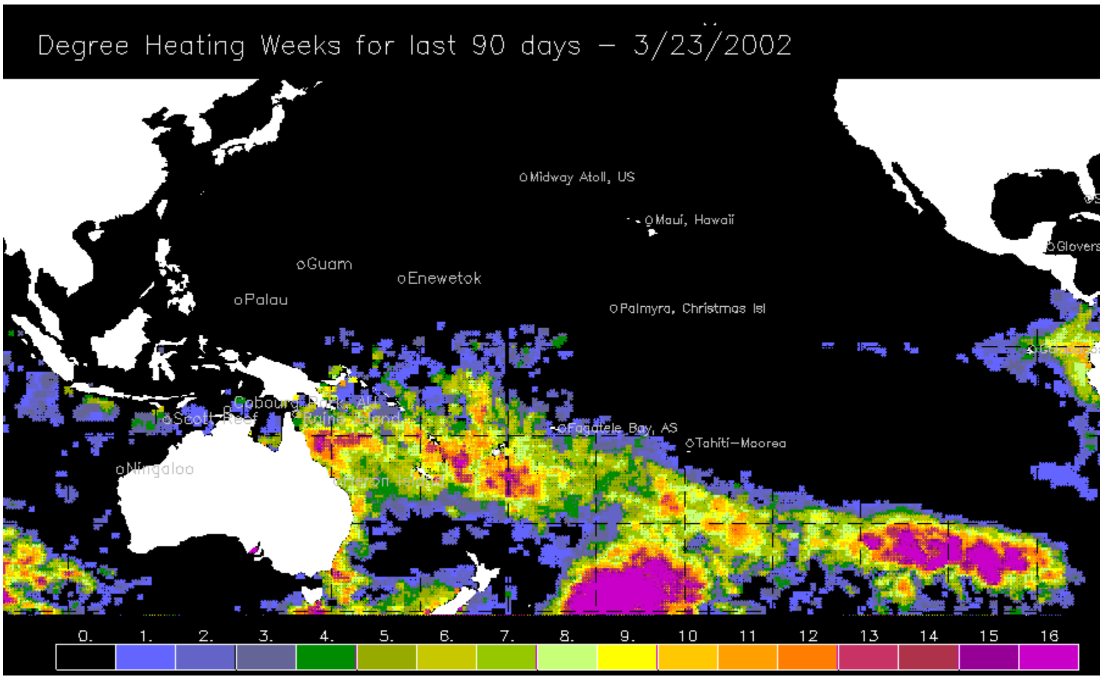


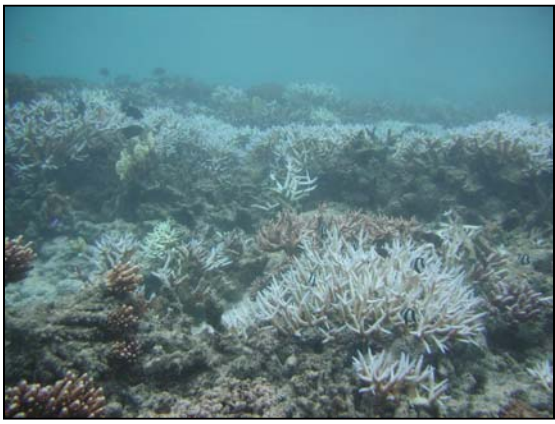
Very large *Porites* bommie (10m diam.) at Afuli Cove, Tau (photos: L. Basch, NPAS).

Mass Coral Bleaching

In early 2002 (Jan to March), American Samoa was on the edge of a widespread temperature anomaly in the Pacific Ocean (see below). Temperatures were recorded up to 2^{o}C above normal in some locations (eg the Great Barrier Reef), which caused severe coral bleaching.

The reefs of Samoa experienced sea temperatures close to the threshold where bleaching was likely to occur (0.5-0.75^{o}C). This study confirmed that the reefs on the five main volcanic islands experienced low to moderate bleaching in March 2002 (see below), with the highest levels of bleaching recorded on the north side of Tutuila. Bleaching was less severe than in 1994, which remains the worst coral bleaching event on record in American Samoa.



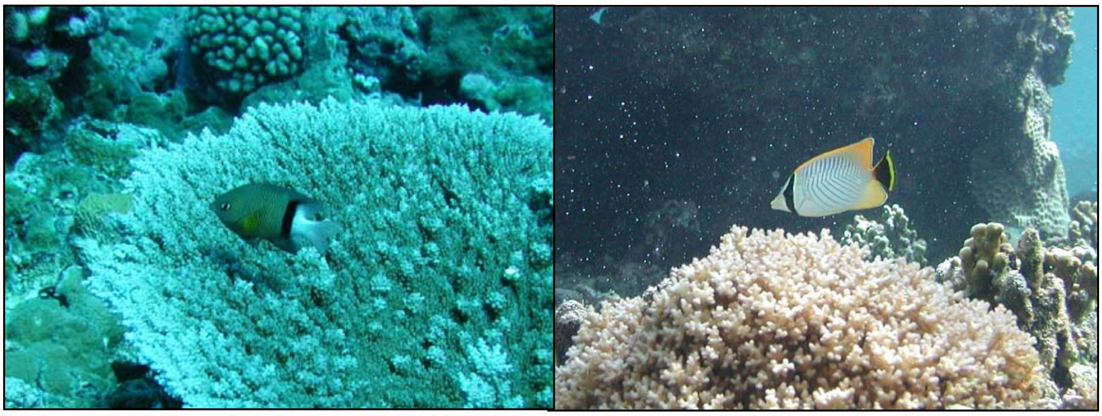


Sea water temperature anomaly (top: NOAA 2002) and coral bleaching in Ofu Lagoon (bottom: L. Basch, NPAS)

Reef Fish Communities

Coral communities provide important habitat for reef fishes, and there have been some major changes in the fish communities on Tutuila and Aunu'u over the last few decades, in response to changes in both the coral communities (see above) and human activities (particularly fishing).

In the mid 1970s, the reefs of Tutuila and Aunu'u supported a rich and diverse fish fauna, because the reefs were in good condition and fishing pressure was relatively low. When the reefs were devastated by COTS in the late 1970s, there were major impacts on some components of the fish fauna. In particular, there was a decline in abundance of species that are closely associated with the coral communities. Two good examples are the damselfish *Plectroglyphidodon dickii* and butterflyfish *Chaetodon trifascialis* (see below), which are closely associated with branching and plate coral. The populations of these species have started to recover in the last few years, along with their host corals. Impacts on other fish species by the COTS outbreak, including fisheries species, were surprisingly small.



Plectroglyphidodon dickii (left) and *Chaetodon trifascialis* (photos: L. Basch, NPAS).

While some components of the fish fauna now appear to be in good condition on Tutuila and Aunu'u, others are conspicuous by their absence (or small size and low abundance). This is due to the impacts of fishing on the major fisheries families (particularly groupers, parrotfishes, and snappers).

When the fish communities are compared among islands that have recently experienced low, moderate and high levels of fishing (Manu'a Islands, Aunu'u and Tutuila respectively), it is clear that the fish populations on Tutuila are overfished. Fisheries species are much less abundant on Tutuila and Aunu'u than in the Manu'a Islands. Furthermore, large species that are particularly vulnerable to overfishing (sharks, some parrotfishes and maori wrasse: see below) are now rare or absent on Tutuila and Aunu'u, but still occur in the Manu'a Islands. Some of these species, particularly parrotfishes, were heavily targeted by the commercial nightime scuba fishery that operated on Tutuila from 1995 to 2001.

Maori wrasse (photo: R. Myers); and blacktip reef shark, Ofu (photo: L. Basch, NPAS)

These results demonstrate that the Governor made the right decision to ban the scuba fishery. If fishing pressure can be maintained at low levels on Tutuila over the next few years, the fish communities may recover from the effects of fishing, since these species still occur in the Territory (particularly in the Manu'a Islands). However, it may be several years before the first signs of recovery are apparent.

The fish communities on Ofu and Olosega have been affected by the impacts of chronic COTS predation on the coral communities on those islands. In particular, species that are dependant corals that are the preferred food of the starfish (eg branching or plate coral: see above) are uncommon.

<u>Mass Recruitment of Surgeonfish (*pala'ia*)</u>

In March 2002, the reefs of American Samoa experienced a mass recruitment event of one of the major fisheries species, *Ctenochaetus striatus*. In some places, the recruits (locally known as *pala'ia*) were present in very high densities and formed large schools (up to 5000 individuals), which roved over the reef flat, lagoon and outer reef slope (see below).

Pala'ia schools in the lagoon and on the reef slope at Ofu (photos: P. Craig & L. Basch, NPAS).

Mass recruitment of this species appears to be a fairly predictable event in American Samoa, which occurs around the new moon in February/March each year. These events are well known to the Samoan people, who target them in a specific, tailor made fishery. This is somewhat analogous to the way in which Samoans predict and utilise the spawning of the palolo worm, which is also available to the fishery for only a few days each year (and is related to the same lunar phase in October and/or November).

Pala'ia were also targeted by carnivorous fishes (eg jacks), which were observed striking at the schools. Not surprisingly, mortality was high. Further studies are required to understand the population dynamics of this important species in Samoa.

Key Macroinvertebrates

Giant Clams

In a similar pattern to the fish, giant clams (see below) were more abundant in the Manu'a Islands (particularly on Tau) than on Tutuila and Aunu'u. Given that giant clams are highly prized in the fishery, this is probably due to overfishing on Tutuila and nearby Aunu'u.

One concern is that the remaining individuals on most islands in American Samoa (particularly Tutuila) are now present in such low densities that their reproductive success and subsequent recruitment may be limited. Indeed giant clam recruitment is low on most of the main volcanic islands, except Tau. These results confirm the importance of Rose Atoll as a refuge for giant clams in American Samoa, and highlights the importance of Tau as a potential refuge for giant clams in the main volcanic islands.

Crown-of-thorns Starfish

There was a major crown-of-thorns starfish (COTS) outbreak on Tutuila and Aunu'u in the late 1970s, which devastated the coral communities. COTS were rare on those islands for several decades prior to that event, and have been rare ever since. However, Samoan traditional knowledge indicates that starfish outbreaks have occurred on Tutuila in the past.

In contrast, the reefs on Ofu and Olosega in the Manu'a Group appear to support chronic low to moderate populations of the starfish (see below), which have played an important role in structuring the coral reef communities on the those islands. One hypothesis is that the ongoing presence of the starfish may be related to the presence of the lagoon on Ofu. A similar situation may exist on 'Upolu in neighbouring Samoa.

Giant clam and crown-of-thorns starfish, Ofu Lagoon (photos: L. Basch, NPAS)

Marine Protected Areas

Marine Protected Areas (MPAs) can play an important role in protecting biodiversity, and as a fisheries management tool. At present, only 6% of reefs in American Samoa are MPAs, which is much less than the 20-50% recommended by scientists. More ‘no-take’ MPAs should be established in American Samoa, particularly on Tutuila (or nearby Aunu’u), were overfishing is a problem. The best candidates for new MPAs in American Samoa include Aunu’u, Vatia (Tutuila), Afuli Cove (Tau), Asaga (Ofu) and Sili (Olosega).

This survey included sites in three of the four existing MPAs in American Samoa: Fagatele Bay National Marine Sanctuary (FBNMS), the Ofu Unit of the National Park of American Samoa (NPAS), and the Ofu-Vaoto Marine Park. Therefore, it provides an opportunity to assess the status of the reefs in these MPAs, and compare them to other reefs in the Territory.

The coral reefs of FBNMS (see below) have recovered well from the large scale disturbances of the last few decades, and are now in good condition. In fact the reefs in the Sanctuary support some of the healthiest coral communities on Tutuila. Unfortunately, like most other places on the island, Fagatele Bay appears to have been overfished. The density and biomass of the major fisheries families are relatively low, and several large reef fish species that are particularly vulnerable to overfishing are now rare or absent. This highlights the need for improved enforcement of the fishing restrictions in the Bay.

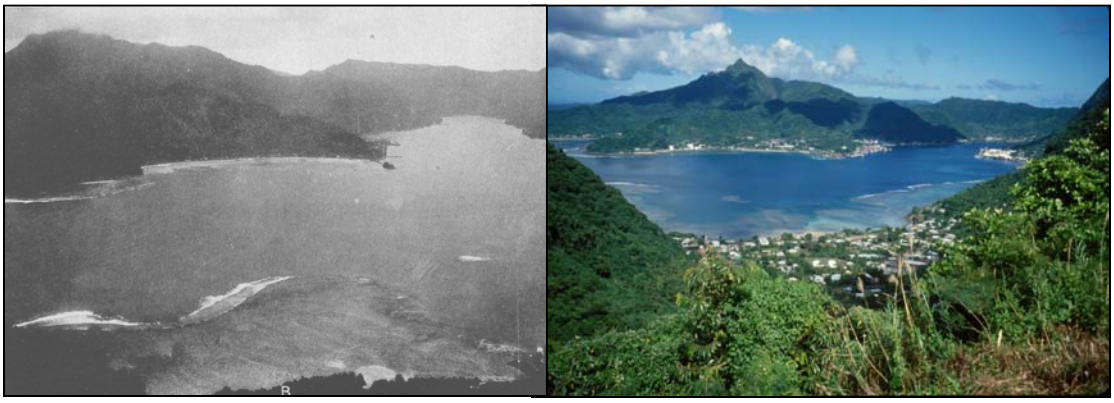
The reefs in the Ofu Unit of the NPAS (see below) are also in good condition. The NPAS includes Ofu Lagoon, which is the best developed natural lagoon system on the main volcanic islands. Despite chronic COTS predation, the lagoon supports spectacular coral reef communities (see above), which are otherwise unique in American Samoa. The lagoon may also play an important role in the ecology of the reefs on Ofu and Olosega, since it may act as a nursery for some important fisheries species (particularly parrotfishes), and play an important role in maintaining the chronic COTS population on those islands (see above).

The Ofu-Vaoto National Park is part of the same lagoonal system as the NPAS, and requires protection. However, the coral reef communities are not as spectacular, because the large massive corals that dominate the lagoon in the NPAS are less abundant.

National Park of American Samoa, Ofu Unit (photo P. Craig) and Fagatele Bay National Marine Sanctuary (photo FBNMS).

Long Term Monitoring

This study demonstrates the important role that long term monitoring programs can play in understanding the natural variability and long term trends in the coral reefs of American Samoa. One benefit of this study is that it provides an overview of the condition of the reefs on all the main volcanic islands simultaneously. It also provides a broad scale perspective for understanding the results of the site dedicated monitoring programs in Fagatele Bay National Marine Sanctuary and Pago Pago Harbour (Aua transect: see below), which provide a much longer term perspective on the reefs of Tutuila (85 and 25 years respectively).



Aua Transect in Pago Pago Harbour (on reef flat in foreground) in 1917 (photo: Mayor 1924a) and 1996 (photo: A. Green).

Unfortunately, the two remote atolls (Rose and Swains) could not be resurveyed this year, due to logistic constraints. They should be resurveyed as soon as possible, particularly Rose, due to the high conservation status of the atoll.

INTRODUCTION

Coral reefs are diverse marine ecosystems that flourish in the clear, tropical waters of the South Pacific. American Samoa is fortunate to have well developed coral reefs surrounding all islands in the Territory (Green 1996a). These reefs are an important natural resource for the Samoan people, since they provide the basis for the valuable inshore fishery (Craig et al 1993, Craig 2002). They also play an integral role in the rich cultural heritage of the islands, and provide other important ecosystem services (including shoreline protection).

Large Scale Disturbances

Unfortunately, the reefs of American Samoa have experienced a series of large scale disturbances over the last few decades, including a major outbreak of the coralivorous crown-of-thorns starfish (*Acanthaster planci*), several severe hurricanes, and mass coral bleaching events (Green 1996a, Green et al 1999). The reefs on the main island of Tutuila and nearby Aunu'u have been devastated by these disturbances on several occasions, while those in the Manu'a Islands and two remote atolls have escaped serious damage from most of these events (Green 1996a).

Crown-of-thorns starfish

The crown-of-thorns starfish (COTS, locally know as *alamea*) is a natural inhabitant of the reefs of Samoa. This species feeds on corals and is usually uncommon, where it causes minimal damage to coral communities. However, this species is subject to dramatic increases in numbers, called population outbreaks. The degree to which these outbreaks are caused by natural or human related activities remains a matter for debate. Whatever the cause, starfish outbreaks can cause major damage to coral reefs. Even moderate outbreaks have been know to cause major damage over a period of several years (Zann 1992).

In 1977-79, the reefs of Tutuila experienced a major COTS outbreak (Birkeland & Randall 1979, Birkeland et al 1987). This was an unusual event for Tutuila, since starfish were rare on the island for several decades prior to this event (Birkeland & Randall1979, Birkeland 1982, Birkeland & Lucas 1990). However, Samoan traditional knowledge indicates that starfish outbreaks may have been a recurring phenomenon in the past (Birkeland & Randall 1979, Birkeland 1981, Birkeland & Lucas 1990, Zann 1992). Birkeland and co-workers proposed that the outbreak was due to heavy rainfall following a period of drought, which washed a pulse of nutrients into the water (Birkeland & Randall 1979, Birkeland 1982). This increase in nutrients may have increased the survival of starfish during their planktonic larval stage, by stimulating phytoplankton blooms which provide food for the larvae.

This major outbreak in the late 1970s caused severe damage to the coral communities around most of Tutuila and Aunu'u (Birkeland & Randall 1979, Birkeland et al 1987, Zann 1992), although some bays escaped damage (Birkeland et al 1987, Green et al 1997a). Even though large scale control measures were undertaken (~487,000 were removed: Birkeland 1982, Zann 1992), the starfish remained abundant and systematically devastated the coral communities on these islands (Birkeland & Randall 1979).

The impacts of the COTS outbreak are well described based on the long term monitoring program in Fagatele Bay National Marine Sanctuary (FBNMS: Green et al 1999). Prior to the starfish outbreak, the reefs in Fagatele Bay comprised healthy coral reef communities characterised by high coral cover (30-50%: especially table *Acropora*). Unfortunately, the coral communities in Fagatele Bay were devastated by the starfish outbreak in 1979, which lead to a dramatic reduction in coral cover in the Bay. The effects of the starfish outbreak tended to be most severe in more sheltered locations (i.e. deeper water $\geq$9m), and less severe in more exposed locations (i.e. shallow water $\leq$ 6m). It was assumed that this was because the starfish were unable to maintain their position on the substrate in areas of strong surge. Almost 10 years later, the coral communities in deeper water had started to recover from the starfish outbreak.

Coral communities provide important habitat for coral reef fishes, and long term monitoring of Fagatele Bay and other sites around Tutuila, showed that there were some changes in the fish communities as a result of the habitat degradation caused by the starfish outbreak (Birkeland et al 1987, 1996, *in prep*, Buckley 1986, Green et al 1999). In particular, there was a dramatic decline in small, site-attached species that are closely associated with live coral colonies (such as the damselfish *Plectroglyphidodon dickii* and the hawkfish *Paracirrhites arcatus*), and an increase in species that prefer coral rubble or algae. Impacts on other species, including fisheries species, were surprisingly small (Buckley 1986, Birkeland et al. 1987).

Fortunately, the reefs of the Manu'a Islands were not affected by the massive starfish outbreak that devastated the reefs on Tutuila in the late 1970s (D. Itano *pers. comm*). However, COTS predation appears to have been chronic (at low to moderate levels) in the Manu'a Islands for many years (particularly on Ofu), which has probably caused some damage to the reefs (Itano & Buckley 1988a, Zann 1992, Green 1996a, Mundy 1996). In particular, COTS predation has probably had a significant impact on the coral communities in Ofu Lagoon, by favouring less preferred prey species (particularly massive *Porites* and *Millepora*) and disadvantaging preferred species (particularly *Acropora* : Zann 1992)

The reefs on the main island of ‘Upolu in neighbouring Samoa, also appear to experience chronic low to moderate levels of COTS predation (Zann 1991, 1992, Green 1996a,b), as well as occasional large scale outbreaks (including the late 1970s at the same time as the outbreak on Tutuila: Birkeland & Randall 1979. In contrast, very few COTS have been observed on the two remote atolls (Rose and Swains). This is consistent with Birkeland’s hypothesis, that COTS outbreaks tend to occur around high islands and not around atolls (Birkeland 1982).

<u>Hurricanes</u>

The reefs of American Samoa are subject to infrequent but sometimes severe hurricanes. In the early 1990s, the reefs of Tutuila and Aunu’u experienced two severe hurricanes (Ofa in 1990 and Val in 1991: Green et al. 1999), which caused major damage to the reefs (especially Val: Birkeland et al 1996, Green 1996a, Green et al 1999).

The impacts of these hurricanes on Tutuila are well described based on the long term monitoring of FBNMS (Green et al 1999). This study showed that in contrast to the

COTS outbreak (see above), the hurricanes affected the coral communities in shallower, inner portions of the bay (≤9m) to the greatest extent. They also caused major changes to the physical structure of the reef, since large coral colonies were overturned and destroyed. Fortunately, the reefs of Fagatele Bay have proved resilient to such disturbances, and recovery from the hurricanes was already well underway by the mid to late 1990s (Green et al 1999). Reef slopes had been consolidated with a lush growth of pink coralline algae, and coral recruitment was high. Most other sites around Tutuila and Aunu'u were also in the early stages of recovery by the mid 1990s (Green 1996a, Mundy 1996), particularly where water quality was good (Green 1996a).

The Manu'a Group and Rose Atoll were less affected by the most recent hurricanes, but were badly hit by Hurricane Tusi in 1987 (P. Craig *pers. comm*). Swains Island experienced a violent storm that devastated the island and reefs in 1987 (Green 1996c). However, Green (1996a,c) showed that the reefs on these islands had recovered from these disturbances, and were in good to excellent condition again by the mid-1990s. In 1998, Hurricane Ron passed within 8km northeast of Swains Island, although it did not appear to cause significant damage to the reefs on the atoll (Page & Green 1998).

Hurricane Ofa also caused major damage to the coral reefs on the neighbouring island of 'Upolu in Samoa (Zann & Sua 1991), although recovery was well underway by the mid 1990s (Green 1996b).

Mass Coral Bleaching

Coral bleaching is a stress condition in corals which involves a breakdown of the symbiotic relationship between corals and unicellular algae (zooxanthellae: GBRMPA 2002). These microscopic plants live within the coral tissue and provide the coral with food and their normal healthy colour. The symptoms of bleaching include a loss of colour as zooxanthellae are expelled from the coral tissue, sometimes leaving corals bone white. Bleaching stress is also exhibited by other reef animals that have a symbiotic relationship with zooxanthellae, such as soft corals, giant clams, and some sponges.

While many different stresses can cause coral bleaching, the main cause of widespread bleaching is elevated sea temperature (GBRMPA 2002). Additional stresses such as high light intensity, low salinity and pollutants are known to exacerbate these effects.

Reef corals are very sensitive to sea temperatures outside their normal range. Elevated temperatures of 1^{o}C above the long term monthly summer average are enough to cause coral bleaching in many dominant coral species (GBRMPA 2002). If conditions are only mildly stressful, corals can recover from bleaching, but if conditions are severe enough, they may die.

In early 1994, American Samoa experienced unusually hot and still weather conditions, which resulted in unusually high water temperatures (N. Daschbach *pers comm*) and stressful conditions for corals. These conditions resulted in the most serious coral bleaching event ever recorded in Samoa. During this event, coral bleaching was severe and widespread (at least Tutuila and Manu'a Islands: Craig et al.

1995, Goreau & Hayes 1994) and extended down to a depth of 30m in some places (eg Masefau and FBNMS). Observations from FBNMS indicate that bleaching was most pronounced in the shallow, inner portions of the Bay (N. Daschbach *pers comm*). Bleaching affected several taxa including hard corals, anemones and zooanthids, and some families of hard coral were more severely affected than others (especially Pocilloporidae: N. Daschbach *pers comm*, Birkeland et al 1996). The impact of this event on the reefs of American Samoa is unclear, since it is unknown how much of the coral and other benthos recovered or died. However, coral mortality was estimated to be high in some locations (eg 50% in Ofu Lagoon: P. Craig *pers comm*).

In March 1998, American Samoa again experienced unusually hot and still weather conditions accompanied by unusually low tides. This resulted in widespread death of corals on the reef flat and crest at many sites around Tutuila (Birkeland et al *in prep*), and elsewhere in the archipelago (eg 'Upolu).

In early 2002 (January to March), a temperature anomaly with sea surface temperatures up to 1.5-2^{o}C higher than long term seasonal averages was detected in the Western Pacific (NOAA 2002a), with the worst affected area centered on the Great Barrier Reef in Australia. As a result, the GBR experienced its worse coral bleaching event on record (GBRMPA 2002). The warm water anomaly that caused the bleaching on the GBR extended east across the Pacific to Fiji, which also experienced bleaching (ReefBase 2002). American Samoa was right on the edge of this hot spot, and experienced sea surface temperatures 0.5-0.75^{o}C above normal (NOAA 2002a). This indicated that sea surface temperatures in American Samoa may have reached levels where bleaching was likely to occur.

