Results of the Territorial Coral Reef Monitoring Program of American Samoa for 2011, Benthic Section.

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Contents

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Executive Summary

- Most indices continue to show that the reefs of American Samoa are in relatively good condition.

- Average coral cover on reef slopes is now 31%, higher than the averages for the Pacific, South Pacific, U.S. Pacific, Great Barrier Reef, and Caribbean. The latter two have just 10% and 8% coral cover left. Coral cover is lower than it was here before crown-of-thorns starfish ate almost all the coral in 1978, and lower than it was in the past in the Pacific and Caribbean.

- Average coral cover on both reef slopes and reef flats has increased over the 8 years of this monitoring program, while coral cover has decreased in the Caribbean, Pacific, Indian Ocean, Red Sea, and Great Barrier Reef.

- Coral cover on reef slopes increased on four reefs, was steady on five reefs, and decreased on one reef.

- There are very few dead corals, fewer than the averages for the South Pacific, Indonesia, the Philippines, the Indo-Pacific, and the world.

- Coralline algae, which is considered good, is plentiful, and macroalgae, which is considered bad, is rare most places. Most of the reef is covered by corals and coralline algae, both of which help build the reef, which is good.

- Water on the reef slopes is relatively clear, and has remained so, indicating relatively good water quality.

- Reefs inside the harbor are in poor condition, likely due to sediments, nutrients, and chemical pollution. Coral diversity on slopes inside the harbor is lower than outside, probably due to nutrients and/or pollution. Water quality is particularly low at the head of the harbor, indicated by murky water.

- Vatia was badly damaged by the tsunami in the inner bay and by Hurricane Heta in the outer bay. The outer bay is recovering, but the inner bay is not, due to nutrients fueling turf algae. Fagatele Bay was damaged by the tsunami but began recovering immediately.

- A coral disease outbreak followed Hurricane Wilma in Vatia Bay, but ended a few months later. Disease was also found on two groups of *Porites* corals on Ofu. All *Porites rus* corals in front of Vaoto Lodge were infected and partly dead, and a few in Hurricane House pool were infected.

- This report presents 111 graphs, 16 tables and four appendices in 151 pages.

Abstract

In 2011, transect data was collected on the reef slopes and reef sites, and coral biodiversity data was collected on reef slopes and reef flats (for the first time). Both transects and coral biodiversity were also taken from both the reef flat and pools at Ofu as well (for the first time). Bleaching data continued to be taken at both the airport and Alofau pools, year-round. Data was also taken from 81 diseased colonies of *Porites* corals in an Ofu pool.

Most indices continue to support the view that the benthic portion of American Samoan coral reefs are in relatively good condition. Mean coral cover was 31% on the reef slope. Coral cover continued to be highly variable from one site to another, but mean coral cover showed much smaller amounts of variation over time. Mean coral cover has increased over the years, and compares favorably to coral cover on the Great Barrier Reef, South Pacific, the whole Pacific, and particularly the Caribbean. However, it is still less than the Caribbean in 1977, Pacific in 1980, American Samoa in 1978, near-pristine reefs around the world, and near-pristine reefs in the U.S. Pacific. The increase in coral cover over time here is in contrast for the means for reefs in the Pacific, Indian Ocean, Red Sea, Caribbean, and global averages, all of which have been decreasing. The "Live Coral Index" which reflects the proportion of corals that are alive, is steady and higher than in the world, the Indo-Pacific, Philippines, Indonesia, and South Pacific. American Samoa has much more crustose calcareous algae plus coral than it has turf plus macroalgae, which is considered good. If the macroalgae is divided into calcifying algae and non-calcifying algae, and all organisms that calcify added up, 70% or more of the substrate is covered by calcifiers, so the reef slopes have good cover of calcifiers. Coral cover increased at four sites, Masacre, Fagasa, Tafeu, and Leone, decreased at Vatia, and was steady at five sites, Aunu'u, Amaua, Faga'alu, Nu'uuli, and Fagatele. The decrease recorded at Vatia was due to the tsunami of Sept. 29, 2009, and/or Hurricane Wilma on Jan. 24, 2011. The tsunami badly damaged the inner half of the bay, and the Hurricane damaged the outer half of the bay. The transects straddle the mid section of the bay. Mean coral cover on slopes inside the harbor was much lower than outside the harbor, which may have been due to pollution in the harbor, since there is a published paper showing lower coral diversity in polluted areas. Coral cover in transects continues to be primarily encrusting, mainly composed of *Montipora grisea*, *Pavona varians, Montipora informis,* and *Pavona chiriquensis*. The second largest type of coral cover is columnar/plate colonies of *Porites rus*., which is actually the single species with the greatest cover. The number of genera showed downward trends but the number of coral species was largely steady. The number of coral species in transects is greater on the South side than the North side, and this has remained so over time. The number of coral species is positively correlated with the amount of coral cover at a site. This is because where there is more coral cover, there are more corals in the transects, and in general as you look at more individual corals you find more and more species because it is a larger sample of the coral population. Coral biodiversity was recorded on roving dives on the slopes, and for the first time several sites in Pago Pago harbor were included. There has been a small decrease in the number of coral species recorded in biodiversity dives since 2005 when monitoring started. Slightly more coral species were recorded on the south side in biodiversity dives than on the north, but in previous years the difference was small