Human Impacts

In the absence of serious human impacts, coral reefs are resilient natural ecosystems that can recover from most large scale disturbances in one to two decades. This is the case for most of the reefs in American Samoa (Green 1996a, Green et al 1999). However, there is some concern regarding human impacts in some locations, particularly on the heavily populated island of Tutuila (especially in Pago Pago Harbour). In some situations, human activities may have caused a decline in coral reef health, which has inhibited their ability to recover from large scale disturbances (Green 1996a). Of particular concern are impacts from overfishing and poor water quality (Craig 2002).

Fortunately, human impacts appear to be less of a threat to the reefs on the less populated islands of the Manu'a Group, and minor on the two remote atolls (except for the shipwreck on Rose: Green 1996a, Green et al 1997b). Aunu'u may experience moderate levels of human impacts due to the relatively high population density of this small island (see *Description of Study Area*), and its proximity to the main island of Tutuila.

<u>Fishing</u>

Like most Pacific Island countries, American Samoa has undergone many social, economic and environmental changes last century. For example, there has been a shift from a subsistence to a mixed economy, which now includes both market and subsistence sectors (Hill 1977, Craig et al 1993). Where once families depended on the coral reefs and plantations for their livelihood, many now receive monetary income from working for the government or industry.

This has been accompanied by a change in the nature of the local fishery from a subsistence level to a largely artisanal and recreational fishery, with some subsistence fishing continuing (Hill 1977, Craig et al 1993). In addition, fishing practises have shifted from the use of traditional methods including *paopao* canoes and specialised fishing methods (eg fish traps, nets and lures), to modern methods including the use of power boats, scuba equipment and spearguns (Wass 1980). There has also been a decline in traditional fisheries management practices (Wass 1980).

Accompanying these changes, has been a massive increase in the human population. On the main island of Tutuila, the population has increased dramatically from about 5,000 in 1900 to the present level of 55,400 in 2000 (American Samoa Census 2000). Most of the population live on Tutuila (96.7%), with a much smaller percentage on Aunu'u (0.8%), the Manu'a Islands (2.4%) and Swains Island (<0.1%). Rose is uninhabited. The population is continuing to increase at a very fast rate, with a 22% increase recorded between 1990 and 2000. This was primarily due to an increase in the population on Tutuila, since the population in Manu'a has declined in recent years (see *Description of Study Area*).

Limited information is available for the coral reef fishery in the Territory, and most of that which is available is for the main island of Tutuila (Craig et al 1993, Craig 2002). Coral reef resources are harvested on a daily basis on Tutuila, and comprise 40-80% of the fisheries landings each year (Craig et al 1993, Saucerman 1995, 1996). A monitoring program of the coral reef fishery in and around Pago Pago Harbour, detected a decline in subsistence catch and catch per unit effort from 1979 to 1991-1995 (Saucerman 1995, 1996). Saucerman (1995) concluded that while these were warning signs for the fishery, there did not appear to be a significant problem with overfishing at that time. Unfortunately, this monitoring program was discontinued from 1995-2001, but was recommenced this year. The artisanal catch was also monitored in 1994, but is currently assessed using market invoices with limited success (Craig 2002).

In the mid 1990s, a new, high technology commercial fishery became established on Tutuila (the nightime scuba fishery: Page 1998). This type of fishery can quickly lead to overfishing, because the fish are particularly vulnerable to capture while sleeping at night. The use of scuba exacerbates the situation, because the fishermen are able to dive deeper for longer, and are able to catch fish that were previously afforded some protection in deeper water.

The nightime scuba fishery led to a dramatic increase in the catch of reef fishes on the island. Page (1998) demonstrated that parrotfishes were heavily exploited by this fishery, with a 15 fold increase in catch while it was operating. He also estimated that 18.7% of the standing crop of parrotfishes on Tutuila was harvested in just one year (1997). One concern was that many parrotfishes were being caught before they reached sexual maturity, which could lead to a reduction in the number of young fish recruiting to the reef in future (Page 1998).

This highly efficient fishery was banned by Executive Order by the Governor of American Samoa in April 2001 (and subsequently banned by DMWR regulation in January 2002), due to concerns that the reef fish populations were being overfished. Fortunately, the fishery did not become established on the other islands in the Territory. A case study of the response to the nightime scuba fishery is provided in Attachment 1.

Fishing rates are largely unknown for the other islands. Despite the paucity of information, fishing pressure is presumed to be lower in the lightly populated Manu'a Islands. For example, Itano & Buckley (1988a) reported that the Manu'a Islands appeared to be lightly fished, based on the presence of large, unwary fish and high densities of giant clams. Fortunately, the NPAS has recently commenced a survey of the coral reef fisheries in the Manu'a Islands, which will provide the first quantitative fisheries data for those islands (P. Craig *pers comm*). In contrast, fishing pressure on Aunu'u is presumed to be moderate, based on the relatively high population density on this small island (see *Description of Study Area*), and its close proximity to Tutuila. Fishing pressure on the remote atolls is presumed to be light on Swains (which has a small population), and limited to isolated instances on Rose (which is uninhabited).

The major components of the coral reef fishery in American Samoa are reef fish, giant clams and the palolo worm (Ponwith 1991, Craig et al 1993). At present, the most important reef fish families caught are surgeonfishes, groupers, snappers, parrotfishes and squirrelfishes (Saucerman 1995, Craig et al 1997). Archaeological studies in the Manu'a Islands indicate that reef fish (and these families in particular) and giant clams have been important components of the fishery for thousands of years (Nagaoka 1993).

Several studies have examined the effects of fishing on fisheries resources in American Samoa. An interview survey of local fishermen in 1994-95 showed that all participants believed that fishing for giant clams had declined in living memory, while fewer people believed that fishing for reef fish (70%) or palolo (43%) had declined (Tuilagi & Green 1995). More recently, subsistence fishermen raised concerns that fishing had become increasingly more difficult, while the nightime scuba fishery was operating (Append 1).

Some biological studies have also examined the effects of fishing on fisheries resources. Page (1998) demonstrated that parrotfishes were overfished on Tutuila. In contrast, Craig et al (1997) reported that while one of the major target species of surgeonfish (*Acanthurus lineatus*) experienced heavy fishing pressure, it did not appear to be overfished.

Giant clams, locally known as *faisua*, are an important food item in Samoa, but their accessibility and life history characteristics make them particularly vulnerable to over-harvesting. Green & Craig (1999) examined that status of giant clam populations on eight islands in the Samoan Archipelago, and concluded that they were overfished throughout most of the archipelago. This information was consistent with local fisheries statistics for Tutuila, which showed a decline in the harvest of giant clams over the last two decades (see Green & Craig 1999). One concern is that the remaining individuals are now present in such low densities that their reproductive success, and subsequent recruitment, may be diminished.

Green & Craig (1999) demonstrated that Rose Atoll was an important refuge for one of the three species of giant clam (*Tridacna maxima*) that occurs in American Samoa, since it was the only island that still supported a healthy population of those clams. Unfortunately, Rose is not able to act as a refuge for the other clam species also known to occur in Samoa, *Tridacna squamosa*, because it does not occur out there. The presence of subfossil shells also suggests that a third species, *Hippopus hipposus*, used to occur in Samoa, but is now locally extinct (Munro 1986, Nagaoka 1993) except for hatchery reared animals. Whether this is due to overfishing (*H. hippopus* is particularly vulnerable to overfishing because it occurs in shallow water), or a natural reduction in range (Samoa was the eastern extent of its range) is unclear (Munro 1986).

In general, the palolo fishery appears to be in relatively good condition on the south side of Tutuila and in Manu'a where most of the fishing for this species occurs (Tuilagi & Green 1995). This is probably because the palolo's coral reef habitat is still in good condition at most locations, and the fishery is very short term (a few days a year) and only targets the reproductive products of the worm (Caspers 1984), so the worms themselves are not harvested. The exception is inner Pago Pago Harbour, where palolo fishing no longer occurs as it did >50 years ago, presumably because of the almost complete destruction of the coral reefs in the area due to dredging, land filling and chronic pollution (Tuilagi & Green 1995). The status of other invertebrate species that are important in the coral fishery (eg octopus, sea urchins and spiny lobsters: Saucerman 1996) is unknown.

Destructive fishing practices are illegal in American Samoa, since they can cause severe damage to coral reef habitats (particularly dynamite fishing: Itano 1980, Tuilagi & Green 1995). However, there is some evidence that illegal fishing practices (particularly dynamite fishing, but also the use of traditional fish poisons) continue to be used on Tutuila (Itano 1980, Tutuila and Green 1995, Birkeland et al in prep). For example, in an interview survey of fishermen on Tutuila, 25% of people reported that dynamite fishing had occurred in the last year, while only a few (9%) knew of traditional poisons (*ava niu kini*) being used over the same time period (Tuilagi & Green 1995). In that survey, a higher percentage of people reported the use of these illegal fishing techniques on the north side of the island. This is probably because many of the bays on the north side are relatively remote and unpopulated, and the reefs are not protected by the presence of a village.

More recently, some evidence of dynamite fishing has been observed in FBNMS on the south side of the island (Birkeland et al *in prep*). Despite its protected status, Fagatele Bay may be vulnerable to illegal fishing practices, because it is uninhabited and enforcement is intermittent. Furthermore, it is likely that both FBNMS and the isolated reefs in the National Park of American Samoa (NPAS) on Tutuila, were targeted by the nightime scuba fishery (Page 1998, Birkeland et al *in prep*).

Water Quality

Fortunately, water quality is good around most of American Samoa, because the islands are steep with narrow fringing reefs (and limited lagoon development) so the reefs are continually flushed by clear oceanic waters (Craig 2002). Exceptions include heavy sedimentation at some sites after rain (due to natural causes and poor land use practices), and nutrient enrichment from human and animal waste in populated areas (Craig 2002). This is of particular concern in narrow embayments which are not as well flushed by oceanic water, particularly Pago Pago Harbour, which is considered a Special Management Area.

Pago Pago Harbour Special Management Area

Early last century, human habitation in Pago Pago Harbour was restricted to a few small traditional villages, and lush coral reefs lined the shore (Mayor 1924a,b). Since then, the Harbour has experienced some major changes and become a heavily populated urban and industrial area, with a busy port and two tuna canneries (Green et al 1997a). This has resulted in some major changes to the reefs in the Harbour area. In particular, approximately 97% of the reefs in the inner harbour have now been completely destroyed by dredging and filling operations (IUCN/UNEP 1988). There has also been a serious decline in water quality as a result of chemical pollution from industry and agriculture (fuel spills, heavy metals and pesticides) and solid waste disposal (Green et al 1997a). The Harbour also receives high sediment loads after periods of heavy rain, but it is unclear how much of this is natural or has been exacerbated by human activities (since major sediment plumes were reported in the Harbour by Mayor 1924a). Of particular concern has been the chronic eutrophication of the area caused by the effluent from the tuna canneries, which have operated in the inner Harbour since 1956 (Green et al 1997a).

Furthermore, a toxicity study in the early 1990s showed that the fish and substrates in the inner Harbour contained high levels of heavy metals and were unfit for human consumption (see Craig 2002). Preliminary results of a toxicity study conducted this year (P. Peshut, ASEPA *pers comm*) indicate that elevated levels of heavy metals (particularly mercury, arsenic and PCBs) continue to be present in fish in the inner Harbour (although lead levels were lower than previously detected). The source of these heavy metals remains unclear, but may involve natural factors (arsenic may be naturally occurring in volcanic soils) or those related to human activities (for mercury, PCBs and lead: P. Peshut *pers comm*).

In that last few decades, the reefs in the Harbour have also endured two severe hurricanes (1990 and 1991) and nine fishing vessels grounded during Hurricane Val in 1991 (NOAA 2002b). However, they appear to have escaped the major COTS outbreak in the late 1970s (Green et al 1997a).

Several studies have demonstrated that the coral reefs in the Harbour have declined due to poor water quality. For example, a long term study of the "Aua transect" on the reef flat on the east side of Harbour, showed that there had been a serious decline in the coral reef community at that site since it was first surveyed in 1917 (Mayor 1924a, Dahl & Lamberts, 1977, Dahl 1981, Green et al 1997a). For example, the diversity of corals that are particularly vulnerable to poor water quality had declined (eg *Acropora* species: Green et al 1997a). Observations by the Samoan community indicated that the lush coral reefs at Aua disappeared in the 1950s, probably due to a decline in water quality as the result of several human activities that started operating at that time (dredging, tuna canneries, fuel spills: Green et al 1997a). Another long term monitoring program of the coral communities on the other side of the Harbour (in front of the Rainmaker Hotel at Utulei) also showed that the coral communities in the Harbour were declining, presumably from the effects of chronic sedimentation and pollution on coral recruitment (Birkeland et al. 1994, 1996). Mundy (1996) also concluded that the poor condition of the coral communities in the Harbour was probably due to the long term effects of poor water quality.

Fortunately, water quality has improved substantially in the Harbour in the last 12 years, since there has been an improvement in the management of waste from the tuna canneries (Green et al 1997a, Craig 2002, ASEPA *unpubl data*). This has resulted in a dramatic reduction in the nutrient levels in the Harbour (Craig 2002, ASEPA *unpubl data*). The shipwrecks were also removed in 1999-2001 (NOAA 2002b), and restoration included removing the vessel structures and debris, and restoring the injured reef flat resources (including transplanting corals to minimise further damage during the cleanup). Unfortunately, fuel spills remain frequent in the Harbour area (P. Peshut *pers comm*).

More recent surveys have demonstrated that the coral communities in the outer Harbour may be starting to show some signs of recovery, in response to improved water quality. For example, a survey of the Aua transect in 1999 indicated that the reef flat communities appeared to be in good condition for the first time in decades (healthy coral and crustose coralline algae), which was attributed to improved water quality (Birkeland & Green 1999). There had also been a mass recruitment of *Acropora nana* and *Pocillopora danae*, which resulted in a dramatic increase in living coral cover and abundance on the transect (Birkeland & Green 1999). The fact that *Acropora* species were abundant on the transect again was considered a good indicator of improved water quality, since they are particularly vulnerable to pollution. Similarly, a substantial increase in *Acropora* recruits (particularly *Acropora hyacinthus*) was observed at Utulei in 1999 for the first time in two decades (C. Birkeland *pers comm*), indicating that those reefs may be starting to recover also. Despite these encouraging signs, the coral communities in the Harbour are still a long way from resembling the lush coral communities described by Mayor (1924a,b) early last century.

Long Term Monitoring and Survey Objectives

Two long term monitoring programs have been underway in American Samoa for some time. Long term monitoring of the "Aua Transect" in Pago Pago Harbour has been in place since 1917 (Mayor 1924a), which makes it the second oldest coral reef monitoring program in the world (Green et al. 1997a). The results of that study provide a valuable long term perspective of how the reefs in the Harbour have changed over the last century (see *Water Quality* above). In contrast, the long term monitoring program of FBNMS has been in place since 1985, although some data are also available for the late 1970s (Green et al 1999). The Sanctuary program provides a valuable opportunity to understand the natural variability and long term trends in coral reefs on Tutuila, in the absence of most anthropogenic processes.

While these programs provide valuable information for those sites, they do not provide a broad scale perspective of the condition of the reefs throughout the Territory (although the FBNMS program does include some other sites around Tutuila). In the mid 1990s, a quantitative baseline survey was conducted throughout the Samoan Archipelago to assess the status of the reefs following a series of large scale disturbances (Green 1996a). This detailed survey described the status of the reef fishes, their habitat characteristics (benthic communities at the growth form level), and key macroinvertebrates, in a range of habitat types on eight islands in the Samoan Archipelago (including all five volcanic islands and two remote atolls in American Samoa, and the main island of ‘Upolu in independent Samoa). A companion survey of the corals (at the species level) was conducted by Mundy (1996) on the five volcanic islands in American Samoa at the same time.

The primary objective of this study is to repeat the baseline survey of the five main volcanic islands of American Samoa (Tutuila, Aunu’u and the Manu’a Islands) conducted by Green (1996a). Unfortunately it was not possible to repeat the survey of ‘Upolu and the two remote atolls (Green 1996a), due to logistic constraints.

This survey will focus on describing the trends in the coral reef communities on these islands over the last six years. In particular, it will determine if:

- the reefs are recovering from the large scale disturbances of the last few decades; and/or
- there are any detectable impacts from human activities (particularly due to fishing or poor water quality) on these reefs.

It will also:

- provide a broad scale perspective for interpreting the results of the long term monitoring programs in FBNMS and Pago Pago Harbour; and
- document two large scale events that took place during the survey (coral bleaching and a mass recruitment event of a major fisheries species).

A companion coral survey (at the species level) was conducted at the same time as this survey (using the same transects). The results of that survey are reported separately by Fisk & Birkeland (2002).

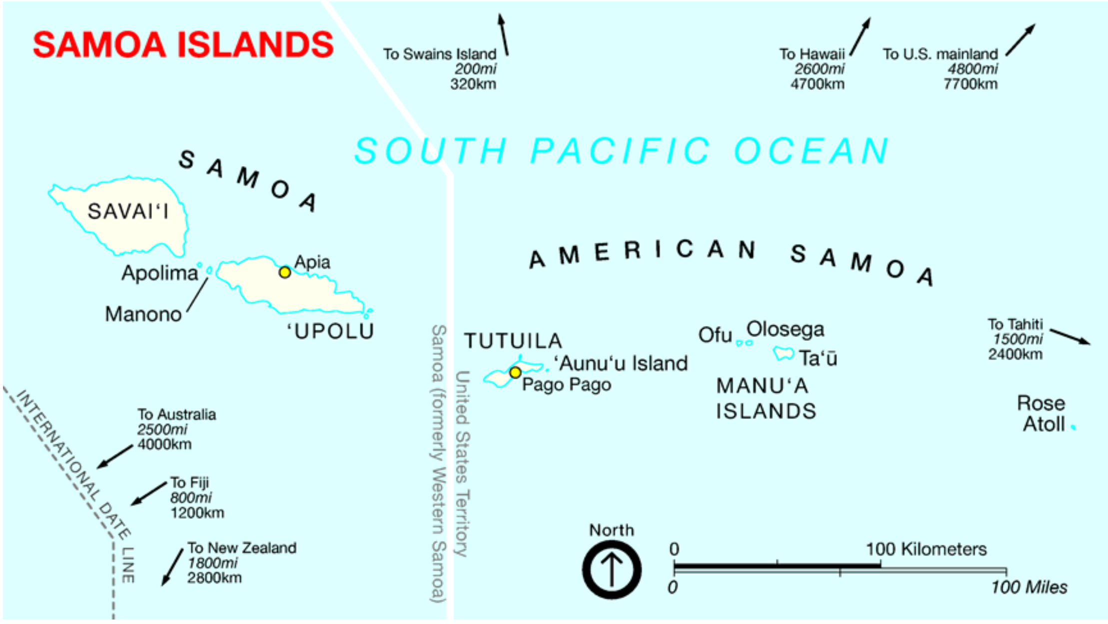
METHODS

Description of Study Area

Samoan Archipelago

The Samoan Archipelago is located in the Central Pacific at lat. 13-14^{o} S and long. 168-172^{o} E, and is divided into two countries: independent Samoa and American Samoa (Fig. 1). Samoa comprises seven islands in the western end of archipelago, including the two large islands of 'Upolu and Savai'i (Fig. 1). American Samoa encompasses five emergent islands of volcanic rock (Tutuila, Aunu'u, and the Manu'a Islands) and two remote atolls (Rose and Swains: Fig. 1).

Fig 1 Map of the Samoan Archipelago (map courtesy of NPAS).



This study will focus on the five main volcanic islands of American Samoa. These islands differ in terms of their size, age, and human habitation. The main island of Tutuila (Fig 1, 2) is the oldest, largest and supports most of the population (97%) and the highest population density (Table 1). The islands of the Manu'a Group (Ofu, Olosega, and Ta'u: Fig. 1, 3), are located 102 km east of Tutuila. These islands are smaller, younger, and have a much lower population density (Table 1). Aunu'u is a small island off the southeast coast of Tutuila (Fig. 2), which has a moderately high population density (Table 1).

The population of American Samoa is rapidly increasing. The total population of 57,291 recorded in 2000, represented a 22% increase in the Territory since the last census in 1990 (2.1% per year: Craig 2002). The increase was primarily due to a 24% increase in the population on Tutuila, since the population in Manu'a declined by 20%.

Table 1 Island and reef type, size, and human population of each island in American Samoa (Hunter 1995, American Samoa Census 2000).

Island	Island Type	Reef Type	Island Area (km^2)	Reef Area (km^2)	Human Population (in 2000)	% Human Population (in 2000)	Population Density (per km^2)
Tutuila	Volcanic	f,ns	142.3	243	55,400	96.67%	389.3
Manu'a Is							
Ofu	Volcanic	f,ns	7.5	3.2	289	0.50%	38.5
Olosega	Volcanic	f,ns	5.4	2	216	0.38%	40.0
Ta'u	Volcanic	f,ns	45.7	1.7	873	1.52%	19.1
Aunu'u	Volcanic	f,ns	1.6	0.5	476	0.83%	297.5
Swains	Atoll	a	3.6	3.3	37	006%	10.2
Rose	Atoll	a	0.1	7	0	0	0
Nil	Nil	sb	na	10	0	0	0
Total			**206**	**271**	**57,291**	**100%**	

Where: a=atoll; f=fringing; ns=nonstructural reef community; sb=submerged bank or shoal; and reef area is for Territorial Waters (0-3nm from shore), and 0-100m deep (Hunter 1995)

Reef and Habitat types

Most of the reefs on the volcanic islands of American Samoa are narrow fringing reefs that are close (<200m) to shore. These reefs can be divided into six recognizable habitat types, which differ in their position on the reef profile, depth and degree of wave exposure (described in detail by Green 1996a). At most sites, the reef slope descends from the crest at a slope of 45-90^o down to the reef base (depth=10-30m), where it joins the sand flat which stretches away from the reef towards open water

Location of Study Sites

The location of each study site is described in Append 2. Geographic co-ordinates (on WGS84 datum) were taken at each site surveyed on the reef slope in 2002 by C. Birkeland and A. Green (Append 2) using a hand held GPS. These co-ordinates were used to plot the location of the study sites on rectified satellite images of the islands (by W. White, DMWR: Figs 2 & 3). However, the co-ordinates recorded for three sites (Aunu'u, Fagaitua, and Lepula) appeared to be incorrect, since they did not represent their correct locations on the images. Therefore, their locations on Figs 2 & 3 are based on site descriptions only (Append 2). New co-ordinates for these sites were taken from the rectified satellite images (by W. White: see Append 2), which will require verification in the next field survey.

Where possible, transects started in an easily defined location (eg near a natural landmark such as a channel or *ava*) and were laid in a predefined direction along a depth contour. The location of the transects was described in detail (Append 2) to allow them to be relocated in future surveys.

Unfortunately, that was more difficult in Ofu Lagoon. While the starting position could be easily described (Append 2), the actual location of the transects was not well defined because they followed the edges of the coral in the lagoon (and not a depth profile). Therefore, it was possible to lay the transects in slightly different directions in each survey. For that reason, it is recommended that permanent transects be established in the lagoon for future surveys.

Fig. 2. Map of the main island of Tutuila and nearby Aunu'u, American Samoa, showing the location of each study site.

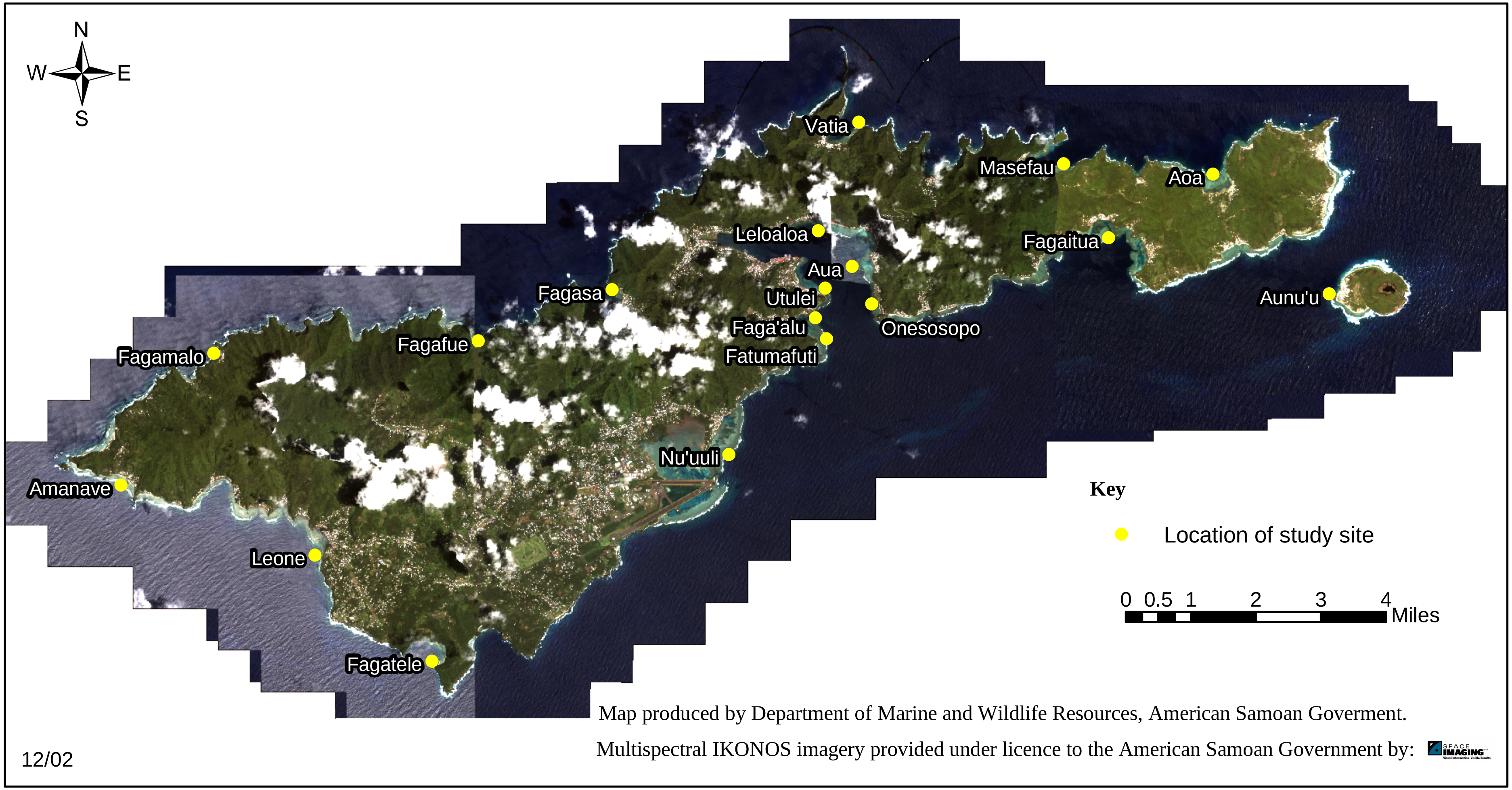
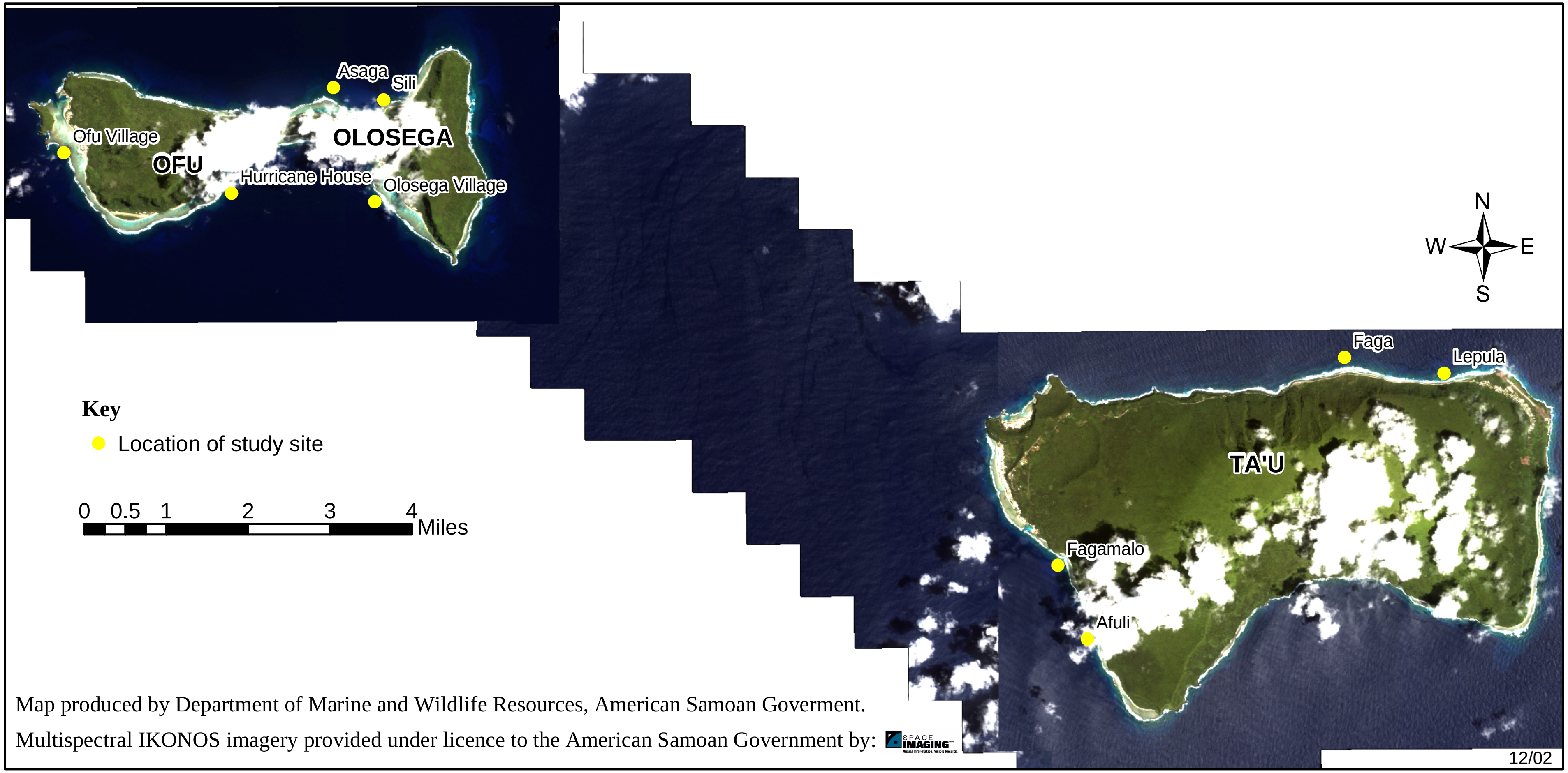


Fig. 3. Map of the Manu'a Islands, American Samoa, showing the location of each study site.



Map produced by Department of Marine and Wildlife Resources, American Samoan Goverment.

Multispectral IKONOS imagery provided under licence to the American Samoan Government by: SPACE IMAGING

The two sites surveyed in Ofu Lagoon were in Pools 200 and 400 (Fig 4), which were called Vaoto Lodge and Hurricane House respectively (Append 2).

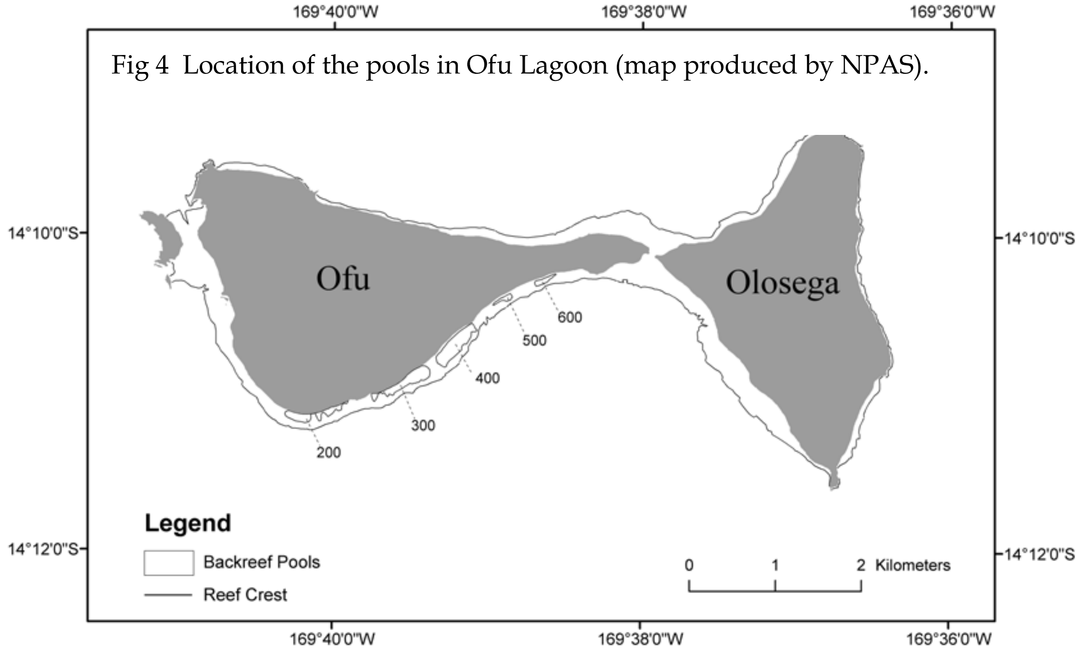


Fig 4 Location of the pools in Ofu Lagoon (map produced by NPAS).

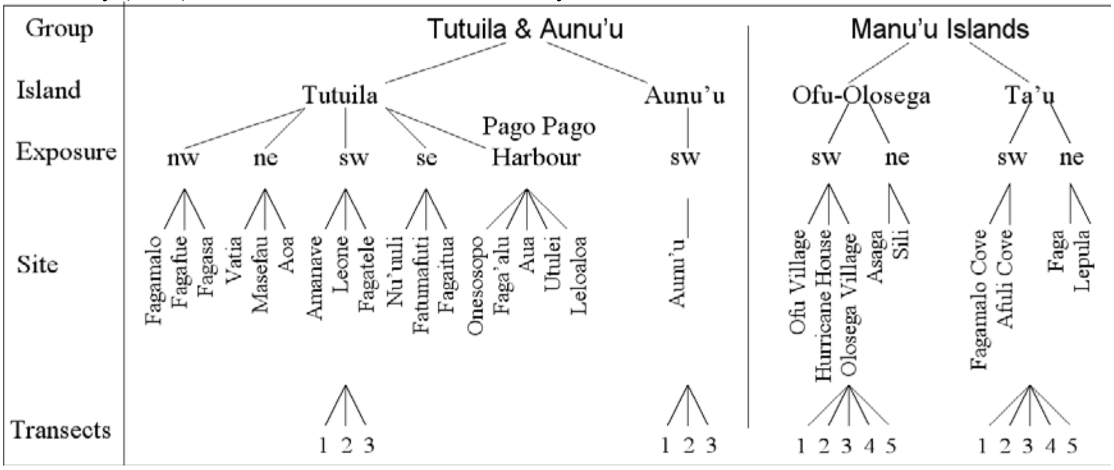
Baseline Survey Design

A detailed baseline survey of the coral reefs on eight islands in the Samoan Archipelago was conducted from October 1994 to November 1995 (Green 1996a). This survey included all seven islands in American Samoa (five volcanic islands and two remote atolls) and the main island of ‘Upolu in Samoa, and provided a rigorous scientific basis for the long term monitoring of these reefs. Key components of the survey included quantitative surveys of benthic communities (at the growth form level), fish communities (at the species level), and key macroinvertebrates (giant clams and COTS). The results are described in detail by Green (1996a) and Green & Craig 1999).

All sites surveyed were areas of well developed continuous reef tract. Where possible, sites were distributed around each island to include the variation associated with exposure (Fig 5). Sites on the southern sides of the islands are exposed to the prevailing southeast Trade Winds from April to September. In contrast, sites on the north sides are more protected from the Trade Winds, but tend to be harder hit by hurricanes which occur from October to March. Five of the sites on Tutuila were located within Pago Pago Harbour on the south side of the island, which tends to be relatively protected from the prevailing wind conditions. The number of sites surveyed on each island ranged from 1 to 17 (Append 2, Fig 5), depending on logistic constraints (a combination of the time available on each island, weather conditions, and the area of available reef tract).

In the baseline survey, coral reef communities were compared among habitat types on several islands (Green 1996a). Sites were also compared among and within islands based on a single habitat type. Reef slopes (depth=10m) were used for this comparison because they are well represented on each island. It is also the habitat type where fish species richness, density and biomass tend to be highest, which is particularly relevant for measuring the status of coral reef communities and the impacts of human activities (particularly the effects of fishing, much of which takes place on the reef slope).

Fig 5 Sampling design for sites where reef slopes were surveyed in the baseline survey (Green 1996a) and this survey (2002). Note: Hurricane House was surveyed for the first time in 2002.



Surveys were conducted using five replicate transects at each site using the methods described below for each taxa.

<u>Reef Fish Communities</u>
Reef fishes were surveyed using visual census techniques along five replicate 50m x 3m transects along the reef slope (depth=10m) at each site (total area=750m^2 per habitat per site: Green 1996a). These transect dimensions were used because Green (1996d) determined that they yielded the most precise estimate of abundances of highly mobile, diurnal species such as wrasses. Transect lengths were measured using 50m tapes, and transect widths were measured using known body proportions. The size of each fish (total length in cm) was estimated visually and recorded directly onto underwater paper.

A restricted family list was used which comprised only those families which are amenable to visual census techniques, because they are relatively large, diurnally active and conspicuous in coloration and behaviour (Table 2). This method excludes species that are not amenable to the technique because they are very small, nocturnal or cryptic in behaviour (eg gobies, blennies, cardinalfish).

Fishes were surveyed by three passes along the transect counting different species in each pass. The first count was of large, highly mobile species, which are most likely to be disturbed by the passage of a diver (such as parrotfishes, snappers and emperors). This count was conducted while an assistant followed laying out the tapes, so the observer could concentrate of looking up and ahead on the transect. The tapes then remained *in situ* until all the surveys were completed at that site. The second count was of medium sized mobile families (including most surgeonfishes, butterflyfishes and wrasses), which are less disturbed by the presence of a diver. The third count was of small, site attached species (mostly damselfishes), which are least disturbed by the presence of a diver. Fish counts were be separated by a ~5 minute waiting period. Benthic communities and key macroinvertebrates were surveyed along the same transects after the fish counts were completed (see below), as were the coral communities (see Fisk & Birkeland 2002).

Table 2 Reef fish families included in surveys of the Samoan Archipelago (Green 1996a, this survey).

Class (common name)	**Family**	**Family Common Name**
Chondrichtyes	Carcharinidae	whaler or requiem sharks
(sharks & rays)	Ginglymostomatidae	nurse sharks
	Hemigaleidae	weasel sharks
	Myliobatidae	eagle rays
Osteichthyes	Acanthuridae	surgeonfishes & unicornfishes
(bony fishes)	Aulostomidae	trumpetfishes
	Balistidae	triggerfishes
	Caesionidae	fusiliers
	Carangidae	trevallies
	Chaetodontidae	butterflyfishes
	Diodontidae	porcupinefishes
	Echeneidae	suckerfish
	Ephippidae	batfishes
	Fistularidae	flutemouths
	Haemulidae	sweetlips
	Kyphosidae	drummers
	Labridae	wrasses
	Lethrinidae	emperors
	Lutjanidae	snappers
	Malacanthidae	sand tilefishes
	Monacanthidae	leatherjackets
	Mugilidae	mullets
	Mullidae	goatfishes
	Nemipteridae	coral breams
	Ostracidae	boxfishes
	Pinguipedidae	sandperches
	Pomacanthidae	angelfishes
	Pomacentridae	damselfishes
	Scaridae	parrotfishes
	Scomberidae	mackerels
	Scorpaenidae	scorpionfishes
	Serranidae	groupers
	Siganidae	rabbitfishes
	Sphyraenidae	barracudas
	Synodontidae	lizardfishes
	Tetraodontidae	puffers
	Zanclidae	moorish idol

Fishes were compared among locations (island, habitat, site) on the basis of species richness, density and biomass. Where: fish species richness was the total number of species recorded on the transects, and fish density was converted to the number of individuals per hectare (ha). Fish biomass was calculated by converting estimated fish lengths to weights using the allometric length-weight conversion formulae [weight (kg) = (total length in cm x constant a)^b] where a and b are constants for each species. Constants were not available for most species in Samoa, so they were obtained from New Caledonia (Kulbicki unpubl data: Append 3), which was the closest geographic area where this information was available.

Since surveys were conducted throughout the year, these comparisons were made based on adult fishes only to avoid the temporal effects of recruitment on the data. Adults were defined as individuals that were more than one third of the maximum total length of each species (Append 3). Individuals less than one third maximum total length were considered juveniles, which had recruited during the previous year.

Benthic Communities

Benthic communities at each site were described using a point-based method for habitat description. This technique was originally developed for describing forest habitats for birds by Weins & Rotenberry (1981), but it has been successfully adapted to describing coral reef habitats for fishes (Choat & Bellwood 1985, Green 1996a,d). This method was used to provide an estimate of the percent cover of each substratum type on each of the fish transects. At 2m intervals along each transect, a 2 m transect was run perpendicular to the direction of the main transect. Three sampling points were then used along each of the 2m transects (one directly under the 50 m tape, and one 1 m either side). Twenty-five 2m intervals along the main transect were sampled in this manner, yielding 75 sample points per transect. Habitat data was not collected at four sites on the volcanic islands of American Samoa (Asaga and Sili on Ofu-Olosega, and Faga and Lepula on Tau) due to logistic constraints.

At each point, the substratum was recorded as belonging to one of four major substratum categories and 24 subcategories (Table 3). The cover of each category type could then be calculated as the percentage of the 75 points that it occupied on each transect. Habitat characteristics were then compared among locations based on the cover of each major substratum category (and subcategory).

Table 3 Major substratum categories and subcategories used in surveys of the Samoan Archipelago (Green 1996a, this survey).

Major Categories	Subcategories
Coral	plate, massive, digitate, branching, encrusting, foliaceus, mushroom
Miscellaneous	hydrozoan, sponge, clam, zooanthid, soft coral, ascidian, echinoderm
Macroalgae	encrusting pink coralline algae, branching pink coralline algae, fleshy macroalgae, halimeda, blue green algae, encrusting algae
Nonliving	reef matrix, rock, sand, rubble, crevice/hole

Key Macroinvertebrates (Giant Clams and Crown-of-Thorns Starfish)

A separate pass of the transects was conducted to quantify the abundance and size of two key macroinvertebrates: giant clams and crown-of-thorns starfish (COTS). Each individual was counted, its size measured and recorded on underwater paper.

All clams were measured using maximum shell length. The minimum size of clams reliably detected was 2cm. Size structure was compared among islands and years using three categories: recruits ($\leq$ 5 cm), immature (6-11 cm), and mature ($\geq$12). These categories were based on the results of a growth and maturity study of the most abundant species, *Tridacna maxima,* at Rose Atoll (Radtke 1985).

All COTS were measured using maximum diameter. It was recognised that since COTS can be cryptic (and hide during the day), that these counts are likely to be an underestimate of their actual abundance.

Resurvey Design

This study focused on repeating the surveys of the five main volcanic islands of American Samoa (Tutuila, Aunu'u and the Manu'a Islands) in March 2002. Unfortunately, the two remote atolls (Rose and Swains) and 'Upolu Island in Samoa could not be repeated this year due to logistic constraints.

The survey focused on a single habitat type, reef slopes (depth=10m), since they were the primary focus of the baseline survey (see above). The shallow lagoons on Ofu were resurveyed also, due to their importance to the local community and the NPAS.

Most (26) of the 28 sites surveyed on the reef slopes of these islands in the baseline survey were resurveyed in 2002 (Append 2, Green 1996a). One site (Tau Village) was dropped from the survey because the reef was not well developed at that site, and there were already two other survey sites on the southwest side of Tau (Fig 3). The other site (Amouli on Tutuila) was dropped from the survey because it was decided that three sites was adequate for the southeast side of the island, which was consistent with the number of sites surveyed on each of the other three exposures (southwest, northwest and northeast) around the island. One new site (Hurricane House) was added on the south side of Ofu to include a site in the NPAS.

<u>Reef Fish Communities, Benthic Communities, Key Macroinvertebrates</u>
Reef fishes communities, benthic communities and key macroinvertebrates were resurveyed using the same methods as the baseline survey with one exception. Three transects (instead of five) were used at each site on Tutuila and Aunu'u, so all the sites could be resurveyed in the limited time available. Therefore, comparisons among times on these islands were based on the first three transects at each site only. However, five transects were still used at each site in the Manu'a Islands, so comparisons among times in Manu'a were still based on five transects at each site.

<u>Large, Vulnerable Fish Species</u>
Some large fish species that are particularly vulnerable to overexploitation were counted using an adaptation of a new methodology developed specifically for this purpose by J.H. Choat (*pers comm*). The new method was developed to improve estimates of the abundance of these species, since they tend to be uncommon and clumped in distribution, so smaller transects dimensions (eg 50x3m) are not able to gain reasonable estimates of their abundance. The objective of this methodology is to cover a wide area of the reef slope during a single pass over a set time period (usually 15 mins) scanning the reef slope for these species. If a standard width is used (eg 20m), these estimates can be converted to a standardised area. Species counted using these methods include sharks, maori wrasse (*Cheilinus undulatus*), and large species of parrotfish where maximum sizes can reach 70 -120cm (*Bolbometopon muricatum*, *Cetoscarus bicolor*, *Chlorurus microrhinos*, and *Scarus rubroviolaceus*).

The first pass of the fish surveys was used to count these species, using a transect width of 20m. Therefore at each site, a combined area of 3000m^2 (on Tutuila and Aunu'u) or 5,000m^2 (in the Manu'a Island) was surveyed using these methods. These counts were converted to a standard density (per ha) for comparison among islands.

<u>Fish Recruitment</u>
Patterns of fish recruitment were described in 2002, since the survey took place over a short time period (less than one month) during a major recruitment event. This was done based on the density of juveniles recorded on the transects at each site (see *Baseline Survey Design, Fish Communities*).

Fish Species Lists

The species list recorded in the baseline survey (Green 1996a) was updated to provide a complete list of all the species recorded in these surveys. In addition, a more detailed list of the species observed in Ofu Lagoon was compiled at the request of the NPAS.

The NPAS has recognised that Ofu Lagoon is divided into a series of pools, which they have numbered consecutively (Fig 4). A species list was compiled for each pool using two sources of information:

- the data collected during the quantitative surveys of the pools at Vaoto Lodge (Pool 200) and Hurricane House (Pool 400) in both 1996 and 2002; and
- all species observed in each of the major pools (Pools 200, 300, 500 and 500/600) based on 45-55 mins of observation in each pool during the survey in 2002.

Coral Bleaching

A broad scale survey of coral bleaching was conducted by recording observations at each site (with advice from coral biologists Chuck Birkeland and David Fisk) using a standardised bleaching form developed by the Great Barrier Reef Marine Park Authority (Append 4). Information recorded included estimated total coral cover, dominant coral types, which corals (if any) had bleached (at growth form and species level where possible), the percentage of corals that had bleached, and the severity of bleaching.

RESULTS

Benthic Communities

Cover by each substratum category and subcategory type was extremely variable among islands, sites and years. However, some trends were apparent.

General Trends: Reef Slopes

In 1996, coral cover was low on most islands, while cover by macroalgae or non-living substratum categories was moderate to high (Fig 6, Append 5). Cover of other miscellaneous substratum types was very low. In 2002, coral cover had increased substantially on Tutuila and Aunu'u, with a corresponding decrease in macroalgae and non-living substratum (Fig 7, Append 5). Cover of miscellaneous substratum categories remained very low in 2002 (Fig 7).

At the site level, coral cover was low to moderate at each site on Tutuila and Aunu'u in 1996, ranging from 4-36% (Fig 8, Append 5). Coral cover was substantially higher at most sites in 2002 (Fig 8), ranging from low to high (16-82%). This represented a 2 to 10 fold increase in coral cover, with the most dramatic increases recorded at Aunu'u, Aoa, Vatia, Fagamalo, Fagaitua, Amanave and Fagatele. Only two sites (Fatumafuti and Nu'uuli) did not show a dramatic increase in coral cover due to unknown causes.

The differences among surveys were more complicated in the Manu'a Islands. In 1996, coral cover was low to moderate at all sites surveyed on the reef slopes, but tended to be slightly higher on Ofu and Olosega than on Tau (Fig 8, Append 5). The situation was reversed in 2002, when coral cover was higher on Tau than on Ofu and Olosega (Fig 8). This was due to an increase in coral cover on Tau, and a decrease at Olosega Village. Coral cover at Ofu Village was similar in both years, but slightly lower in 2002. As a result of these changes, coral cover on Tau was more similar to that on Tutuila than it was to Ofu and Olosega in 2002 (Figs 8-10).

In 1996, the highest coral cover was by massive and/or encrusting coral on most islands (Fig 9, Append 6), although branching and foliaceus coral were also important on Aunu'u and Ofu respectively. The dominant macroalgae type at most sites was pink coralline algae (4 –59%) and/or encrusting (1-58%) algae, with other categories contributing less than 10% each (Append 6).

The increased coral cover on Tutuila and Aunu'u in 2002 was primarily due to an increase in encrusting and branching coral (Figs 9-10, Append 6). Foliaceus, massive and plate coral had also increased, but to a lesser extent. The dominant macroalgae at most sites was still pink coralline algae (12 –51%) and/or encrusting (0.5-44%) algae, with other categories contributing less than 10% each Append 6).