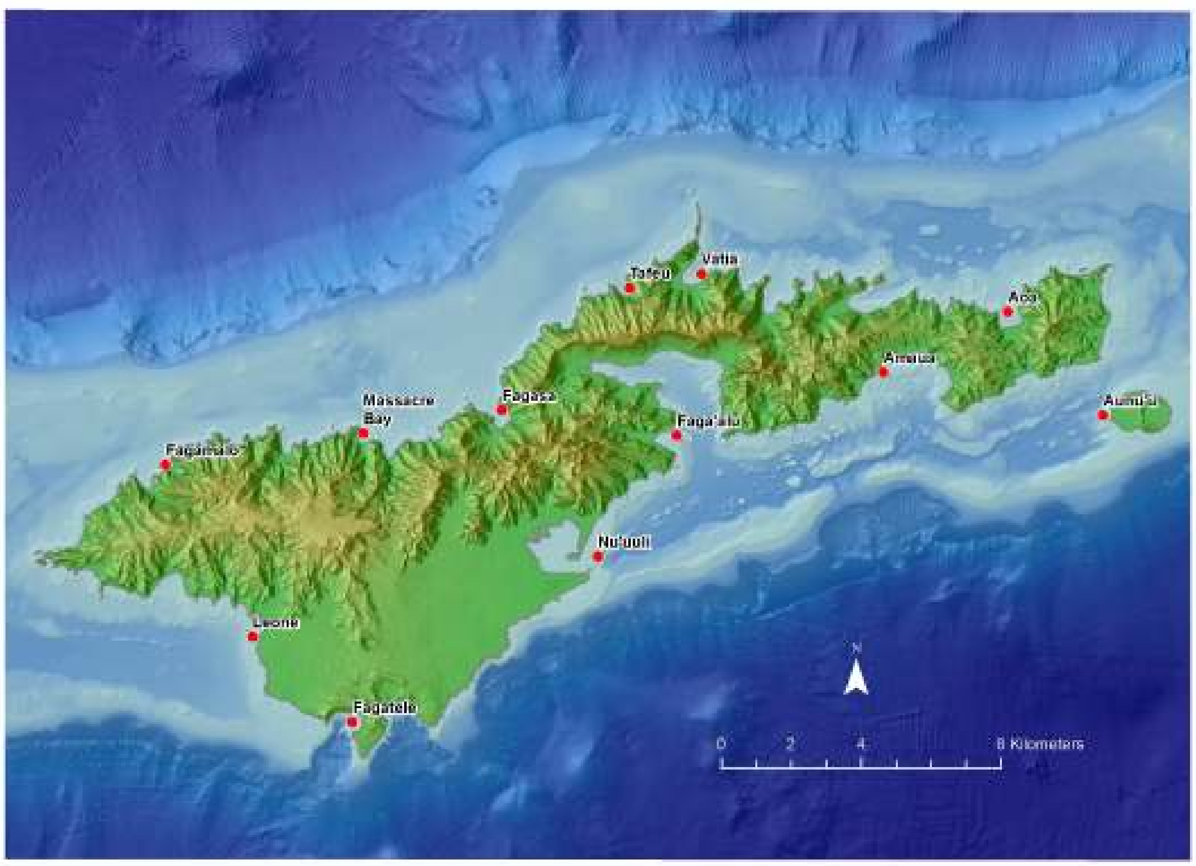
or not present. The number and diversity of invertebrates recorded has increased greatly over time, as the author became better and better at spotting small invertebrates of various kinds in the belt transects. It is surely not a real increase in the number of invertebrates. Mean coral cover on outer reef flats was 28.5%, just 2.5% less than on the reef slope. Previous monitoring found it was lower on inner reef flats. Again, variation between sites was large, but variation over time less. Reef flats on the south side had coral cover equal to that on the north, but north reef flats had more turf and south reef flats had more rubble. There was an increasing trend in coral cover on reef flats since 2007. The live coral index was high and stable on reef flats just as it was on the reef slopes. The amount of coral plus crustose coralline algae (CCA; both are considered good) was 50%, and has risen over the years. The amount of turf plus macroalgae (considered bad or mixed/neutral) decreased over the years. The amount of coral plus CCA was higher on the slope than the reef flat, primarily because low tides kill corals on the reef flat, a natural phenomenon. The total cover of calcifying organisms on the reef flat (which includes calcifying macroalgae, *Halimeda*) has increased over the years and the amount of non-calcifying area (everything else) has decreased. There is more calcifying cover on the slope than on the reef flats. Coral cover decreased on three reef flat sites, was steady at four, and increased at three. Vatia reef flat showed a sudden decrease in the time period of the tsunami and Hurricane Wilma. The most common lifeform of corals on the reef flats was encrusting, followed by *Acropora* branching, foliose, branching, and tables. Encrusting corals were the most common lifeform on both the slopes and the reef flats, and *Montipora grisea* was the coral species with the most cover on both slopes and reef flats. The number of genera and species of corals increased on reef flats over time. A total of 19 coral species were recorded only on the reef flat, and 33 species were recorded only on the slope in transects. Another 13 species