Fig 6 Mean cover (+/- se) of each major substratum category on each island in 1996.

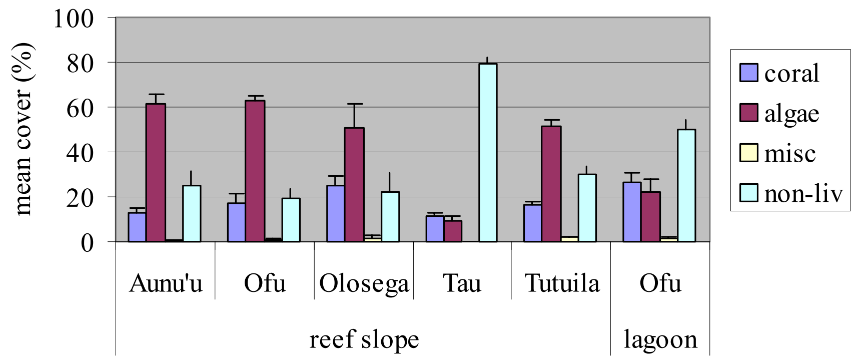


Fig 7 Mean cover (+/- se) of each major substratum category on each island in 2002.

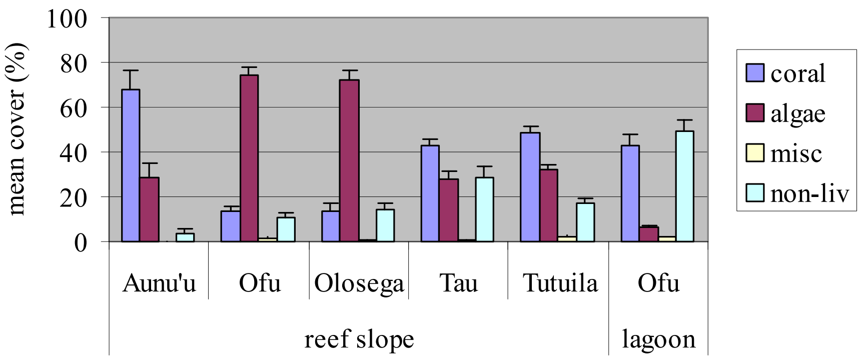
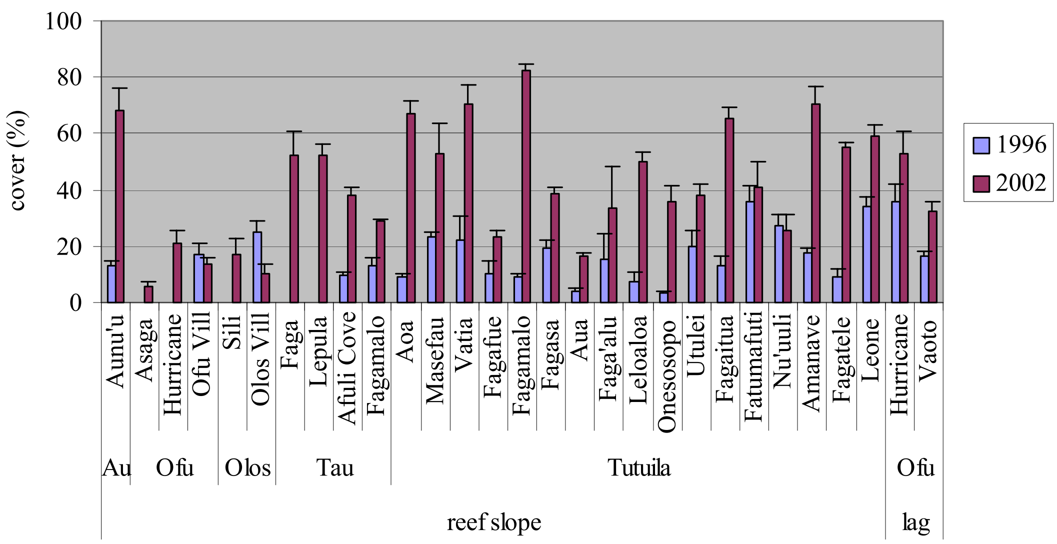
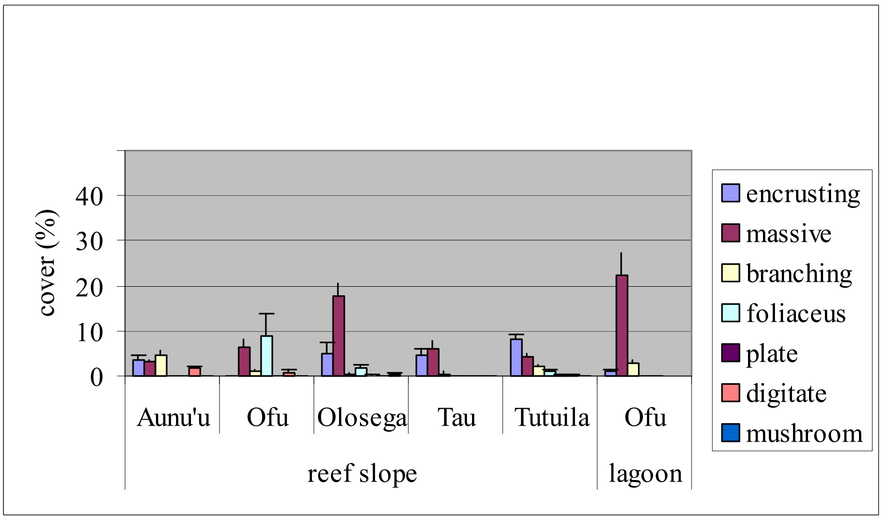
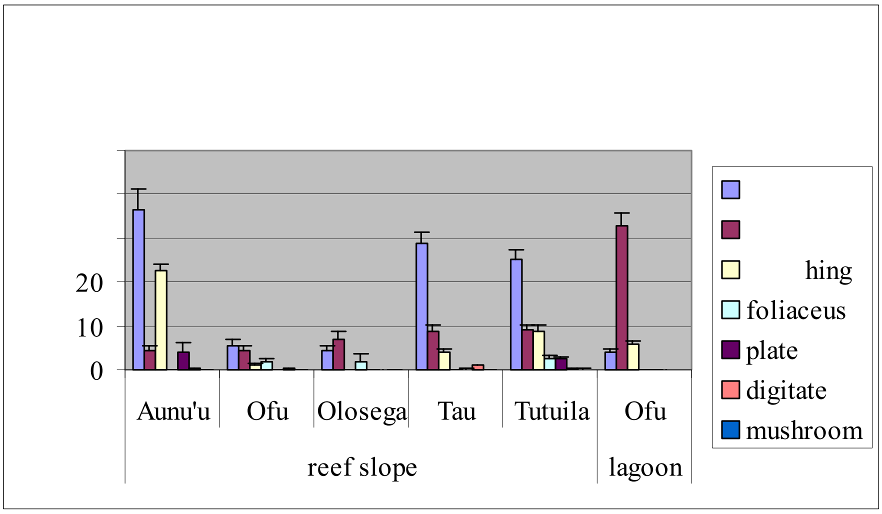


Fig 8 Mean coral cover (+/- se) at each site in 1996 and 2002. Five sites (Asaga, Hurricane House, Sili, Faga and Lepula) were not surveyed in 1996.



The decline in coral cover at Olosega Village between 1996 and 2002 (Fig 8) was primarily due to a decline in massive coral from 18 to 4% (Fig 9 & 10, Append 6). In contrast, the increase in coral cover on Tau was largely due to an increase in encrusting and branching coral (Fig 9 & 10, Append 6). While coral cover was similar at Ofu Village in both 1996 and 2002 (Fig 8), there was a change in the relative cover of the major coral types, with a decrease in foliaceus and massive coral and increase in encrusting coral (Append 6).





General Trends: Ofu Lagoon

Coral cover in Ofu Lagoon was similar to, or higher than, that on the adjacent reef slope in both years (Figs 6-8). The type of coral cover also differed between these two habitat types. The coral communities in the lagoon at Hurricane House were dominated by massive corals (15-50%: Figs 9 & 10, Append 6), particularly large *Porites* colonies. In contrast, the most abundant coral types on the adjacent reef slope were encrusting and massive corals (8.7% and 7.73% respectively: Append 6). Coral cover was also lower in the lagoon at Vaoto, because the large massive corals that dominate the lagoon at Hurricane House were less abundant.

Coral cover in the lagoon appeared to have increased over the last few years (Figs 6-8), with a corresponding decrease in cover of algae and non-living substratum (Figs 6-7). The increase in coral cover was primarily due to a higher cover of massive coral recorded on the transects in 2002 (Figs 9-10). This may have been due to an actual increase in cover, or a variation in the location of the transects between surveys (see *Methods, Location of Study Sites*).

Reef Fish Communities

Fish communities varied among islands, sites and years in terms of their species richness, density and biomass. However, some trends were apparent.

General Trends: Reef Slopes

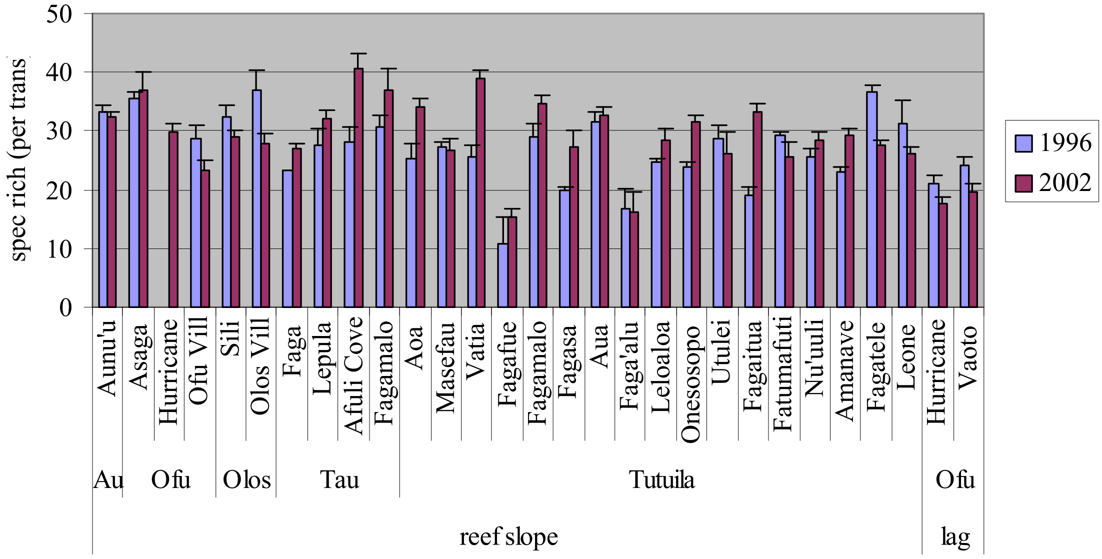
Species Richness

Species richness was moderate to high on Aunu'u and in the Manu'a Islands (Fig 11), but was much more variable on Tutuila, ranging from low (Fagafue) to high (Vatia).

Patterns in species richness over time differed among islands (Fig 11). Species richness tended to be similar in both years on Aunu'u. While on Ofu, it was either similar in both years (Asaga) or slightly lower in 2002 (Ofu Village). Species richness was also lower on Olosega in 2002 (Sili and Olosega Village), but higher on Tau. With few exceptions (eg Fagatele), species richness tended to be similar in both years or higher in 2002 at most sites on Tutuila (eg Vatia).

The differences in species richness over time at each site were primarily due to changes in some of the most species rich families (Labridae, Pomacentridae, Chaetodontidae, Acanthuridae and Scaridae: Append 7).

Fig 11 Mean species richness (+/- se) of adult reef fishes at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.



Density

Fish density was moderately high on Aunu'u and in the Manu'a Islands (Fig 12). In contrast, density was much more variable on Tutuila, ranging from low (eg Fagafue and Fagasa) to high (eg Aua).

In general, density tended to be higher in 2002 than in 1996 at most sites. This was primarily due to an increase in the most abundant families: Pomacentridae, Acanthuridae, Scaridae, Labridae, and Chaetodontidae (Append 8). In particular, the two most abundant families (Pomacentridae and Acanthuridae) were more abundant at most sites in 2002 than in 1996 (Figs 13 &14), which accounted for most of the increases in density over time. Other noticeable increases in fish density in 2002 (Fig 12) were due to more transient caesionids recorded at Vatia (Append 8), more acanthurids, mullids, chaetodontids, pomacanthids and zanclids recorded at Aua, and more schooling lethrinids (*Gnathodentex aurolineatus*) recorded at Fagatele, Asaga and Sili.

Fig 12 Mean density (+/- se) of adult reef fishes at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.

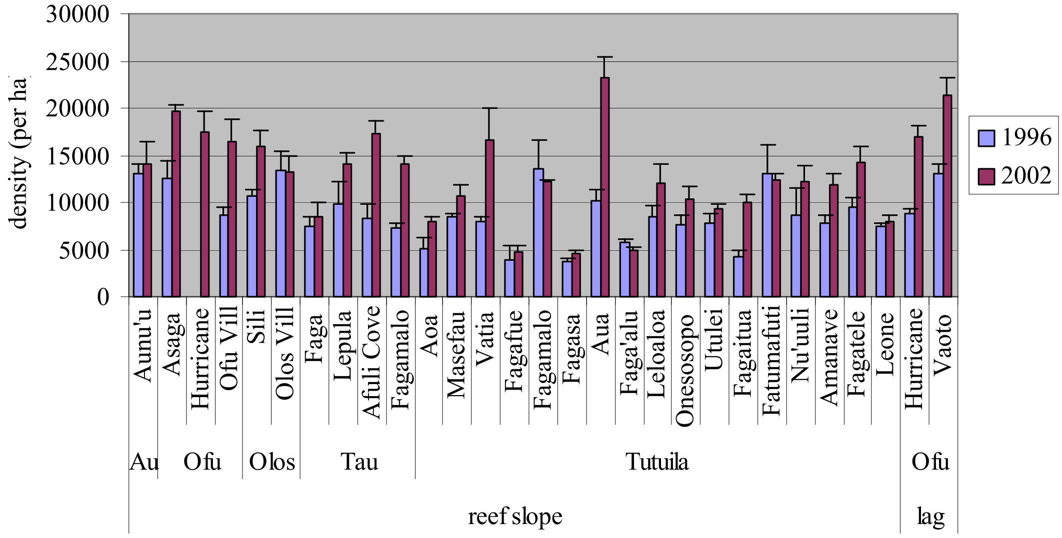


Fig 13 Mean adult density (+/- se) of damselfishes (Pomacentridae) at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.

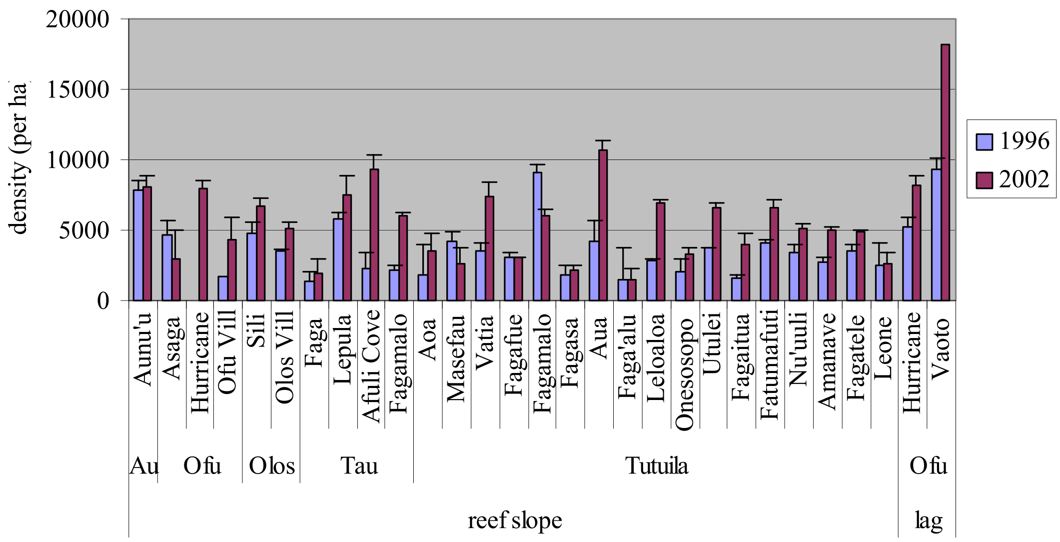
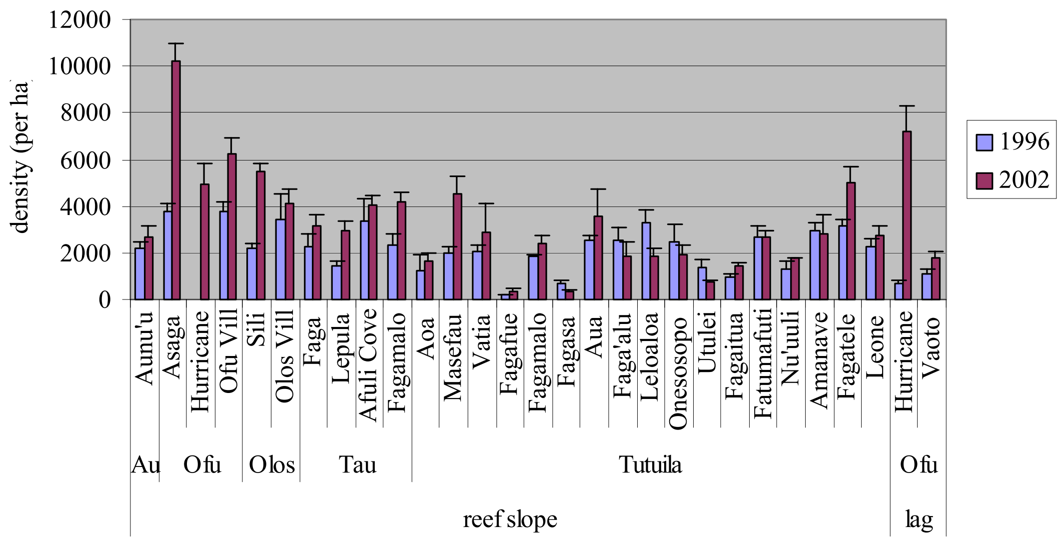


Fig 14 Mean adult density (+/- se) of surgeonfishes (Acanthuridae) at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.

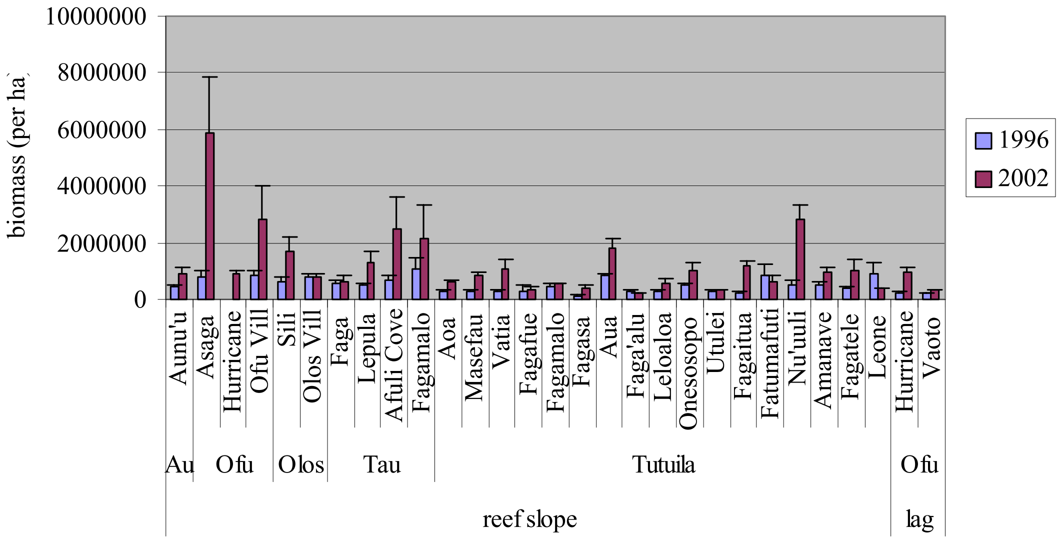


Biomass

Fish biomass was highly variable among both sites and years, although some trends were apparent (Fig 15). Biomass varied from low to high on the reef slopes in Manu'a, and from low to moderate on Tutuila and Aunu'u. The higher biomass recorded at some of the sites in Manu'a was primarily due to target families in the local fisheries, including Acanthuridae, Labridae, Lethrinidae, Lutjanidae, Scaridae and Serranidae (Append 9; see also *Discussion, Fishing*). Furthermore, the very high biomass recorded at Asaga in 2002 was due to the presence of large reef fishes (particularly maori wrasse and parrotfishes), which are vulnerable to fishing and rare or uncommon on Tutuila and Aunu'u (see *Discussion, Fishing*).

At most sites, biomass tended to be higher in 2002 than 1996. This was primarily due to the higher densities of the most abundant families recorded that year (see *Fish Density;* Appends 8 & 9). However, the higher biomass at Aua in 2002 was mostly due to a higher biomass of mullids (primarily *Mulloides vanicolensis*), acanthurids, chaetodontids, pomacanthids, and zanclids recorded at that site that year (Append 9). In contrast, the higher biomass recorded at Nu'uuli in 2002 was primarily due to a higher biomass of lethrinids, lutjanids, mullids and scarids recorded that year.

Fig 15 Mean biomass (+/- se) of adult reef fishes at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.



Recruitment

The survey took place during a mass recruitment event in 2002. Juveniles of 14 families were recorded on the transects that year, and the densities of the most abundant species are summarised in Append 10. By far the most abundant juveniles were surgeonfishes (Acanthuridae), due to the mass recruitment pulse of *Ctenochaetus striatus* at that time (Append 10; see *Discussion, Mass Recruitment of Surgeonfish*). Other abundant juvenile surgeonfishes included *Zebrasoma scopas*, *Ctenochaetus cyanocheilus* and *Acanthurus nigrofuscus* (Append 10).

The next most abundant juveniles were in the families Pomacentridae (particularly *Pomacentrus vaiuli*, *Chrysiptera taupou*, and *Pomacentrus brachialis*), Mullidae (particularly *Mulloides vanicolensis*), Scaridae (unidentified juveniles), and Chaetodontidae (particularly *Chaetodon reticulatus*, *C. pelewensis*, and *C. unimaculatus*) respectively (Append 10).

Species List

The species recorded during the entire baseline survey in 1996 (all habitats and islands) and this resurvey in 2002 are listed in Append 3. A total of 305 species from 37 families were recorded. Most of the species (301) were bony fishes, while 4 were cartilaginous fishes (sharks and rays). The most species rich families include the Labridae (59 species), Pomacentridae (41 species), Acanthuridae (35 species), Chaetodontidae (29 species), Serranidae (22 species) and Scaridae (21 species). A breakdown of the relative abundance of most of the species by habitat type is provided in Green (1996a).

Wass (1984) recorded a total of 991 species and 113 families of fishes in Samoa. Of these, 890 were considered shallow water or reef inhabiting species (generally found at depths <60m). Therefore, these surveys recorded more than one third of the reef associated species recorded by Wass (1984). That is quite high considering that these surveys only included a restricted family list of those families that are amenable to visual census techniques (see *Methods, Table 2*). This resulted in some of the most species rich families being excluded from the survey, including Gobiidae (101 species), Blennidae (47 species), and Holocentridae (30 species: Wass 1984).

Of the families that were included, there was substantial variation in the percentage of species reported by Wass (1984) that were also recorded in these surveys. For example, >90% of the species recorded by Wass (1984) were also recorded here for families that are closely associated with reefs and inhabit the depths included in these surveys ($\leq$20m: eg damselfishes, butterflyfishes and wrasses). Lower percentages of species were recorded for reef associated families where species move on and off the reefs (eg 24% of Carangidae) or families that include cryptic species (eg 84% of Labridae) or species that occur in deeper water (eg 36% of Lutjanidae and 41% of Serranidae species).

General Trends: Ofu Lagoon

Fish communities in the Ofu Lagoon differed from those on the reef slopes in terms of their species richness, density and biomass.

Species Richness

Species richness was moderately high in the Ofu Lagoon (Fig 11), but tended to be lower than on the adjacent reef slope (eg Hurricane House). This was due to a lower species richness of all of the major families in the lagoon (Append 7).

Fish Density

Fish density in Ofu Lagoon was relatively high compared to the reef slopes at most sites (Fig 12). In a similar pattern to that recorded for the reef slopes (see above), the higher density recorded in the lagoon this year, was primarily due to higher density of the most abundant families (Append 8), particularly the Pomacentridae at Vaoto and Acanthuridae at Hurricane House (Append 8, Figs 13 & 14). This was largely due to a higher density of some of the most common lagoon species, including the roving acanthurids (*Ctenochaetus striatus* and *Acanthurus triostegus*) and more sedentary pomacentrids (*Chrysiptera taupou*, *Stegastes nigricans* and *S. albifasciatus*), recorded on the transects this year.