were more common on reef flats than slopes, and a further 13 were more common on slopes than on reef flats. This supports the view that these two zones are very different places with different coral communities. The number of coral species in biodiversity searches varied greatly from one reef flat site to another. The mean number of corals on reef flats inside the harbor was the slightly more than outside the harbor. There were fewer coral species in biodiversity searches on the reef flats than on the slopes. There were more coral species on reef flats on the north than the south side of the island, while on the slopes there were more on the south than the north. Biodiversity searches on the reef flats found 10 species that were found only on the reef flat and 78 species that were found only on the slope. There were also 10 other species that prefer the reef flat and 27 that prefer the reef slope and eight that prefer pools. Slightly more corals species were found in biodiversity searches on reef flats in the harbor than outside the harbor. More coral species were found outside the harbor on the slope than inside the harbor on the slope which was in turn more than on reef flats inside and outside the harbor. North side reef flats had considerably more coral species than the south side in biodiversity searches. Outer reef flats on Tutuila had more coral cover than on Ofu-Olosega, but inner reef flats on Tutuila had less coral cover than on Ofu-Olosega. In biodiversity searches, there were more coral species in Ofu-Olosega pools than reef flats, more coral species on Ofu-Olosega than on Tutuila, and slightly more coral species on Tutuila reef flats than in pools. Bleaching in the airport pool was less in 2011 than in previous years. At Alofau, bleaching had decreased in 2010, but then increased in 2011 back toward the levels seen in previous years. A coral disease outbreak in Vatia following Hurricane Wilma killed some corals in the genus *Acropora* and damaged others, but subsided over several months and returned to normal levels. Colonies of *Porites rus* in the pool in front of Vaoto Lodge on Ofu were diseased when observed in 2011, with significant damage from the disease.

This report presents 111 graphs, 16 tables and four appendices in 151 pages.

In sum, most of the indicators of reef health indicate that the reefs of American Samoa are in relatively good condition.

Methods

The 12 reef slope sites are shown in the map below. All are on Tutuila and nearby Aunu'u.



The benthic methods were the same as in 2010. In the core monitoring, four 50-m tapes were laid on a depth contour between 8 and 10 m deep. A space between them of about 10 m was kept. Benthic categories were recorded under each 0.5 m point on the tape. Benthic categories included live coral, dead coral, dead coral with algae, crustose calcareous algae, branching coralline algae, fleshy macroalgae, turf algae, rock, sand, rubble, soft coral, and sponge. "Branching coralline algae" included a soft feathery species that was the most common in that category. That species is *Cheilosporum spectabile*. Any rock that is not white has turf on it, and was recorded as turf. Corals were identified to lifeform, genus, and species when possible, and if the macroalgae was *Halimeda* or *Dictyota*, or something else that was identifiable, that was recorded in as much detail as possible (usually genus). Soft corals were recorded to genus when possible. Hard coral lifeforms included encrusting, massive, foliose, branching, columnar, submassive, mushroom, *Millepora*, *Acropora* branching, *Acropora* table, *Acropora* digitate, and *Acropora* encrusting. Only the top visible layer was recorded of any multilayer formations such as corals or macroalgae, so all categories of cover add up to 100%. Diurnal, non-cryptic macroinvertebrates were counted in a half-meter wide belt transect beside each 50 m tape. Invertebrates were identified to the most detailed level possible. Spaces between coral branches were not searched. Hard and soft corals were not counted. Horizontal visibility was recorded using the tape. Two transect tapes were recorded on the first dive, and an additional two tapes were done on the second dive. Sites were re-located using the GPS and markers as indicated in the 2005 report. One day was required for each site. In 2008, a total of 12 sites were recorded, including the original 11 plus Masacre Bay. For 2011,10 sites were recorded since the lack of a working boat near the end of the year restricted monitoring fieldwork. Damage to boat ramps were repaired early in the year, facilitating monitoring work.

As in 2007-2010, the rugosity measurements were omitted, because a third team member was not available and when included it lengthened dive times to the point where running out of air was a distinct possibility, thus reducing the margin of safety. Further, it appears that the measurement depends primarily on exactly where the chain falls, and that changes in rugosity caused by coral growth will take quite a few years before they would be detectable. A hurricane could make changes in rugosity quickly by removing corals, and if significant hurricane damage occurs, the rugosity measurements can be repeated. Until changes in coral cover or other rugosity changes are apparent, repeating the measurement of rugosity is not worth the increased risk of running out of air. In future years it is hoped that an additional team member can record the rugosity measure, or additional boat dives are available to take the rugosity measure. In the meantime, it will be considered a lower priority item, and will be done on an opportunistic basis.

When laying the tape, the primary consideration is to keep the tape between 8 m and 9 m deep. The tape is passed along the sides of projections, including live corals such as *Pocillopora* and table corals, which usually have an overhanging side. If it is passed around first one side of one projection and then the other side of another, it is anchored securely from wave action moving it either way at that point. An attempt is made to anchor the tape in this fashion as often as possible, but in some areas there is little to anchor the tape on. A continuing problem is what to do about clefts in the reef. A cleft that is narrow and deep is crossed straight to an anchoring point on the other side. If it is large, then the tape may be laid along one side of it, going up toward shallower water but staying at 8-9 m depth, and then when the bottom rises to that depth, crossing to the other side and continuing on that side out of the canyon. The principle problem with that is finding an anchoring point near the head of the canyon that can hold the tape at the head. The tape is read at each point by reading the substrate under the point at the time at which the diver is directly above the point. A string and weight are not used, as surge and the movement of the tape in the surge makes that a much more difficult and slow procedure. If the tape is stretched between two points far apart and the surge is heavy, the tape can move a meter or more in either direction with each wave. This opens up an opportunity for bias, as the point on the tape sweeps across a variety of benthic patches. If the point on the bottom is recorded that is first seen from a vertical viewpoint, then bias is minimized. An attempt is made to minimize bias in laying the tape by choosing a route based on depth and anchoring points for the tape, not the substrate.

The direct observation underwater of what is under points makes it easier to identify species, and so allows greater taxonomic resolution than video techniques.

For coral biodiversity, one hour search dives were conducted at each site. The dive begins at the bottom of the reef (but always well above 30 m deep) and continues as a roving dive as the diver ascends up the slope, searching for as many coral species as can be found. The presence of coral species is recorded underwater, and once out of the water, estimates of abundance of each species are recorded on a 0-5 ("DACOR") scale, with the names "not found," "rare," "uncommon," "common," "abundant," and "dominant." Rare was defined as just 1-2 colonies, and dominant was defined as composing more than half of all corals. The other categories were intermediate values, but not defined as individual corals were not counted, since that would greatly slow the survey and reduce the number of species found. This technique compliments the transect tapes since it covers the entire depth range of the slope, and produces a much larger sample that includes much rarer species than the transect tapes which only produce data on 100 points per tape. So the sample is much larger than the transects, but the quantitative accuracy is much lower. It compliments but does not replace the transects. Sites inside the harbor were added this year in addition to the usual sites outside the harbor.

Data collection on reef flats was continued, using transects. In addition, coral diversity data from roving search snorkels on reef flats was carried out for the first time. The methods for both are similar to that on reef slopes. Reef flats are quite different from reef slopes, are a large and important part of the reefs, and are subject to different disturbances than reef slopes, such as low tide events that have no effect on reef slopes. Monitoring reef flats is an important compliment to monitoring reef flats.