Biomass

Biomass in Ofu Lagoon was similar to or lower than that recorded on the reef slopes at most sites, including the adjacent slope at Hurricane House (Fig 15). The higher biomass recorded in the lagoon at Hurricane House in 2002 than in 1996, was due to the higher biomass of acanthurids (*Ctenochaetus striatus* and *Acanthurus triostegus*), mullids (*Mulloides vanicolensis*), and the pomacentrid (*Stegastes nigricans*) recorded on the transects that year (Append 9).

Recruitment

By far the most abundant recruits in the lagoon were surgeonfishes (Acanthuridae) due to the mass recruitment pulse of *Ctenochaetus striatus* (see *Discussion, Mass Recruitment of Surgeonfish*). The next most abundant juveniles were in the families Pomacentridae (particularly *Chrysiptera glauca* and *C. taupou*), and Scaridae (unidentified juveniles). Juvenile *Acanthurus nigrofuscus* were also common.

Recruitment patterns differed between the lagoon and outer reef slope, due to a difference in habitat preference by some species. For example, the high density of damselfish recruits was due to species that tend to be more abundant in the lagoon (*Chrysiptera glauca* and *C. taupou*). However, there was also evidence to suggest that some species that also occur on the adjacent reef slope, recruit in higher densities in the lagoon. For example, the highest densities of juvenile parrotfishes were recorded in the lagoon. Similarly, the highest densities of juvenile *Ctenochaetus striatus* (*pala'ia*) were also recorded in the lagoon (see Append 10, see *Discussion, Mass Recruitment of Surgeonfish*). However, since the *pala'ia* were highly mobile, it is unclear if they recruited directly into the lagoon, or whether they recruited to other habitats (eg reef slope) and moved into the lagoon (or vice versa).

Species List

A total of 113 species have been recorded in the Ofu Lagoon to date (Append 11). Most of these species were recorded in Pool 400 at Hurricane House (102) and in Pool 200 at Vaoto Lodge (86), probably because more time has been spent surveying those areas.

However, when a similar amount of time was spent making a species list for each pool, the number of species was surprisingly similar for most pools (Table 4). The lower number of species recorded in Pool 200 may have been due to the less time spent in that pool.

Table 4 Number of species observed in each pool in Ofu Lagoon during a timed count in March 2002.

Pool	**Number of Species**	**Count Duration**
200	62	40 mins
300	74	50 mins
400	75	50 mins
500/600	77	55 mins

In general, the pools tended to be characterised by a moderately high species richness of labrids (27 species), scarids (21 species), pomacentrids (14 species), acanthurids (17 species), and chaetodontids (13 species). The most abundant families were acanthurids and pomacentrids (Append 8).

The fish communities in these pools comprise a mixture of resident, roving and transient species. Resident species, which reside in the pools, probably include cirrhitids, blennies, monacanthids, small pomacanthids (eg genus *Centropyge*), most pomacentrids, scorpaenids, sygnathids, tetraodontids and mudskippers. Roving or mobile species, which may stay in the lagoon but rove around the area (and may move between pools), would probably include most acanthurids (eg *Ctenochaetus*, *Acanthurus* species), most balistids, most chaetodontids, holocentrids, most labrids, mugilids, mullids, muraenids, ostracids, pinguipedids, large pomacanthids (eg genus *Pomacanthus*), large pomacentrids (eg genus *Abudefduf*), some scarids, and zanclids. Transient species, which may move between the lagoon and the outer reef slope (possibly associated with tidal movements), may include some larger acanthurids (eg *Nasos* and large *Acanthurus* species such as *A. nigricauda*), carangids, kyphosids, lethrinids, lutjanids, and most scarids.

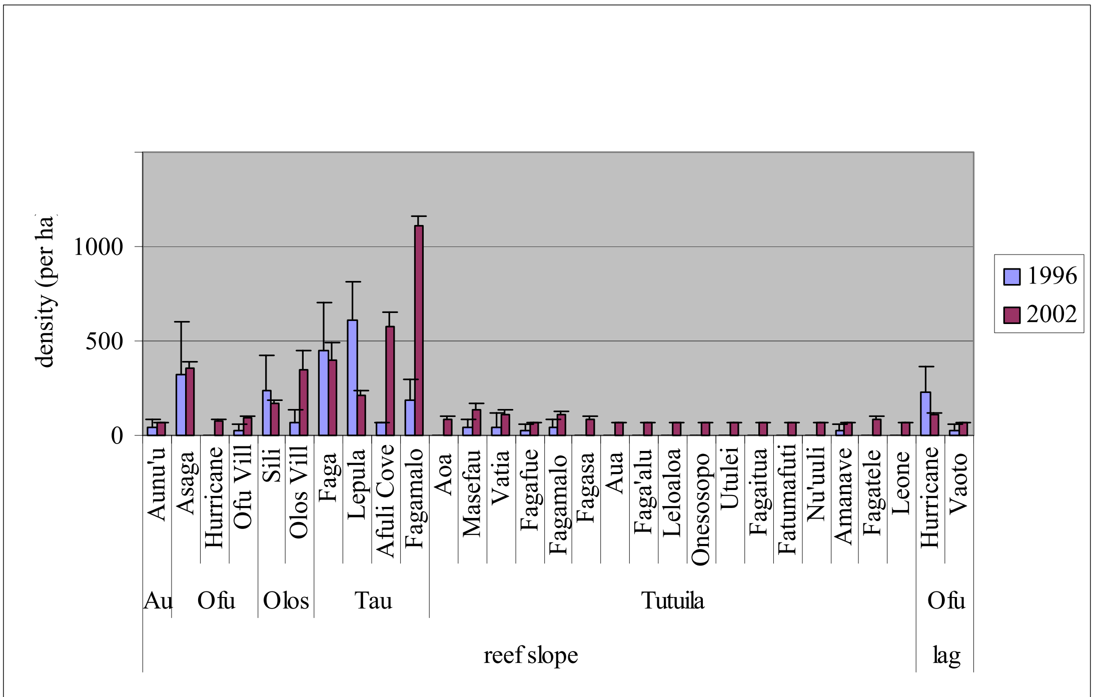
This species list (Append 11) should be treated as a starting point for the lagoon, since more species are likely to be observed in the pools over time. In particular, I would expect a higher number of transient species to be observed in the more open pools (eg Hurricane House), especially at high tide.

Key Macroinvertebrates

<u>Giant Clams</u>

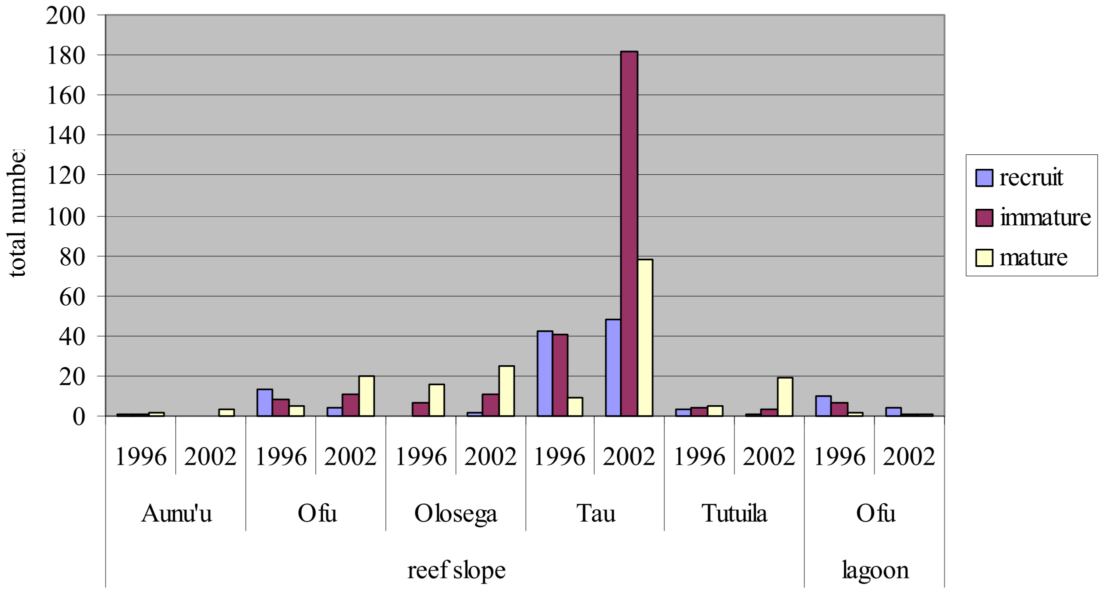
The highest density of giant clams was recorded in the Manu'a Islands in both years, particularly on Tau (Fig 16). Much lower densities were recorded on Aunu'u and Tutuila. Low to moderate densities were recorded in Ofu Lagoon, which were comparable to those on the adjacent reef slope.

Variation among years was high at some sites. For example, density at two sites on Tau (Afuli and Fagamalo) was much higher in 2002. In contrast, density appeared higher at some sites in 1996 than 2002 (eg reef slope at Lepula and the lagoon at Hurricane House), although these differences may not be significant (due to the high variation among transects in 1996).



Maturity also varied among islands (Fig 17). On Tau, where the most clams were recorded, the number of recruits was relatively high each year. However, the much higher number recorded in 2002 was primarily due to a higher number of immature and mature clams that year (Fig 17). Recruitment was much lower on the other islands in both years. On Tutuila, Olosega, Ofu and Aunu'u, the low density of clams was mostly due to the presence of a few mature individuals. In contrast, the low numbers of clams in Ofu Lagoon was mostly due to the presence of recruits and immature clams.

Fig 17 Maturity of giant clams on each island in 1996 and 2002.



Crown-of-Thorns Starfish

The results of the baseline survey for crown-of-thorns starfish (COTS) are reported here for the first time. In that survey, COTS were rare or uncommon throughout most of the archipelago (Append 12), with no starfish recorded on the transects in Manu'a or on the two remote atolls (although one individual was observed on Rose). Most starfish were observed on 'Upolu, with low to moderate densities recorded in the lagoon (Sa'anapu and Lefaga) and on the reef slope at two sites on the northwest side (at Faleasi'u and Vaitele: Append 12, Table 5). Moderate densities were also recorded on the reef slope (10m) at Utulei in Pago Pago Harbour (Append 12, Table 5). No starfish were recorded on crests, reef flats or deeper reef slopes (20m) at all. Most of the starfish recorded in this survey were relatively large (28 to 40 cm: Table 5), although one small individual (18cm) was recorded at Faleasi'u.

Table 5 Number of individuals and size (diameter in cms) of all crown-of-thorns starfish recorded in 1996 and 2002.

Survey	Island	Site	Habitat	Number of individuals	Size (cm)
1996	Tutuila	Utulei	reef slope (10m)	3	42;42;42
1996	'Upolu	Faleasi'u	reef slope (10m)	5	18;30;35;40;40
1996	'Upolu	Vaitele	reef slope (10m)	2	40;40
1996	'Upolu	Lefaga	lagoon	2	28;32
1996	'Upolu	Sa'anapu	lagoon	1	15
2002	Ofu	Ofu Village	reef slope (10m)	1	35
2002	Tutuila	Utulei	reef slope (10m)	1	42

Low densities were recorded on the transects on the reef slopes at only two sites in 2002 (Ofu Village and Utulei in Pago Pago Harbour: Table 5), although feeding scars were observed in some locations (eg on the foliaceus coral *Echinopora* at Ofu Village, see Append 14). Most of the starfish recorded in this survey were relatively large (35-42cm: Table5).

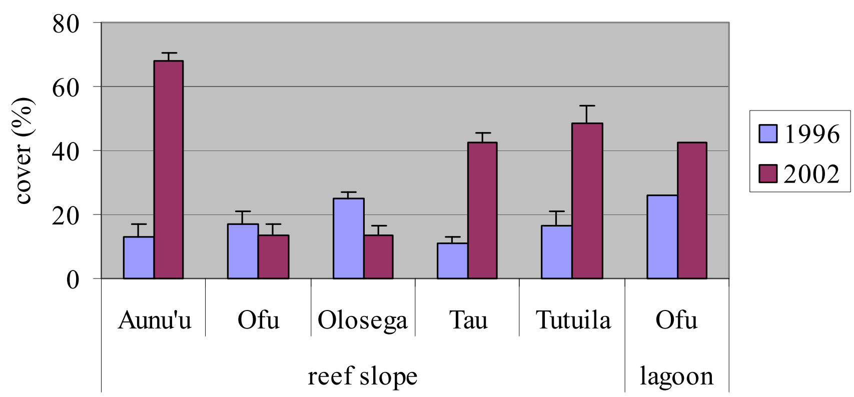
DISCUSSION

Recovery from Large Scale Disturbances on Tutuila and Aunu'u

The coral reefs of Tutuila and Aunu'u have shown a dramatic recovery from the large scale disturbances of the last few decades. By the mid 1990s, the reefs at most sites were already in the early stages of recovery (Green 1996a, Mundy 1996). Many reefs that had been reduced to rubble by the hurricanes in 1990 and 1991, had already been consolidated by pink coralline algae and coral recruitment was high. Coral cover was increasing rapidly, with a three to five fold increase recorded at some sites over just 18 mths (Green 1996a). At most sites, the rapid increase in coral cover was primarily due to encrusting corals. However, at some sites (eg Vatia), other growth forms (eg plate and branching) had also become established and were growing rapidly. Similarly, the reefs of Manu'a and the two remote atolls were recovering well from the effects of a hurricane and severe storm in 1987 (Green 1996a,c, Page & Green 1998).

The reefs at most sites on Tutuila and Aunu'u have continued their rapid recovery over the last six years (see also Fisk & Birkeland 2002). A three to five fold increase in coral cover was recorded on each island (Fig 18), which represented a two to ten fold increase at most sites (Fig 8). The reefs on Tau have also improved dramatically, with a four fold increase in coral cover (Fig 18). In contrast, coral cover has declined on Ofu and Olosega (Fig 18), probably due to the chronic effects of COTS on those reefs (see *Chronic Impacts of Crown-of-Thorns Starfish in the Manu'a Islands* below).

Fig 18 Mean coral cover (+/- se) on each of island in 1996 and 2002.



Over the last few years, the coral communities at most sites on Tutuila, Aunu'u and Tau have also become more lush and diverse. Encrusting coral remains dominant, but cover of other growth forms (eg branching, massive, plate etc) has increased (Figs 9 & 10), particularly on Aunu'u and the north side of Tutuila (eg Vatia and Fagamalo: Append 6). As a result, the reefs at these sites are in particularly good condition and quite spectacular. These results demonstrate that most of the reefs on these islands are healthy and resilient to large scale disturbances.

Some reef fish species are closely associated with the coral communities, and their population trends tend to follow those of their host corals. In this study, patterns in the distribution and abundance of these fishes were compared over the last six years to determine if they were responding to the changes in the coral communities.

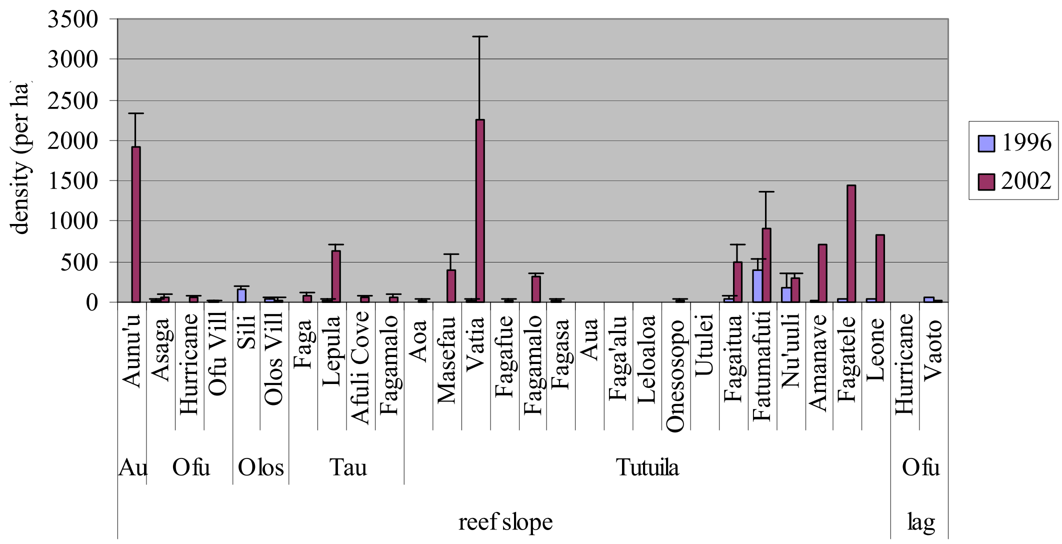
Some of these species have increased in abundance, in response to the recovery of the coral communities on Tutuila and Aunu'u. For example, the damselfish species *Plectroglyphidodon dickii* is closely associated with robust branching corals of the genus *Acropora* and *Pocillopora* (Myers 1999*).* This species showed a dramatic decline in abundance on Tutuila in the late 1970s, where coral communities were devastated by the COTS outbreak (Buckley 1986, Birkeland et al 1987), and their abundance remained low for many years (Birkeland et al 1994, *in prep*). However, *P. dickii* has shown a rapid increase in abundance at some sites on Tutuila and Aunu'u over the last six years (Fig 19: particularly at Vatia, Aunu'u and Fagatele), where there has been a significant increase in cover of branching coral (Fig 20).

Butterflyfishes (Chaetodontidae) have often been used as indicators of the health of coral communities (Reese 1995). However, not all chaetontids are good candidates for this, since different species are associated with corals to varying degrees (depending on their feeding preferences: Reese 1995). In this study, their was no clear relationship between increased coral cover (Fig 8) and changes in chaetodontid density (Fig 21) at the family level. Chaetodontid density did tend to increase at most sites on Tutuila (eg Fagamalo, Fagaitua), along with an increase in coral cover. However, some sites that experienced the greatest increases in cover (eg Aoa, Vatia, Amanave) did not show a similar increase in chaetodontid density. Furthermore, some sites (eg Aua) that did not show a substantial increase in cover, had significantly higher chaetodontid densities in 2002.

The relationship between chaetodontid density and coral cover becomes clearer when it is examined at the species level. One good example is *Chaetodon trifascialis*, which is closely associated with plate corals and feeds exclusively on coral polyps and mucus (Myers 1999). This species was absent or rare at most sites in 1996 (Fig 22) when the cover of plate corals was low (Fig 23). However by 2002, plate coral cover had increased at several sites (eg Aoa, Vatia, Fagamalo and Leone: Fig 23), along with the density of *C. trifascialis* (Fig 22).

In contrast, the increase in chaetodontids at Aua in Pago Pago Harbour in 2002 (Fig 21), was largely due to an increase in abundance of *Chaetodon lunula* (Append 13). This was not due to an increase in coral cover (which was low at that site: Fig 8), because this species feeds on benthic invertebrates and is not closely associated with coral cover (Myers 1999). Similarly, the increase in chaetodontid density at Aunu'u in 2002 was primarily due to large schools of *Hemitaurichtyes polylepis* (Append 12), which are midwater planktivores that are not closely associated with the coral communities (Myers 1999).

Fig 19 Mean adult density (+/- se) of the damselfish *Plectroglyphidodon dickii* at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.



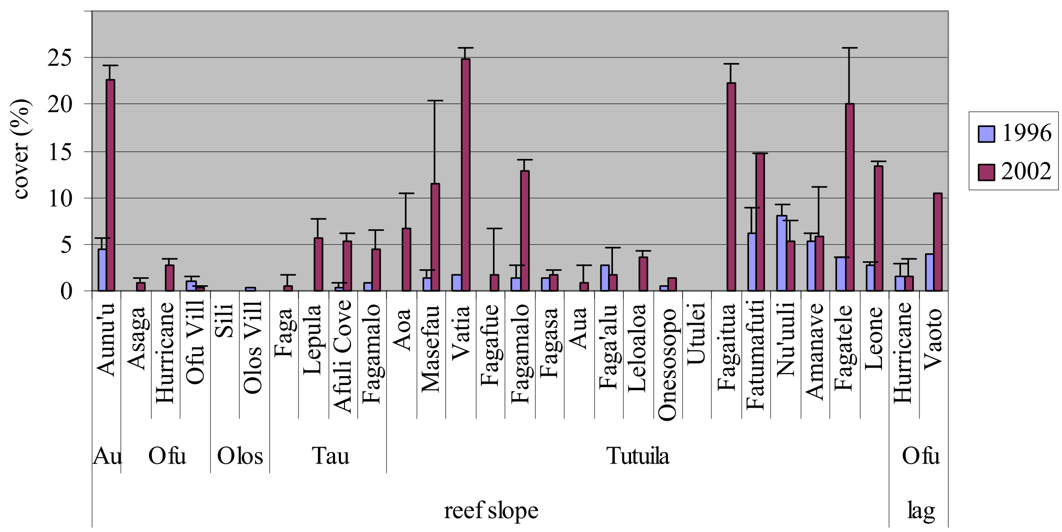
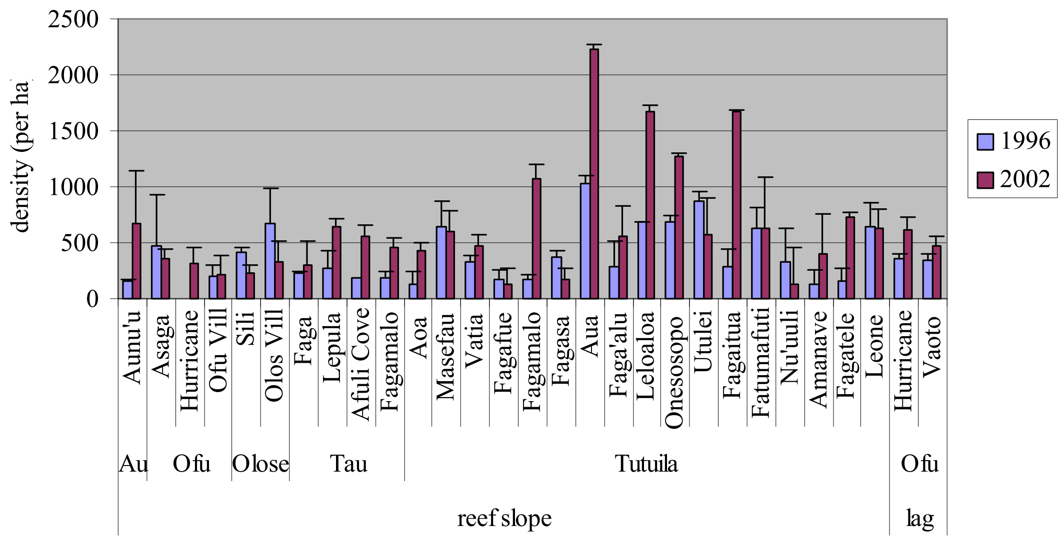


Fig 21 Mean adult density (+/- se) of butterflyfishes (Chaetodontidae) at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.