GPS of the locations of the sites are listed below in Tables 1, 2, and 3.

Table 1. Reef Slope Monitoring Sites:

Site	GPS Coordinates
Fagamalo	-14º 17.872S, -170º 48.726W
Masacre Bay	-14º 17.374S, -170º 45.577W
Fagasa	-14º 17.016S, -170º 43.383W
Tafeu	-14º 15.109S, -170º 41.354W
Vatia	-14º 14.888S, -170º 40.205W
Aoa	-14º 15.474S, -170º 35.332W
Aunu'u	-14º 17.076S, -170º 33.818W
Amaua	-14º 16.418S, -170º 37.312W
Faga'alu	-14º 17.404S, -170º 40.598W
Nu'uuli	-14º 19.287S, -170º 41.850W
Fagatele Bay	-14º 21.859S, -170º 45.753W
Leone	-14º 20.534S, -170º 47.339W

Table 2. Reef Flat Monitoring Sites (approximate locations from a map):

Fagamalo	-14º 18.2 S -170º 49.4 W
Fagasa	-14º 17.5 S -170º 43.5 W
Vatia	-14º 15.3 S -170º 40.2 W
Aoa	-14º 15.8 S -170º 35.3 W
Alofau	-14º 16.9 S -170º 36.3' W
Amaua	-14º 16.7 S -170º 37.3 W
Gataivai	-14º 17.3 S -170º 40.8 W
Faga'alu	-14º 17.9 S -170º 40.9 W
Coconut Pt.	-14º 19.2 S -170º 41.7 W
Fagatele Bay	-14º 22.1 S -170º 45.5 W
Leone	-14º 20.6 S -170º 47.1 W

Table 3. Bleaching Monitoring Sites (approximate locations from a map):

Site	Coordinates
Airport pool	-14º 20' S -170º 42'
Alofau	-14º 16.9 S -170º 36.3'

Dates of collection of data are shown in Tables 4-9.

Table 4. Dates of collection of benthic transect data for each reef slope site.

Location	**Date**
Masacre	12/9/11
Fagasa	3/17/11
Tafeu	9/22/11
Vatia	9/29/11
Aoa	5/22/11
Aunu'u	8/5/11
Amaua	3/3/11
Faga'alu	8/3/11
Nuu'uli	1/19/11
Fagatele	2/24/11
Leone 1	2/25/11
Leone 2	8/4/11

Table 5. Dates of collection of benthic coral diversity data for each reef slope site.

Location	**Date**
Fagamalo	2/21/12
Masacre	2/21/12
Vatia	2/16/12
Aoa	2/16/12
Aunu'u	8/11/11
Amaua	8/11/11
Faga'alu	9/19/11
Faga'alu II	5/19/11
Nuu'uli	5/19/11
Fagatele	4/13/11
Leone	4/13/11
Rainmaker	5/12/11
Gataivai	2/12
Aua	2/12
Onososopo	11/12/11
Leloaloa	8/18/11
Aunu'u North	9/15/11

Table 6. Dates of collection of benthic transect data for each reef flat site.

Location	Date
Fagamalo	10/5/11
Fagasa	9/27/11
Vatia	9/28/11
Aoa	5/20/11
Alofau	4/8/11
Amaua	3/29/11
Gataivai	9/30/11
Faga'alu	9/19/11
Nuu'uli	2/19/11
Fagatele	4/17/11
Leone	2/10/11

Table 7. Dates of collection of benthic coral diversity data from reef flats.

Location	Date
Fagamalo	10/5/11
Fagasa	10/4/11
Vatia	
Aoa	5/30/11
Amaua	10/3/11
Faga'aitua	10/3/11
Alofau	2011
Faga'alu	4/6/11
Faga'alu pool	4/27/11
Coconut Pt.	10/7/11
Coconut Pt pool	5/6/11
Airport pool	4/10/11
Fagatele	9/24/11
Leone	5/18/11
Onososopo	2011
Aua	5/13/11
Leloaloa	11/17/11
Gataivai	10/6/11
Utulei	5/11/11
Fagatoago	

Table 8. Dates of collection of Ofu reef flat transect data.

Vaoto Lodge 2	11/18/11
Vaoto Lodge 1	11/28/11
Pool 500	11/14/11

Table 9. Dates of collection of coral diversity data from Ofu pools and flats.