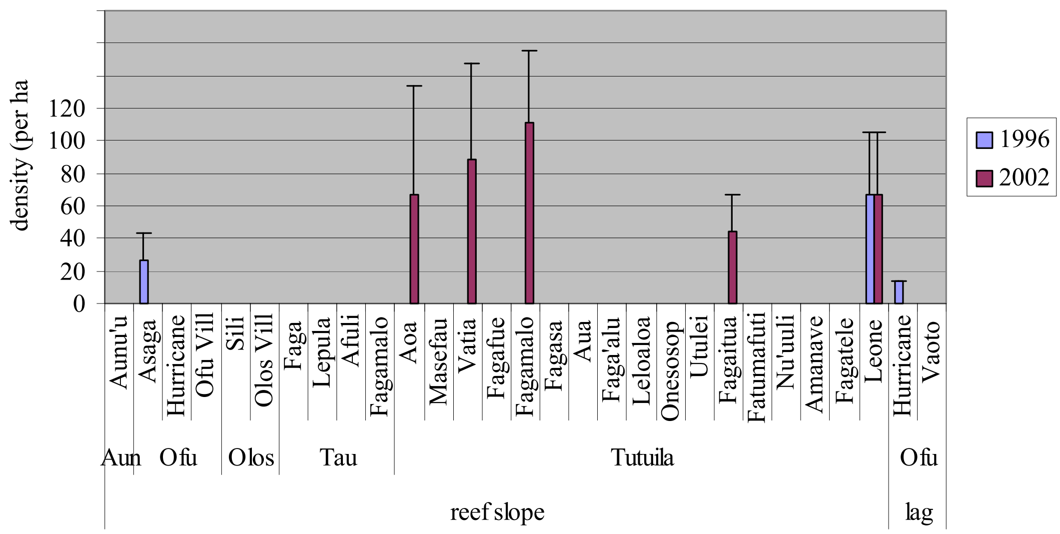
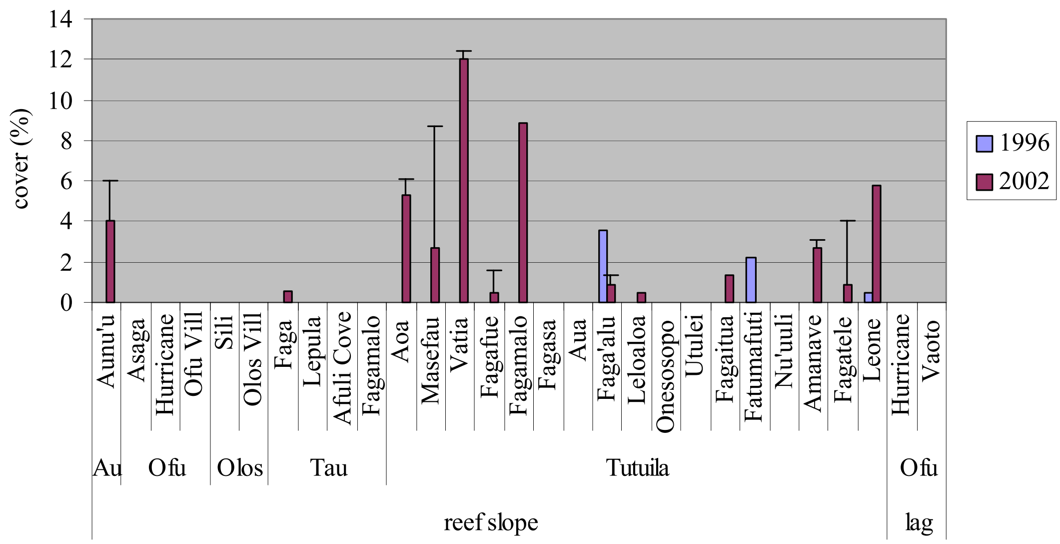


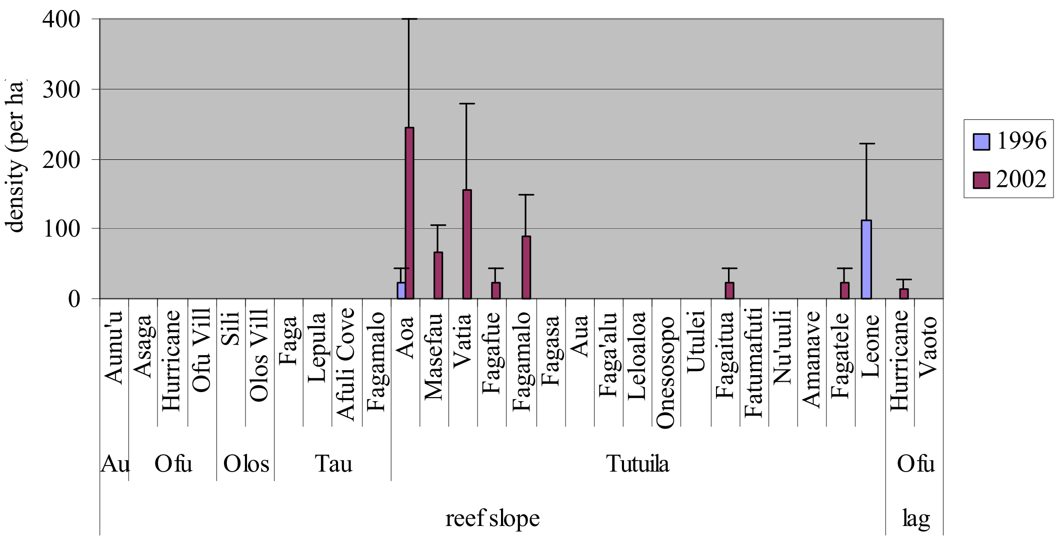
Fig 23 Mean cover (+/- se) of plate coral at each site in 1996 and 2002. Five sites (Asaga, Hurricane House, Sili, Faga and Lepula) were not surveyed in 1996.



Populations of other reef fish species that are closely associated with the coral communities have also started to show signs of recovery over the last few years. For example. the wrasse *Labrichthyes unilineatus* feeds on coral polyps and is known to inhabit coral-rich areas, usually in the vicinity of branching corals (Randall et al 1990, Myers 1999). This species has increased in abundance at some sites on Tutuila over the last six years (Fig 24: mostly on the north side at Aoa, Vatia and Fagamalo), along with the recovery of the coral communities (particularly branching coral: Fig 20).

In summary, the populations of some reef fishes that are closely associated with the coral communities are recovering from the effects of the large scale disturbances over the last few decades, along with their host coral communities. While it may be true that some species may be good indicators for the health of the coral communities in American Samoa (particularly *Plectroglyphidodon dickii, Chaetodon trifascialis* and *Labrichthyes unilineatus*), monitoring these species as indicators of the health of the coral communities alone is not recommended. If the object of a monitoring program is to monitor the health of the coral communities, the corals should be monitored directly. However, if the program is interested in the health of the coral reef ecosystem in general, then both corals and associated reef fishes should be monitored (along with key macroinvertebrates). In that situation, these species may be good candidates for monitoring coral reef health in American Samoa.

Fig 24 Mean adult density (+/- se) of the wrasse *Labrichthyes unilineatus* at each site in 1996 and 2002. The reef slope at Hurricane House was not surveyed in 1996.



Chronic Impacts of Crown-of-thorns Starfish in the Manu'a Islands

Several studies have reported a low to moderate population of crown-of-thorns starfish (COTS) on Ofu and Olosega over the last few decades (Itano & Buckley 1988a, Zann 1992, Maragos et al 1994). COTS were not detected on the transects in the Manu'a Islands in the mid 1990s (this study), although Mundy (1996) saw evidence (feeding scars) of a relatively large population on the reef at Olosega Village in 1995. COTS were also known to be quite abundant on Ofu about two years ago, when the NPAS removed about 40 individuals from the lagoon (P. Craig *pers comm*). This year, COTS were recorded on the transects at Ofu Village only (Table 5), although a few individuals were observed in Ofu Lagoon.

In 1995, Mundy (*pers. comm.*) predicted that the coral communities at Olosega Village were likely to be devastated by COTS predation over the next few years. This appears to have been the case, with a decline in coral cover at that site since the last survey (Fig 8, Append 5 & 6; see also Fisk & Birkeland 2002).

Coral cover has also declined at Sili and Asaga over the last few years. The benthic communities at these sites were not monitored in this survey until this year, when low coral cover was detected at each site (17% and 6% respectively: Fig 6). However, Mundy (1996) surveyed the coral communities at those sites in 1995, and recorded much higher coral cover (>40% for Sili, and ~20% for Asaga). In fact, he reported that the reef at Sili was particularly notable for its spectacular coral communities. That is no longer the case, since there has been a decline in coral cover at that site.

These results suggest that coral cover has decreased on the reef slope at most sites surveyed on Ofu and Olosega over the last few years, probably due to COTS predation (see also Fisk & Birkeland 2002). In contrast, coral cover appears to have increased in Ofu Lagoon. However it is unclear whether that was due to an actual increase in coral cover or a difference in the location of the transects between surveys (see *Methods, Location of Study Sites*).

Chronic low to moderate rates of COTS predation may have also played an important role in determining the relative abundance of corals on Ofu and Olosega (see also Fisk & Birkeland 2002). For example, Zann (1992) noted that the corals in Ofu Lagoon (dominated by large *Porites* colonies and *Millepora*) were characteristic of remanent communities after COTS predation (due to feeding preferences by the starfish). This may also be the case on the reef slopes of Ofu and Olosega, since the coral communities are dominated by less preferred prey species (eg massive corals and encrusting *Montipora*), while more preferred *Acropora* species (eg branching and plate corals) are uncommon (Append 6; see also Fisk & Birkeland 2002). In particular, the composition of the coral community at Ofu Village (dominated by encrusting, foliaceus and massive coral: Append 6), is characteristic of a coral community that has been retained at an early recovery phase by chronic COTS predation (Fisk & Birkeland 2002). Indeed both starfish and feeding scars (on foliaceus coral) were observed at that site in 2002 (Table 5, Append 12, 14).

It is unclear whether COTS have played a role in structuring the coral communities on Tau or not (they have not be reported there to date). However, the relative abundance of branching corals (Append 6) on the island is consistent with the absence of a major COTS outbreak in recent years (C. Birkeland *pers comm*).

The reefs on the main island of ‘Upolu in neighbouring Samoa also appear to have experienced chronic COTS predation, with low to high densities recorded over several decades (Birkeland & Randall 1979, Zann 1991, Zann 1992, Green 1996a,b, this study). Therefore, cots are likely to have been an important factor in structuring the coral reef communities on that island also (Green 1996b).

In contrast, COTS have been rare or uncommon on Tutuila and Aunu’u since the massive outbreak in the late 1970s. At that time, the coral communities and some associated reef fishes were devastated by COTS predation (see *Introduction, Crown-of-thorns Starfish*). However, COTS do not appear to have played a major role in structuring the coral reef communities on those islands over the last few decades.

The impacts of COTS predation on the coral communities on Ofu-Olosega has also affected the reef fish communities. For example, species that are closely associated with corals that are the preferred prey of the starfish (branching or plate *Acropora* species) are uncommon on these islands (eg *Plectroglyphidodon dickii*, *Chaetodon trifascialis*, and *Labrichthyes unilineatus*: see Figs 19, 22 & 24).

It is possible that the chronic low to moderate numbers of COTS on Ofu and ‘Upolu, may be related to the presence of well developed natural lagoons on those islands (these lagoons do not occur naturally on Tutuila, Aunu’u or Tau). One hypothesis is that the lagoons may act as nurseries for the starfish, by retaining larvae in conditions that may enhance their survival (possibly related to water quality conditions, which may result in more planktonic food for the larvae). The starfish may then spread out onto the adjacent reef slopes as they grow. Since Ofu and Olosega are connected by continuous reef tract, the starfish would also be able to move from Ofu to Olosega.

In summary, the results of this study indicate that some of the coral communities on Ofu and Olosega are no longer among the best in the archipelago as reported by Green (1996a) and Mundy (1996). This is probably due to the low to moderate rates of COTS predation on these islands over the last few years. As a result, the coral communities on Tutuila, Aunu’u and Tau now appear to be in better condition than those on Ofu and Olosega.

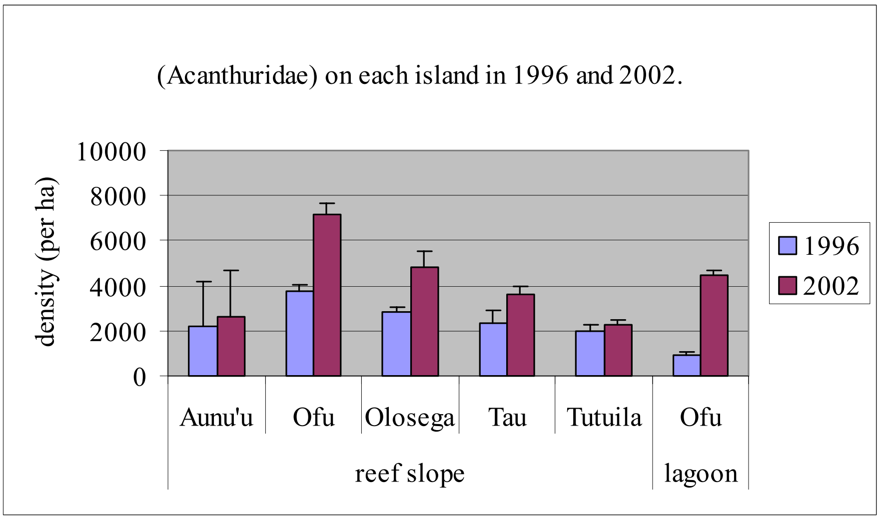
Human Impacts

Fishing

The effects of fishing were examined by comparing the populations of four of the major fisheries families (Acanthuridae, Scaridae, Serranidae and Lujanidae) on islands which have experienced different levels of fishing over the last few years. For this comparison, fishing pressure was assumed to have been high on Tutuila, moderate on Aunu'u, and low in the Manu'a Islands (see *Introduction, Fishing*).

Most of the major fisheries families tended to be more abundant in Manu'a than on Tutuila, including the Acanthuridae (Fig 25), Lutjanidae (Fig 26), and Serranidae (Fig 27). These families were intermediate in abundance on Aunu'u. At the site level, density of these families tended to range from low to moderate on Tutuila and Aunu'u, and from moderate to high in Manu'a (Append 8). This pattern is demonstrated by the Acanthuridae in Fig 14.

These patterns were similar or more pronounced when size was taken into account using biomass (Append 9). For example, the biomass of serranids was also greater at most sites in Manu'a than on Tutuila (Fig 28). Serranid biomass was particularly high at Aunu'u in 2002 (Fig 28), due to the presence of a few large *Cephalopholis argus*.



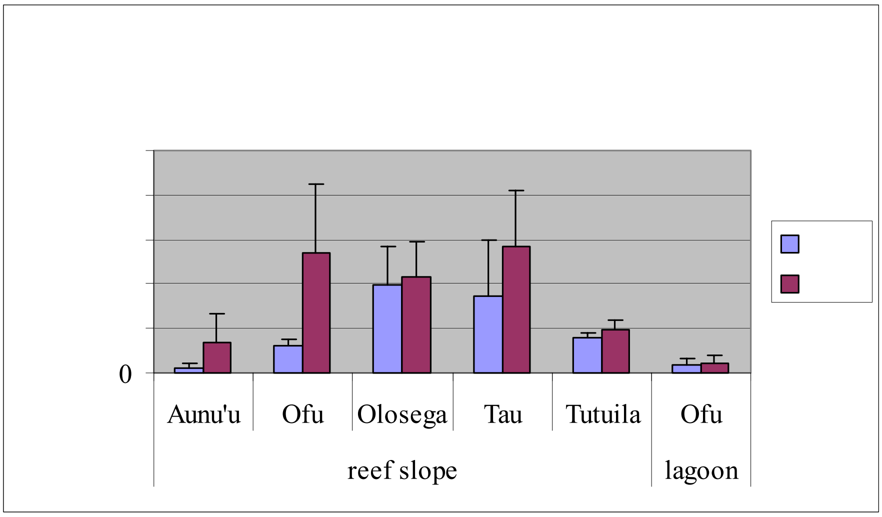
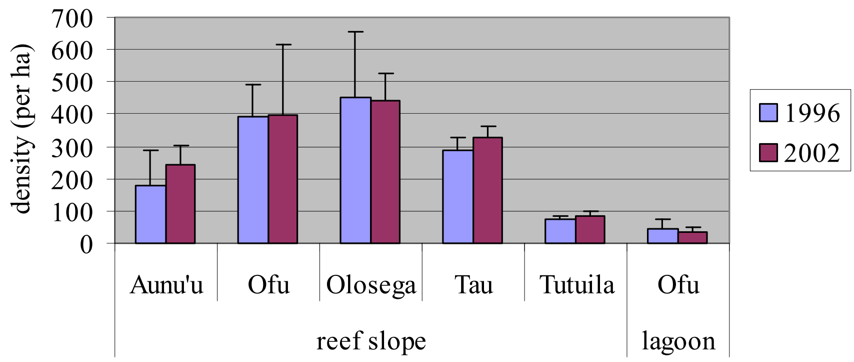
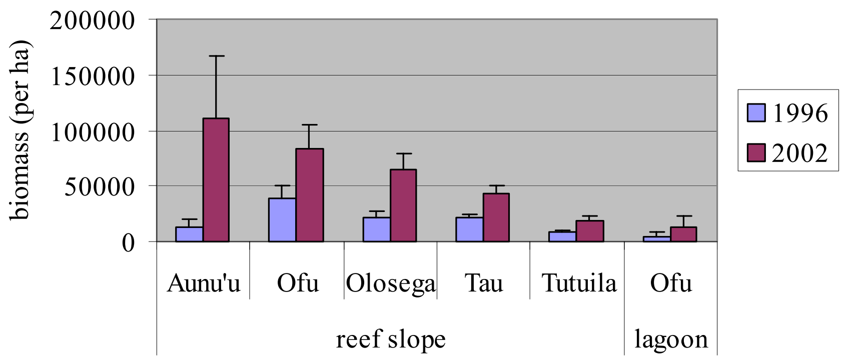


Fig 27 Mean density (+/- se) of adult groupers (Serrandiae) on each island in 1996 and 2002.





These patterns were reflected at the species and genus level for these families. For example, one of the most common grouper species, *Cephalopholis argus*, was more abundant on the reef slopes in Manu'a than on Tutuila and Aunu’u (Fig 29). Another example is the surgeonfish *Ctenochaetus striatus*, which was also more abundant in the Manu’a Islands (Fig 30). This is one of the most abundant fishes in American Samoa, and is the dominant species in the complex of small brown surgeonfishes locally known as *pone*, which is a major component of the subsistence fishery.

Comparisons at the family level are not always the best indication of the impacts of fishing, particularly for families where not all species are targeted by the fishery to the same extent (although most species seem to be taken opportunistically). For example, the differences among islands with different levels of fishing is less clear for the Scaridae (Fig 31), due to the abundance of some of the smaller species (particularly *Chlorurus sordidus* and *C. pyrrhurus*) on Tutuila.

Fig 29 Mean adult density (+/- se) of the grouper *Cephalopholis argus* on each island in 1996 and 2002.

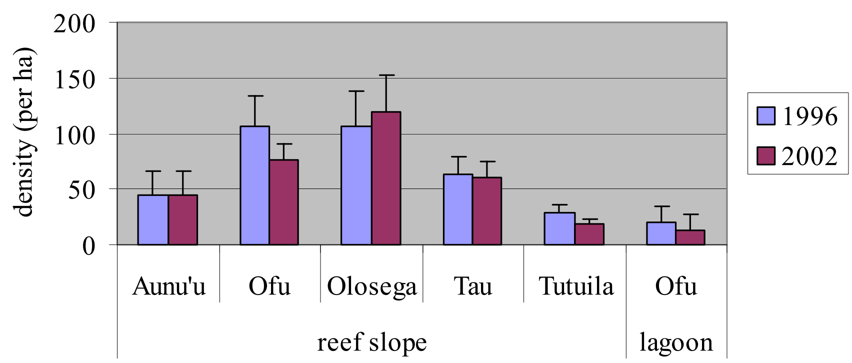


Fig 30 Mean adult density (+/- se) of the surgeonfish *Ctenochaetus striatus* on each island in 1996 and 2002.

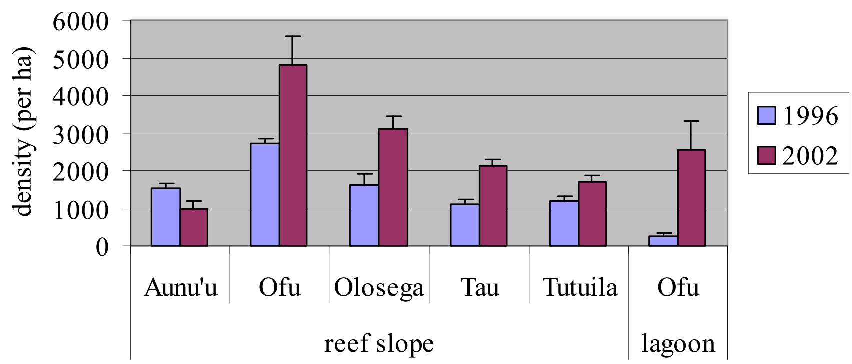
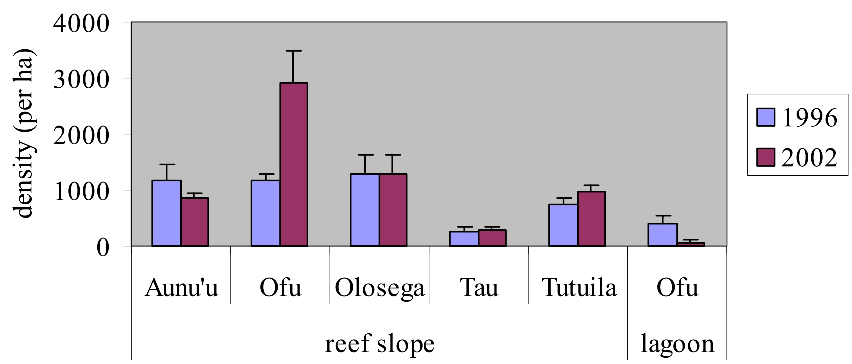


Fig 31 Mean density (+/- se) of adult parrotfishes (Scaridae) on each island in 1996 and 2002.

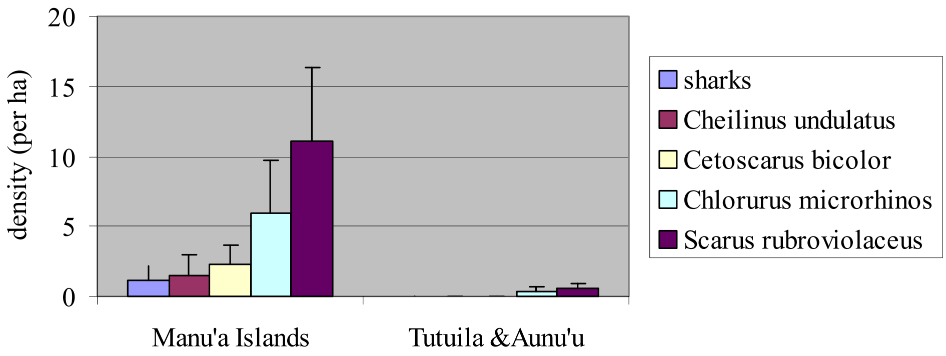


However, the impacts of fishing on parrotfishes were more obvious when the density of larger species that are most susceptible to overfishing were compared among islands. In 2002, these species and others that are also vulnerable to overfishing (eg sharks and the wrasse *Cheilinus undulatus*), were more abundant in Manu'a than on Tutuila and Aunu'u (Fig 32). In fact, no sharks, maori wrasse or *Cetoscarus bicolor* were recorded on Tutuila or Aunu'u at all (Fig 32).

Long term monitoring of Fagatele Bay and other sites around Tutuila show that all of these species are less abundant on Tutuila than they used to be (from the late 1970s to the mid 1990s: Birkeland et al 1987, 1994, 1996, *in prep*, Wass 1982). Anecdotal evidence from Samoan people also suggests that large schools of one of these species (*C. microrhinus*) are no longer seen on Tutuila (Page 1998). Furthermore, the largest parrotfish species, *Bolbometapon muricatum,* is known to occur in American Samoa, since a few individuals were observed on Olosega in 1995, and one was recorded in Fagatele Bay in 1985 (Birkeland et al 1987). However, this species is now rare or absent in American Samoa, since it has not been observed during extensive surveys in the last few years.

It is likely that the decline in these species is due to overfishing. For example, Page (1998) reported that two parrotfishes species, *Scarus rubroviolaceus* and *Chlorurus gibbus* (now *microrhinus*), seemed particularly vulnerable to the nightime scuba fishery, and that their relative abundance and mean size declined while the nightime scuba fishery was in operation. Therefore, it is likely that these species were overfished while the scuba fishery was operating on Tutuila over the last few years. These results demonstrate that the Governor and DMWR made the right decision to ban this highly efficient fishery.

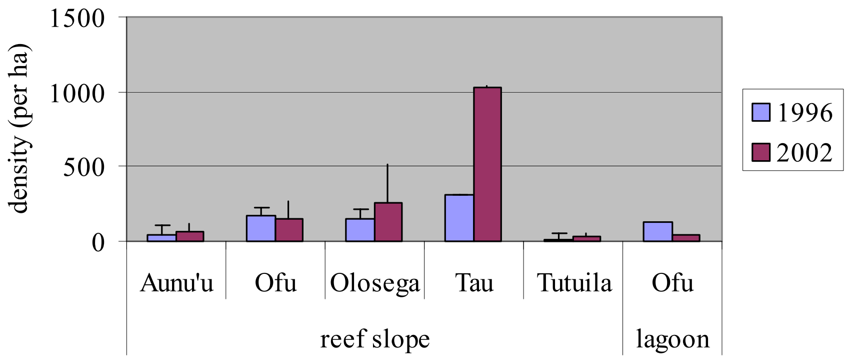
Fig 32 Mean density (+/- se) of large reef fish species on Tutuila and Aunu'a and the Manu'a Islands in 2002.



Overfishing can lead to serious consequences for coral reef ecosystems (Jackson et al 2001). For example, herbivorous fish such as surgeonfishes and parrotfishes play an important role in structuring coral reef ecosystems. Depleting the populations of these fishes can lead to serious ecosystem effects, such as an increase in algae and a decrease in coral recruitment (see Jackson et al 2001). Fortunately, this does not appear to have occurred on the reefs of Samoa as yet, which is demonstrated by the fact that the reefs at most sites are still in good condition and resilient to large scale disturbances.

In a similar pattern to the fish, higher densities of giant clams were recorded in the Manu'a Islands (particularly on Tau) than on Tutuila and Aunu'u (Fig 33). However, the densities were significantly lower than those recorded on Rose Atoll (Green & Craig 1999), which confirms that Rose remains an important refuge for giant clams in the Samoan Archipelago.

Fig 33 Mean density (+/- se) of giant clams on each island in 1996 and 2002.



However, the population of giant clams at Tau also appears to be in good condition, based on the healthy size structure of the population (Fig 17). Recruitment was relatively high, and 25% of the clams were mature, which is comparable to the 24% of mature clams in the population at Rose (Green & Craig 1999).

In contrast, clam populations on the other islands (Tutuila, Aunu'u, Ofu, Olosega) do not appear to be in good condition. Density was low and mostly limited to a few large individuals, and there were very few recruits compared to Rose and Tau (Green & Craig 1999, this study). This indicates that the clam populations on those islands may be in decline, probably due to overfishing and a subsequent lack of recruitment. One concern is that the remaining individuals may be present in such low densities that their reproductive success and subsequent recruitment may be diminished (Green & Craig 1999). This seems to be the case given the low numbers of recruits on all of the islands except Rose and Tau.

The reasons why Tau continues to receive good clam recruitment may be twofold. First, there were more mature clams on Tau than on the other volcanic islands, so self recruitment is possible. However, it is also possible that Tau may receive some level of recruitment from Rose Atoll (Green & Craig 1999). This reinforces the importance of Rose Atoll as a refuge for giant clams in American Samoa, and highlights the importance of Tau as a potential refuge for giant clams in the main volcanic islands.

Given that giant clams are highly prized by Samoans, it seems likely that overfishing has contributed to the low numbers of clams on the main volcanic islands of American Samoa (Green & Craig 1999). This is supported by the results of an interview survey, which found that the numbers of giant clams had decreased substantially on Tutuila in the memory of local fishermen (Tuilagi & Green 1995). It is also consistent with local fisheries statistics, which showed a decline in the harvest of giant clams over the last two decades (Ponwith 1991).

Furthermore, Green & Craig (1999) demonstrated a correlation between the density of clams and the size of the human population on the islands in the Samoan Archipelago. That study demonstrated that the highest clam densities were present on the uninhabited Rose Atoll, and the lowest clam densities were recorded on the most heavily populated islands of Tutuila and ‘Upolu. The Manu’a Islands, with its lower population, was intermediate in both respects. The results of this study have confirmed that trend (Fig 33).

Water Quality

Fortunately, water quality is good around most of American Samoa, because the islands are steep with narrow fringing reefs (and limited lagoon development), so the reefs are continually flushed by clear oceanic waters (Craig 2002). Exceptions include heavy sedimentation at some sites after rain (due to natural causes and poor land use practices), and nutrient enrichment from human and animal waste in populated areas (Craig 2002). This is of particular concern in narrow embayments, which are not as well flushed by oceanic water, such as Pago Pago Harbour. Urban and industrial pollution have also been of concern in Pago Pago Harbour, although water quality has improved in the last decade (Green et al 1997a, Craig 2002, ASEPA *unpubl data*).

Where water quality is good, the reefs of American Samoa have demonstrated that they are healthy, resilient, and able to recover from large scale disturbances. The substratum is quickly consolidated by pink coralline algae, and coral recruitment is high leading to the rapid recovery of the coral communities (Green 1996a, Green et al. 1999, this study). This has occurred at most sites around American Samoa over the last few decades (Green 1996a, this survey).

However some sites have not recovered as rapidly, where water quality is poor (Green 1996a). For example, the coral communities at Fagasa and Fagafue have not recovered as quickly as other sites on the north side of Tutuila (eg Aoa, Vatia, Masefau and Fagamalo: Fig 8), probably due to high sediment loads in those bays (Green 1996a, Mundy 1996). Furthermore, the coral communities at those sites are characterised by encrusting corals and large massive species (Append 6) that are able to cope with high sediment loads (eg *Porites* and *Diploastrea*). A similar situation exists at some sites in the Harbour, where recovery has been relatively slow in areas that receive high rates of sedimentation (eg Faga'alu). Sedimentation is likely to have contributed to these patterns, because coral recruitment, juvenile survival and growth rates all tend to be lower in areas that receive high sediment loads (Maragos 1993, Rodgers 1990, Richmond 1993).

Fish species richness, density and biomass also tend to be lower at these sites (eg Faga'alu and Fagafue: Figs 11, 12 & 15), due to the absence of other coral growth forms (eg branching and plate corals: Append 6), which are the preferred habitat type for some species (see *Recovery of Coral Reefs on Tutuila and Aunu'u* above). The exception is Fagasa, where fish species richness is moderately high due to the presence of branching *Porites cylindrica* at that site[1].

Pago Pago Harbour Special Management Area

Despite some recent improvements, the reefs of Pago Pago Harbour remain in the worst condition of all the reefs in the Territory. Coral cover has increased at most sites in the Harbour over the last few years (Fig 8, Append 5; see also Fisk & Birkeland 2002), which shows that like the rest of Tutuila, these reefs are recovering from the effects of the hurricanes. However, coral cover is still low to moderate compared to other sites around Tutuila (Fig 8; see also Fisk & Birkeland 2002). It is also important to note that most of the cover is by encrusting coral, with little or no

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[1] *P. cylindrica* was recorded as a massive coral in this survey.

branching or plate coral recorded (Append 6). Algal cover is also relatively high (Appends 5 & 6), but it is mostly encrusting algae rather than pink coralline algae at some sites (eg Aua, Onesosopo: Append 6). The low cover of pink coralline algae, branching and plate coral, is most likely the result of ongoing problems with water quality, since they are particularly vulnerable to poor water quality (they are also uncommon in other areas of poor water quality eg Fagasa and Fagafue: Append 6). This indicates that while coral cover is moderately high at some sites, the coral communities are still not in good condition in the Harbour.

However, it is important to note that despite the stressed conditions in the Harbour, these reefs are important since they support habitats and species otherwise unique to Samoa (Birkeland et al 1987, 1994, 1996, Maragos et al. 1994). Good examples are the coral communities at Faga'alu, Utulei and Leloaloa, which are dominated by large massive and foliaceus colonies of *Diploastrea, Oxypora, Merulina* and *Lobophyllia* (Mundy 1996, Append 6).

Recent observations of increased coral recruitment in the Harbour, including species that are particularly vulnerable to poor water quality (eg *Acropora* species), suggest that further recovery maybe underway (see *Introduction, Water Quality*). However, the reefs are still a long way from resembling the lush coral communities described in the Harbour early last century (Mayor 1924a,b). For example, Mayor (1924b) described the reef slope at Aua as comprising lush coral communities, with coral covering an estimated ¾ of the area at a depth of 4-6m. He also reported that most of this cover comprised *Acropora* colonies (87% of colonies counted), and that large colonies of *Acropora hyacinthus* (plate corals 3 feet in diameter) were common, as were large stands of branching *Acropora* (25 square feet in area). Recent surveys have shown that coral cover at this site remains low (<10%: Append 5), and that the dominant corals are encrusting species of *Montipora* (Append 6). Branching and plate *Acropora* colonies are still rare on the reef slope at Aua, although a few colonies have been observed in recent years (C. Birkeland *pers comm*). This is in contrast to the outer reef flat at the same site, where a dramatic increase in recruitment of branching *Acropora* has been observed in recent years (see *Introduction*).

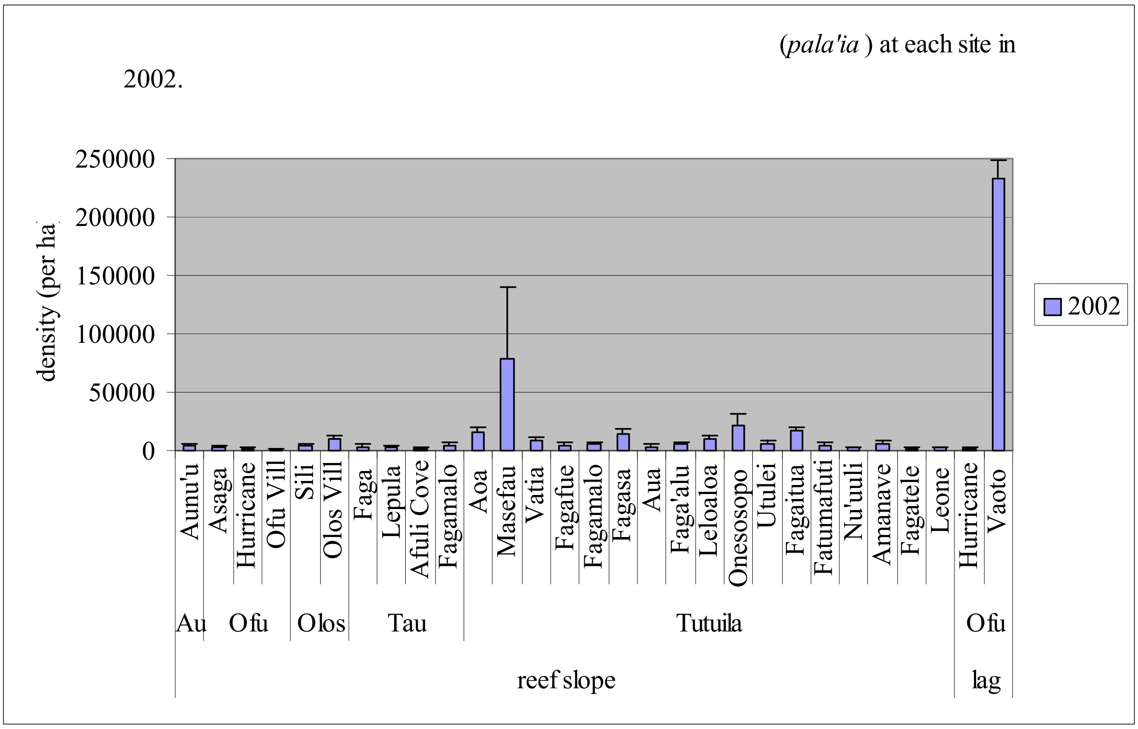
The fish communities in the Harbour reflect the poor condition of the coral communities. Species richness, density and biomass range from low to moderate (Figs 11, 12 & 15, Append 7-9), and the species that are abundant tend to be those that are not closely associated with healthy coral communities. These includes some species of butterflyfish (*Chaetodon lunula*, *Forcipiger flavissimus,* and *Heniochus* species), goatfish (*Mulloides vanicolensis*), angelfish (*Centropyge flavissimus* and *Pygoplites diacanthus*), damselfish (particularly *Pomacentrus brachialis* and *P. vaiuli*), parrotfish (particularly *Chlorurus pyrrhurus* and *Scarus psitticus*), and moorish idols (*Zanclus cornutus*). While those species that do rely on healthy coral communities tend to be rare or less abundant in the Harbour area (eg *Plectroglyphidodon dickii*, *Chaetodon trifascialis*, and *Labrichthyes unilineatus*: Figs 19, 22 & 24).

However in a similar pattern to the coral communities (Birkeland et al 1987, 1994, 1996, Maragos et al 1994), the fish communities in the Harbour are important since they include some species that are rare or uncommon elsewhere in American Samoa. For example, some species (eg *Halichoeres melanurus, Scarus ghobban, Scarus* *dimidiatus*) were only observed in the Harbour during this survey. Furthermore, some species (eg the coral trout *Plectropomus laevis, Centropyge bicolor,* and *Acanthurus xanthopterus*) tend to be more commonly observed in the Harbour area than elsewhere on Tutuila.

Mean biomass of some fisheries families (eg surgeonfishes, parrotfishes and groupers) is also moderately high at some sites in the Harbour compared with elsewhere around Tutuila (particularly at Aua, Onesosopo and Leloaloa: Append 9). This may be due to a combination of factors including the higher abundance of some larger species in the Harbour (eg *Acanthurus xanthopterus*, *Scarus ghobban*, and *Plectropomus laevis*) due to habitat preferences (Myers 1999) and/or reduced fishing pressure (due to toxicity levels in the fish in the Harbour, particularly at Leloaloa).

Mass Recruitment of Surgeonfish *(pala'ia)*

The mass recruitment of *Ctenochaetus striatus* in 2002 was a spectacular event that warrants further description. High to extremely high densities of recruits, locally known as *pala'ia*, were recorded at some sites, particularly in Ofu Lagoon at Vaoto, and on the reef slope at Masefau (Fig 34).



In this study, *pala'ia* were first observed in low to moderate densities on the reef slopes in the Manu'a Islands from March 6-8 2002, although high densities were not recorded until March 10 (at Vaoto in Ofu Lagoon). This indicates that most of the recruitment occurred around March 5-9 2002, in the week preceding the new moon of March 14 2002. Previous surveys have also reported similar events during the same time of the year and lunar phase (around the new moon in Feb/March: Table 6). The exception was in 1985, when recruits were first observed around the full moon in Fagatele Bay (Table 6). However, given the relatively large size of those recruits (7-8 cm), they may have been several weeks old when they were first observed (and therefore may have arrived around the new moon in March).

Table 6 Times when *pala'ia* were first observed relative to the new moon.

New moon	Recruits first observed	Source
21 March 1985	5 April 1985	Birkeland et al (1987)
1 March 1995	6 March 1995	Green (unpubl data)[2]
19 Feb 1996	26 Feb 1996	Green (unpubl data)
14 March 2002	6 March 2002	This study

[2] Green (*unpubl data*) monitored recruitment at several sites around Tutuila following the new moon each month from Feb 1995 to May 1996 (15 months).

These results indicate that *pala'ia* recruitment pulses appear to be relatively predictable events in American Samoa. The arrival of recruits around the darkest period of the month (new moon) is common among reef fishes, and is assumed to be an adaptation to reduce predation upon settlement (Doherty 1991).

Once *pala'ia* had recruited onto the reef, they were present in small (50-100 individuals) to extremely large schools (up to 5000 individuals), which roved over the lagoon and reef slope (down to a depth of 20m). The largest schools were observed in Ofu Lagoon at Vaoto and on the reef slope at Masefau.

The density of recruits recorded at each site depended on several factors, including the timing of the counts. For example, no recruits were recorded at some sites in Manu'a (eg Ofu Village), because the counts took place before the recruitment pulse. Recruit density also depended on the number and size of schools that were present at that site, and whether or not they were recorded on the transects. For example, large schools (up to 1000 individuals) were observed at both Asaga and Vatia, and moderately large schools (100-500 individuals) were also observed at Aunu'u and Fagasa. However, relatively low densities were recorded at those sites because the schools were not recorded on the transects. Similarly, large schools were observed throughout Ofu Lagoon, but low densities were recorded at Hurricane House, because schools were not observed on the transects. These results demonstrate that different methods (which cover a larger area) are required to survey these schools more effectively.

Pala'ia grow very quickly during the first few weeks of benthic life. Recruits were 4-5cm long when they were first observed on the reef, and some individuals were already 7-8cm long a few weeks later. A more detailed growth study of the same recruitment pulse, reported that the mean fork length of *pala'ia* was 9.4cm by November (P. Craig *pers comm*).

Pala'ia also experienced high levels of mortality, since the schools attracted predatory fishes. During the survey, high densities of carangids were recorded on the reef slopes at some sites (Fig 35: eg Fagaitua) where they were striking at the schools. Other predatory fishes (eg aulostomids and serranids) were also observed targeting the schools.

Furthermore, Birkeland et al (1987) speculated that recruit mortality would be high during the first few weeks of benthic life, because many individuals appeared to be in poor condition (shrunken sides and frayed fins). Similar observations were made during this event, where many individuals appeared to be in poor condition several weeks after recruitment (eg at Masefau).

Not surprisingly, *pala'ia* density decreased dramatically in the first few weeks following the recruitment event (Table 7). This decline was probably due to heavy mortality. However without simultaneously monitoring other areas and habitat types, it is unclear how much of this decline was due to mortality or movement. Further studies are required to understand the role of these mass recruitment events (and post settlement movement and mortality) in the population dynamics of this abundant and locally important reef fish.

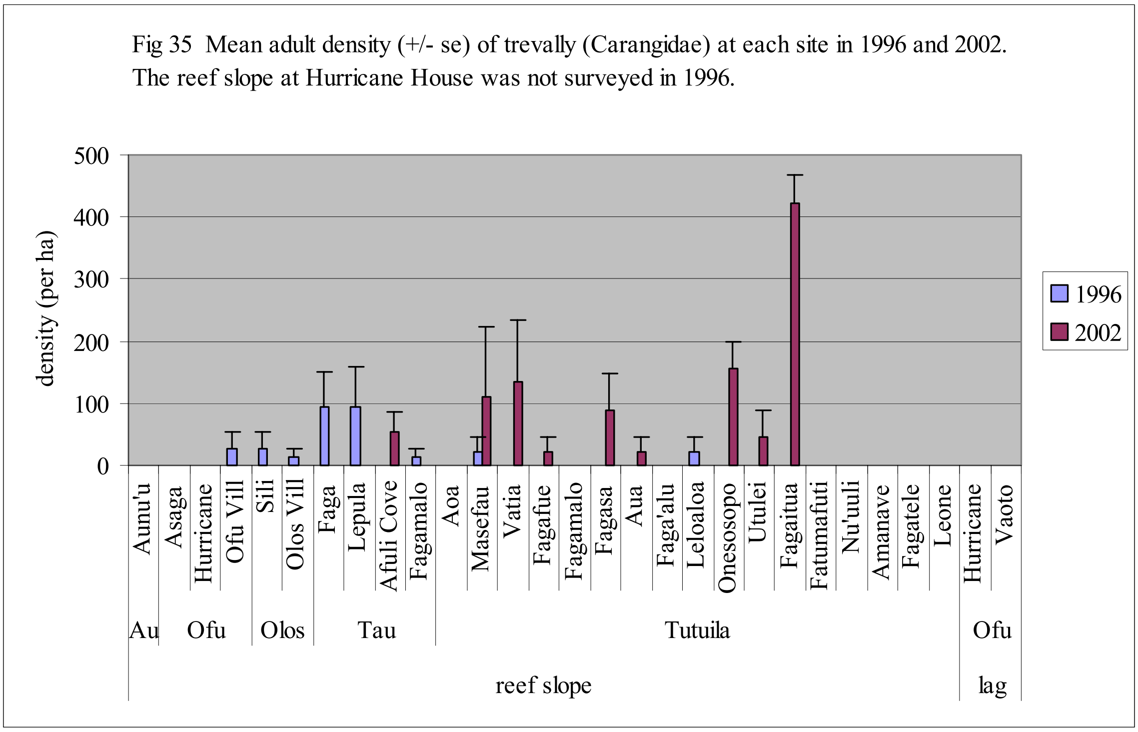


Table 7 Density of juvenile *Ctenochaetus striatus* (per ha) at two sites in Ofu Lagoon from March to November, 2002. Data source: March (this survey; June-November (P. Craig *unpubl data*).

Site	Month	mean	se	n
Vaoto Lodge	March	232826.70	232826.7	5
	June	58.34	7.51	3
	July	49.50	2.17	5
	Oct	34.75	5.35	5
	November	47.53	2.40	5
Hurricane House	March	1693.33	1693.33	5
	June	44.25	2.80	5
	July	51.00	2.80	5
	Oct	27.75	2.80	5
	November	32.00	10.30	5

Mass recruitment events of *pala'ia* are no surprise to the Samoan people, who know about these pulses and target them in a specific, tailor made fishery (P. Craig *pers comm*.). Within days of the recruits arriving (March 9-13), the villagers had spotted them in the shallow water around Ofu-Olosega and had started to collect and eat them (P. Craig *pers. comm*). This is somewhat analogous to the way in which Samoans predict and utilise the predictable spawning events of the palolo worm, which are also only available to the fishery for a few days each year (during the same lunar phase in October and/or November: Caspers 1984, Itano & Buckley 1988b, Mundy & Green 1999).

Fisheries for juvenile fishes are also known to occur in other places in the Pacific. For example, the people of Guam have long harvested the mass recruitment pulses of rabbitfishes, which occur the week prior to the new moon in April and May (and sometimes in June and October: Kami & Ikehara 1976, Amesbury & Myers 2001). Samoans are also aware of, and target, mass recruitment events of juvenile goatfishes (locally known as *i'asina*), and have developed a specialised fish trap for that purpose.

Large scale recruitment events of surgeonfishes have also been reported elsewhere. For example, Pillai et al (1983) described an unusual mass recruitment event of a congeneric species (*Ctenochaetus strigosus*, now *cyanocheilu*s), in Minicoy Atoll (Arabian Sea, India), where this species was previously rare. Recruits appeared to have arrived at a similar size (5-6cm) to *pala'ia* in American Samoa. While Pillai et al (1983) did not record exact densities of *C. cyanocheilus* recruits at Minicoy, they did report that the recruits were present in "enormous" numbers. The recruits also arrived in September, which may be a similar time of the year to Feb/March in Samoa (end of summer). However, unlike Samoa, the recruitment pulse at Minicoy was a surprise to local fishermen, who did not eat them despite catching large numbers in their cast nets (Pillai et al 1983). Pillai et al (1983) also noticed a significant drop in abundance of recruits within a fortnight of their first sighting, and the numbers had significantly declined two months later (by early November).

It is interesting to note that mass recruitment pulses of *C. striatus* do not appear to be a consistent life history characteristic of this abundant and widespread species throughout its range. For example, this species is also abundant on the GBR, were recruits are rare and mass recruitment events have not been observed despite more than 20 years of observations (J.H. Choat & K. Clements *pers comm*). This suggests that the population dynamics of this species is may differ throughout its range. However, similar large scale recruitment events have been observed elsewhere in the Pacific Islands (eg Tahiti: P. Doherty *pers comm*).

Mass Coral Bleaching

In early 2002 (Jan to March), American Samoa was on the edge of a widespread temperature anomaly in the Pacific Ocean (NOAA 2002a), and experienced sea temperatures close to the threshold where bleaching was likely to occur (0.5-0.75^{o}C: NOAA 2002a). This study confirmed that the reefs on the five main volcanic islands experienced low to moderate bleaching in March 2002 (Append 14), with the highest levels of bleaching recorded on the north side of Tutuila. Local managers also reported that bleaching was somewhat worse in the following months (D. Wilson, N. Daschbach and P. Craig *pers comm*).

The results of this survey suggest that American Samoa experienced less bleaching than other areas in the region, where temperature anomalies and levels of bleaching were more severe during the same event (eg Great Barrier Reef, Fiji: see *Introduction, Mass Coral Bleaching*). Bleaching was also less severe than in 1994, which remains the worst coral bleaching event on record in American Samoa.

The 2002 coral bleaching event was described based on the results of two complimentary surveys. In this study, broad scale surveys were conducted at each site based on standardised observations, which centered on, but were not restricted to, the transects at 10m. The other study was a more quantitative assessment of bleaching on the transects at 10m (Fisk & Birkeland 2002). The results of the two bleaching surveys yielded slightly different results on the severity of bleaching at each location. This study found that bleaching was low at most sites in Manu'a, Aunu'u and on the south side of Tutuila, and moderate on the north side of Tutuila (Append 14). In contrast, Fisk & Birkeland (2002) detected more bleaching on the transects at 10m in the Manu'a Islands, than on Tutuila. This was probably due to the different scales of observation of the surveys. This survey probably provides a better overview of bleaching at each site, because it focused on a much wider area of the reef slope, including shallower water where more bleaching was observed (particularly where plate corals were abundant, such as the north shore of Tutuila).

Corals that experienced the most bleaching in 2002 included some massive (particularly *Montastrea curta* and small *Porites*), plate (*Acropora*) and branching corals (particularly *Pocillopora* and *Acropora)*. Bleaching was also observed, but less frequently, in other massive (mostly faviids), encrusting (mostly *Montipora*, but also *Acropora*), foliaceus, mushroom and soft corals (Append 14). A more detailed assessment of the species and percentage of colonies that bleached at one depth (10m) is provided by Fisk & Birkeland (2002).

The extent to which colonies bleached ranged from minor (patchy or pale colouration) to severe (totally white), depending on the site and species present (Append 14, see also Fisk and Birkeland 2002). Most corals experienced minor bleaching (pale or partially bleached), except for some small massives (particularly *Montastrea curta* and *Leptastrea*), branching and plate *Acropora*, which experienced severe bleaching. A wider range of species experienced severe bleaching on the north side of Tutuila where the highest levels of bleaching were observed. The worst bleaching was observed at sites where plate and branching *Acropora* were most abundant (eg. Vatia, Masefau, Fagamalo).

Fortunately, bleaching does not necessarily cause death of coral colonies, and it is unclear how much of the coral that bleached subsequently recovered or died. Observations in Ofu Lagoon indicate that most of the *Millepora* bleached in March, but appeared to have recovered by June/July (C. Birkeland *pers comm*). Similarly, most of the large areas of *Montipora* and *Acropora* that were severely bleached in March, appeared to have recovered by June/July (although some *Acropora* still had bleached branch tips). This may be further evidence that the coral communities in Ofu Lagoon are able to withstand unusually high water temperatures (Craig et al 2001).

Observations at some sites indicated that species that were commonly bleached (particularly *Montastrea curta*) did not bleach as badly if they were shaded by other colonies (eg Vatia, Append 14). This observation indicates that light intensity may have been a contributing factor in the bleaching event (see also Fisk & Birkeland 2002). This phenomena has also been observed on the GBR, where corals that were covered by algae did not appear to bleach (Jompa & McCook 1998).

One complicating factor for the analysis of the impacts of the 2002 bleaching event is coral disease. The Australian Institute of Marine Science's Long Term Monitoring Program detected an increase in a coral disease called White Syndrome on the Great Barrier Reef (GBR) following the coral bleaching event (see AIMS website). To date, White Syndrome has primarily infected plate corals on the GBR, but has been know to kill entire colonies. The exact cause of the disease is unknown, but the increased prevalence may have been linked to the bleaching event (because corals were already stressed, making them more susceptible to disease). A similar phenomenon was observed in Ofu Lagoon in May 2002 (P. Craig *pers comm*). The co-incidence of these observations on both the GBR and in Samoa, suggests that this may have been a regional phenomena (associated with bleaching).

Marine Protected Areas

Marine Protected Areas (MPAs) can play an important role in protecting biodiversity, and as fisheries management tools. There are four MPAs in American Samoa, which account for only 6% of the Territory's coral reefs (Craig 2002). Although community-based fisheries management programs have also been established in some areas on Tutuila (DMWR *pers comm*).

For MPAs to act as fisheries management tools, it is important that as much area as possible is designated as "no-take" and that fishing restrictions are effectively enforced. Until recently, 20% had been identified as a useful target for "no-take areas" in MPAs (see Sampson 2001). However, more recent scientific advice is that for MPAs to be effective, 30-50% is required (J. Roughgarden *pers comm*).

Only one MPA (Rose Atoll National Wildlife Refuge) is a 'no-take' area, although fishing restrictions do apply in others (Table 8). Surveillance and enforcement remains a problem in these areas, and illegal fishing practices continue in some locations (see *Introduction, Fishing*).

Table 8 Fishing restrictions in Marine Protected Areas in American Samoa.

Marine Protected Area	Fishing Restrictions
Rose Atoll National Wildlife Refuge	No-take
Fagatele Bay National Marine Sanctuary	Gear restrictions (no spearfishing or fixed nets). No hook and line or commercial fishing in inner bay.
National Park of American Samoa	Subsistence fishing using traditional gear only (but not natural poisons)
Ofu-Vaoto Marine Park	Subsistence fishing only.

This survey included sites in three of the four MPAs in American Samoa: Fagatele Bay National Marine Sanctuary (FBNMS), the Ofu Unit of the National Park of American Samoa (NPAS), and the Ofu-Vaoto Marine Park. Therefore, it provides an opportunity to assess the status of the reefs in these MPAs, and compare them to other reefs in the Territory.

Fagatele Bay National Marine Sanctuary

Fagatele Bay National Marine Sanctuary (FBNMS) has experienced the same large scale disturbances as the rest of Tutuila over the last few decades (see *Introduction*). The effects of these disturbances on the reefs in the Bay have been well documented by the Sanctuary's long term monitoring program (Birkeland et al. 1987, 1994, 1996, in prep, Green et al 1999), which has demonstrated that these reefs are healthy, resilient, and able to recover from large scale disturbances. The results of this study have shown that while this is true for most of the reefs on Tutuila where water quality is good, the reefs in Fagatele Bay comprise some of the healthiest coral communities on the island.

Unfortunately, like most of the reefs on Tutuila, Fagatele Bay appears to have been overfished. Several large, reef fish species that are particularly vulnerable to overfishing (eg sharks, maori wrasse, and large parrotfishes and groupers) are now rare or absent in the Bay (Birkeland et al *in prep*, this study). Furthermore, the density and biomass of the major fisheries families (Acanthuridae, Scaridae, Lutjanidae and Serranidae) are also relatively low (Append 8, 9).

If Fagatele Bay is to succeed as a marine sanctuary, illegal fishing practices must be stopped (see *Introduction*). Fortunately, the nighttime scuba spearfishery is no longer in operation (Attachment 1). However, other types of illegal fishing continue. Of particular concern is the fact that dynamite fishing has been reported in the Bay on several occasions over the last few years (Birkeland et al *in prep*).

One contributing factor is the relative isolation of the Sanctuary. In previous years, the fact that there was no village in Bay, and that it was relatively difficult to access from both land and water, afforded the reefs some protection from human impacts (including fishing). However, this is no longer the case, since fishing boats can now access the Bay more easily. As a result, the relative isolation is now a disadvantage, because there is no village to protect the Sanctuary, and it is difficult to maintain an enforcement presence in the Bay.

If fishing were to be effectively controlled in Fagatele Bay through improved enforcement, it is likely that the fish communities would recover from the effects of fishing and the Bay could become an effective marine sanctuary. This may be possible, because previous studies have demonstrated that even quite small sanctuaries, like Fagatele Bay, can support a higher biomass of reef fishes (especially large target species) than adjacent areas (Roberts & Hawkins 1997).

<u>National Park of American Samoa</u>
The National Park of American Samoa (NPAS) has three units on Tutuila, Ofu and Tau. While illegal fishing practices are known to have occurred in the Tutuila Unit of the NPAS (Page 1998), this does not appear to have been the case on Ofu and Tau.

Several surveys of the reefs have been conducted in the NPAS over the last 15 years (eg Hunter et al 1993, Green & Hunter 1998). Unfortunately, there is no co-ordinated coral reef monitoring program for the Park at present, although there are plans to develop one (Craig & Basch 2001). In the interim, the results of this survey can provide some information on the condition of the NPAS, since two sites were included in the Ofu Unit of the Park (the lagoon and reef slope at Hurricane House).

Ofu Lagoon is the best developed natural lagoon system on the main volcanic islands in American Samoa. Despite chronic COTS predation, the lagoon supports spectacular coral reef communities, which are otherwise unique in the Territory (Itano & Buckley 1988a, Maragos et al 1994, Green 1996a, this study). The lagoon may also play an important role in the ecology of the reefs on Ofu and Olosega, by acting as a nursery for some important fisheries species (particularly parrotfishes: see *Results, Recruitment*) and maintaining the chronic COTS population on those islands (see *Chronic Impacts of Crown-of-Thorns Starfish in the Manu'a Islands*).

Ofu Lagoon is also an important natural resource, and is used for subsistence fishing and recreation. It also provides the best opportunity for snorkeling in American Samoa, due to its lush coral reef communities, its accessibility, and the calm, protected waters inside the lagoon.

The reef slope at Hurricane House is also in relatively good condition with moderately high fish species richness and density. However, coral cover is not high (~20%), probably because the area has experienced chronic COTS predation (see also Fisk & Birkeland 2002).

Unfortunately, no sites were included in either the Tutuila or Tau Units of the NPAS. In the absence of a dedicated coral reef monitoring program for the Park, some sites should be included in those areas in future surveys (see *Recommendations for Future Surveys*).

<u>Ofu-Vaoto Marine Park</u>

The Department of Marine and Wildlife Resources (DMWR) has a small Territorial Marine Park in front of Vaoto Lodge, which is adjacent to the NPAS on Ofu. This Park has minimal provisions and enforcement, and is threatened by the proposed expansion of the airport runway (P. Craig *pers comm*.). One of the sites in this study is located in the lagoon in this area (Vaoto).

In general, coral cover in the lagoon is lower at Vaoto than at Hurricane House in the NPAS (Fig 8), since the large massive corals that are dominant in the lagoon at Hurricane House are less abundant in this area (Append 6). However, fish species richness is similar at the two lagoon sites (Fig 11), and fish density was higher at Vaoto than at Hurricane House (Fig 12). Furthermore, the highest density of juvenile *Ctenochaetus striatus* recorded in the survey was in the lagoon at Vaoto.

These results demonstrate the importance of the coral reef communities at this site. The area is also known to be important for subsistence fishing on the island. Furthermore, as part of the series of natural lagoons on Ofu, these reefs may play an important role in the ecology of the area (see NPAS above). Therefore, other options should be considered for the proposed extension to the airport runway to protect this area.

<u>Rose Atoll National Wildlife Refuge</u>

The coral reefs of Rose Atoll National Wildlife Refuge were included in the baseline survey in 1996. Unfortunately, they could not be resurveyed this year due to logistic constraints. This survey should be repeated at Rose Atoll as soon as possible, since it provides a rigorous baseline for understanding the natural variability and long term trends on the reefs of the atoll. In particular, it is important to monitor the population of giant clams at Rose, due to their high conservation status in the Samoan Archipelago (Green & Craig 1999, this study).

<u>Other Candidate Areas</u>

The need for more “no-take” MPAs (see above) is of particular importance on Tutuila (and nearby Aunu’u) where overfishing is a problem. The best candidate is Aunu’u Island (see also Fisk & Birkeland 2002), because it is separated from the main island by a channel, water quality is good, the reefs are in good condition, and it could be protected by the resident villagers on the island. However, some areas would need to remain open for subsistence fishing by local villagers.

Another good candidate on Tutuila is the site at Vatia, which is one of the most spectacular reefs on the island. This area could be protected by extending the NPAS a short distance into the Bay. Other reefs on Tutuila that may be good candidates for MPAs include Fagamalo, Amanave and Nu’uuli. If possible, sites on both sides of the island should be included in a network of MPAs, to accommodate the natural variability around the island, and to recognise the higher probability of connectivity among sites on the same side of the island.

The NPAS already protects some reefs on Ofu and Tau in the Manu'a Islands. The proposed extension of the NPAS on Ofu and Olosega will include some additional areas that are good candidates for MPAs, based on their healthy coral reef communities (particularly Asaga and Sili), although they have suffered some damage from COTS predation in recent years.

Some sites on Tau are also good candidates for new MPAs (eg Afuli Cove, Fagamalo Cove and Lepula; see also Fisk & Birkeland 2002), because they comprise healthy coral reef communities, are relatively free from human impacts, and support some of the highest densities of giant clams recorded in the main volcanic islands (Fig 16). In particular, the coral communities in Afuli Cove should be protected, because they comprise some of the largest coral colonies recorded in Samoa (up to 10m in diameter: Append 2).

Monitoring Recommendations

This Survey

Survey Parameters
This survey documented patterns of natural variability and long term trends in the coral reefs of American Samoa, based on benthic communities (growth form level), fish communities (species level), and key macroinvertebrates (giant clams and COTS). Together with the companion coral survey (species level: Fisk & Birkeland 2002), these parameters provide a good overview of the condition of the coral reefs of American Samoa. Therefore, it is recommended that all these parameters continue to be monitored in future surveys, although some minor modifications to the methods may be required (see *Survey Methods* below).

Survey Frequency
Since this is the only co-ordinated interisland survey of the reefs of American Samoa, it should be repeated on a regular basis. Based on this and other long term monitoring programs in American Samoa (FBNMS and the Aua Transect), a three year interval may be appropriate for this survey, given the frequency of large scale disturbances, human impacts, and rates of coral reef recovery. However, since this survey is a major logistic exercise and usually requires the expertise of off island experts, a five year interval may be more feasible.

Survey Timing
The timing of the surveys should also be given some consideration. This year, the survey took place in March, during a mass fish recruitment event. That was fortuitous, because it allowed the event to be described in some detail. However, future surveys should not be conducted in March, unless they are specifically interested in mass recruitment events, because the large numbers of recruits make fish counts much more difficult and time consuming. Later in the summer (late April or May) may be a better time to conduct the survey, because the summer recruitment pulse could still be detected, but without overwhelming the counts.

Surveys of Other Islands
It is important to note that the baseline survey of American Samoa included the two remote atolls, Rose and Swains. Unfortunately, they could not be resurveyed this year due to logistics constraints. The two atolls should be resurveyed as soon as possible to determine the current status of those reefs, and how they have changed over the last six years. This is particularly important for Rose Atoll National Wildlife Refuge, because of the high conservation status of the atoll.

Surveys of Other Habitats
It is important to note that since the baseline study (Green 1996a), this monitoring program has focused on one habitat type (reef slope at 10m), although two sites were included in Ofu Lagoon also (see *Methods, Resurvey Design*). Given that limited time and resources are available for these surveys, they should continue to focus on these habitat types, since they provide a good basis for monitoring the reefs of American Samoa.

However, it is important to note that with few exceptions (eg FBNMS and Aua Transect long term monitoring programs), other habitat types are not the subject of long term monitoring programs in American Samoa (eg offshore banks). This may be important if it is likely that they are more heavily impacted by large scale disturbances or human activities (eg coastal development, fishing). If so, these concerns should be addressed through targeted research or monitoring projects.

Survey Methods
While the original design of this survey is relatively robust, and most of the methods have withstood the test of time, some minor modifications may be appropriate in future. However, the costs and benefits should be carefully considered before any changes are made, to ensure that the value of the long term data is retained as much as possible.

Possible modifications may include:

- Expand the survey to include sites in each MPA, because it can provide some long term monitoring for these areas. This is particularly important where no site dedicated monitoring programs exist (eg NPAS). The survey can also provide a broad scale perspective for interpreting the results of site dedicated monitoring programs (eg FBNMS).
- Reduce the number of transects at each site from five to three. This will still provide rigorous data, but will allow more time to survey all the sites on Tutuila, and to add more sites on Aunu'u and in the Manu'a Islands (for a more balanced design). In particular, one more site should be added on the northwest side of Ofu, and two more sites should be added on the south side of Tau (in the Tau Unit of the NPAS). Another site should also be added on Aunu'u Island, preferably on the southwest side.
- The site at Fagafue on the northwest side of Tutuila should be replaced, since it is shallower and in a different habitat type (at the bottom of the reef slope) to the other sites (see Append 2). It also receives high sediment loads, and is of limited value for long term monitoring. Fagafue should be replaced by another site on the same side of the island. The southeast side of Tafeo Cove would be a good candidate for a replacement site, because it has a well developed reef (Green & Hunter 1998) and will increase the spread of sites on that side of the island. It is also located within the Tutuila Unit of the NPAS, which should be included in this survey (see above).
- Fish counting methods should be reviewed. For the first time in this survey, large, vulnerable fish species were surveyed using a new method specifically developed for this purpose. This is important because these fishes are particularly vulnerable to overfishing, and are not as well surveyed using the smaller transects used in this survey (which are adequate for most species). This new component of the survey should be maintained in future surveys. The existing fish survey methods should also be maintained with one possible modification. A narrower transect width (eg 1m) could be used to count small, sedentary species (particularly damselfishes), because they would still provide rigorous information for those species, and would save considerable time on each transect.
- Companion coral surveys (at the species level) were conducted at the same time as this survey (see Mundy 1996, Fisk & Birkeland 2002). The methods used in those surveys were originally designed to maximise complementarity with the fish surveys (by using the same transects). However, these may not be the best

methods to use to survey the coral communities, and may require some modification in future surveys (see Fisk & Birkeland 2002).

- It is important to continue to monitor Ofu Lagoon, due to its importance to the local community and the NPAS. However, the survey methods used in this study were developed for the reef slopes where it is easier to relocate the position of the transects (see *Methods, Location of Study Sites*). Therefore, the exact location of the transects each year are more likely to vary in the lagoon, and fixed transects should be established to avoid this problem in future.

<u>Other Surveys</u>

Integrated Long-term Monitoring Plan
An integrated long-term monitoring plan has recently been developed for American Samoa (Cornish & Wilson 2002). One key element of the program is the designation of core sites to link the most important, multi-site monitoring programs (including this survey). That is an excellent idea, which should be supported in future. However in contrast to Cornish and Wilson (2002), I recommend that the MPAs should be included as core sites, because dedicated surveys do not always exist for those important areas (see below). I would also include Aunu'u as a core site, because the reefs tend to be in good condition, and provide a useful comparison for the reefs on nearby Tutuila, which tend to be more heavily impacted by human activities (eg fishing).

Fisheries Monitoring Programs
It is important that coral reef fisheries are monitored effectively on the main islands (particularly Tutuila, but also on Aunu'u and in the Manu'a Islands if possible), since overfishing is one of the greatest threats to the long term health of the reefs in the Territory. In particular, any commercial fisheries that become established should be carefully monitored to ensure that overfishing does not occur. Where possible fisheries surveys should make use of historical fisheries data where it exists and is of reasonable quality. In particular, the inshore fishery survey of Tutuila should be maintained in the long term. However if possible, the survey should be expanded to monitor the fishery around the island more effectively (rather than focusing on the Harbour area).

Local Coral Reef Monitoring Programs
Unfortunately, the relevant expertise to conduct scientific surveys at the species level does not always exist on island, and off-island experts are often required. Consequently, scientific surveys tend to be infrequent and repeated at three to five year intervals (if at all).

Therefore, monitoring programs should be conducted more frequently (perhaps annually) by local managers to monitor ecosystem health and the effects of large scale disturbances (eg coral bleaching, COTS) and/or human activities (eg fishing, habitat destruction, pollution) on the reefs in the Territory. These programs could provide targeted information for management, and ensure that local managers were in tune with their resources and able to identify potential threats as they arise. The necessary components of such a program are described in Craig and Basch (2001).

A local monitoring program could also provide a valuable source of information for interpreting changes detected in the scientific monitoring programs. To make the most of that opportunity, both programs should use the same sites, comparable methods, and study similar parameters, so their results can be compared in a meaningful way. In order to be comparable with this survey, local monitoring programs would need to monitor the status of the coral communities (based on cover at the growth form level), their associated fish communities (using a subset of species known to be good indicators of healthy reefs in Samoa: see *Recovery of Coral Reefs on Tutuila and Aunu'u*) and key macroinvertebrates (particularly COTS). A monitoring program for key fisheries species should also be developed using a restricted list of target species (giant clams, and a range of fish species from the four major fisheries families, particularly *Cephalopholis argus*), and large species that are particularly vulnerable to overfishing (eg sharks, maori wrasse, and large parrotfishes: see *Human Impacts, Fishing*).

Marine Protected Areas
Dedicated programs should be developed and implemented (where they do not already exist) to monitor the success of MPAs in American Samoa. A key element in these programs should be a comparison of areas inside and outside the MPAs to determine if their protected status is making a difference or not. These programs should be conducted frequently enough to understand the natural variability and long term trends in the ecosystems being protected, and to detect any threats to ecosystem health as they arise (every year or more frequently for local programs, and every three years for scientific surveys). Existing MPA monitoring programs should be examined to determine if they specifically address these goals or not. In the absence of dedicated MPA monitoring programs, these areas should be included in larger scale monitoring programs of American Samoa, since that may be the only way to monitor their success at present.

Increased Use of Historical Data
Some of the coral reef monitoring programs in American Samoa already make good use of the historical data available for the Territory (eg FBNMS and the Aua Transect). However, other data sets may be available that could be of considerable value to understanding the long term trends in the reefs of American Samoa, if they were resurveyed or incorporated in ongoing monitoring programs.

Of particular interest are the quantitative fish surveys conducted by Wass (1982) in the late 1970s. At present, only three of Wass' 57 sites are part of an existing monitoring program (FBNMS). However, Wass' survey may provide more opportunities for understanding the long term trends in fish communities on Tutuila, since it comprises the oldest quantitative fish data in the Territory.

A resurvey of Wass' transects would require relocating his sites and raw data (DMWR still had this information in 1996), deciding which sites should be repeated, and modifying some of the survey methods to be more consistent with current protocols. For example, the survey method should be changed from one 100m transect per site to three 30m transects, which would allow for approximately the same area to be surveyed, but would introduce some replication into the design. If possible, transects should be stratified within and not across habitat types.

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LIST OF FIGURES

Figure	Page
Fig 1 Map of the Samoan Archipelago.	23
Fig 2 Map of the main island of Tutuila and nearby Aunu'u, American Samoa, showing the location of each study site.	25
Fig 3 Map of the Manu'a Islands, American Samoa, showing the location of each study site.	26
Fig 4 Location of the pools in Ofu Lagoon.	27
Fig 5 Sampling design for sites where reef slopes were surveyed in the baseline survey (Green 1996a) and this survey (2002).	28
Fig 6 Mean cover of each major substratum category on each island in 1996.	34
Fig 7 Mean cover of each major substratum category on each island in 2002.	34
Fig 8 Mean coral cover at each site in 1996 and 2002.	34
Fig 9 Mean cover of each coral category on each island in 1996.	35
Fig 10 Mean cover of each coral category on each island in 2002.	35
Fig 11 Mean species richness of adult reef fishes at each site in 1996 and 2002.	37
Fig 12 Mean density of adult reef fishes at each site in 1996 and 2002.	38
Fig 13 Mean adult density of damselfishes (Pomacentridae) at each site in 1996 and 2002.	39
Fig 14 Mean adult density of surgeonfishes (Acanthuridae) at each site in 1996 and 2002.	39
Fig 15 Mean biomass of adult reef fishes at each site in 1996 and 2002.	40
Fig 16 Mean density of giant clams on the reef slope (10m) and lagoon in 1996 and 2002.	44
Fig 17 Maturity of giant clams on each island in 1996 and 2002.	45
Fig 18 Mean coral cover on each of the five main volcanic islands in 1996 and 2002.	46
Fig 19 Mean adult density of the damselfish *Plectroglyphidodon dickii* at each site in 1996 and 2002.	48
Fig 20 Mean cover of branching coral at each site in 1996 and 2002.	48
Fig 21 Mean adult density of butterflyfishes (Chaetodontidae) in 1996 and 2002.	49
Fig 22 Mean adult density of the butterflyfish *Chaetodon trifascialis* in 1996 and 2002.	49
Fig 23 Mean cover of plate coral at each site in 1996 and 2002.	50
Fig 24 Mean adult density of the wrasse *Labrichthyes unilineatus* in 1996 and 2002.	51
Fig 25 Mean density of adult surgeonfishes (Acanthuridae) on each island in 1996 and 2002.	54
Fig 26 Mean density of adult snappers (Lutjanidae) on each island in 1996 and 2002.	54
Fig 27 Mean density of adult groupers (Serranidae) on each island in 1996 and 2002.	55
Fig 28 Mean biomass of adult groupers (Serranidae) on each island in 1996 and 2002	55
Fig 29 Mean adult density of the grouper *Cephalopholis argus* on each island in 1996 and 2002.	56
Fig 30 Mean adult density of the surgeonfish *Ctenochaetus striatus* on each island in 1996 and 2002.	56
Fig 31 Mean density of adult parrotfishes (Scaridae) at each site in 1996 and 2002.	56
Fig 32 Mean density of large reef fish species on Tutuila, Aunu'u and the Manu'a Islands in 2002.	57
Fig 33 Mean density of giant clams on the reef slope and lagoon in 1996 and 2002.	58
Fig 34 Mean density of *Ctenochaetus striatus* recruits (*pala'ia*) at each site in 2002.	63
Fig 35 Mean adult density of trevally (Carangidae) at each site in 1996 and 2002.	65

LIST OF TABLES

Table		Page
Table 1	Island and reef type, size, and human population of each island in American Samoa.	24
Table 2	Reef fish families included in surveys of the Samoan Archipelago.	29
Table 3	Major substratum categories and subcategories used in surveys of the Samoan Archipelago.	30
Table 4	Number of species observed in each pool in Ofu Lagoon during a timed count in March 2002.	43
Table 5	Number of individuals and size of all crown-of-thorns starfish recorded in 1996 and 2002.	45
Table 6	Times when *pala'ia* recruits were first observed relative to the new moon.	63
Table 7	Density of juvenile *Ctenochaetus striatus* at two sites in Ofu Lagoon from March to November, 2002.	65
Table 8	Fishing restrictions in Marine Protected Areas in American Samoa.	69

LIST OF APPENDICES

Appendix		Page
Appendix 1	American Samoa bans destructive scuba fishery: the role of science and management	87
Appendix 2	Location of study sites surveyed in 1996 and 2002.	89
Appendix 3	Species list of fishes recorded during the baseline survey (Green 1996a) and this survey (2002), including minimum size for inclusion as adults and biomass conversion factors.	93
Appendix 4	Coral bleaching report form.	99
Appendix 5	Mean cover of each major substratum category at each site in 1996 and 2002.	100
Appendix 6	Mean cover of each substratum subcategory at each site in 1996 and 2002.	103
Appendix 7	Mean adult species richness of each of the 12 most abundant fish families at each site in 1996 and 2002.	108
Appendix 8	Mean adult density of each of the 12 most abundant fish families at each site in 1996 and 2002.	111
Appendix 9	Mean adult biomass of each of the 12 most abundant fish families at each site in 1996 and 2002.	116
Appendix 10	Mean density of most abundant juvenile fishes recorded in 2002.	120
Appendix 11	List of all fish species observed in each of the pools in Ofu Lagoon.	123
Appendix 12	Mean density of crown of thorns starfish in 1996 and 2002.	126
Appendix 13	Mean density of the most abundant species of butterflyfish (Chaetodontidae) at each site in 1996 and 2002.	128
Appendix 14	Observations of coral bleaching on the reef slope (10m) at each site in March 2002.	133

LIST OF ACRONYMS

Acronym	Full Name
ASEPA	American Samoa Environment Protection Agency
COTS	Crown-of-thorns starfish
DMWR	Department of Marine and Wildlife Resources
FBNMS	Fagatele Bay National Marine Sanctuary
NPAS	National Park of American Samoa
NPS	National Park Service
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
NOAA	National Oceanic and Atmospheric Administration