Ofu airport pool	11/15/11
Vaoto Pool	11/8/11
Vaoto Reef Flat	11/8/11
Ofu pool 225	11/11/11
Pool 250	11/10/11
2nd Pool, Ofu 300	11/9/11
Ofu Hurricane House	11/9/11
Ofu reef flat 500	11/14/11
Ofu pool 500	11/14/11
Olosega: bridge-Sili flat	11/15/11

Monitoring of bleaching continues as before, with visual estimates of the amount of staghorn bleached in different areas of the airport and Alofau pools, about biweekly. Bleaching on the reef flat and slope are also recorded at Alofau each time data is taken.

Results

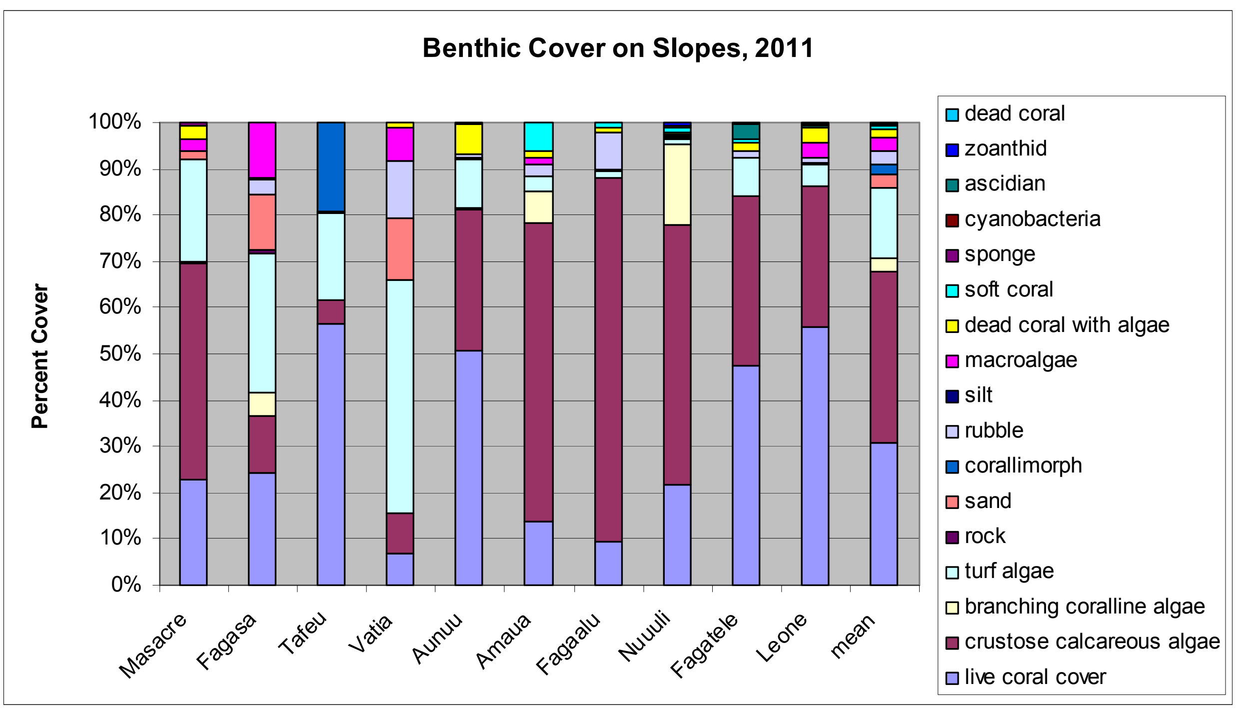
For background information on the coral reefs of American Samoa, see Wells (1988), Craig et al. (2005), Sabater and Tofaeono (2006, 2007), Whaylen and Fenner (2006), Fenner (2008a,b), Fenner et al. (2008), Birkeland et al. (2008), Brainard et al. (2008), Craig (2009), Fenner (2009, 2010, 2011, 2012), Sabater and Carroll (2009), PIFSC (2011), and Carroll (2012).

Reef Slopes

Data was collected from 10 sites, as shown in Figure 1. Average coral cover was 31%. Tafeu, Aunu'u, Leone and Fagatele had the highest coral cover, and Vatia, Faga'alu and Amaua had the lowest cover. Amaua, Faga'alu, and Nu'uuli had the highest cover of crustose calcareous algae. Vatia had the highest turf algae, Tafeu had the only corallimorph cover, Vatia had the highest macroalgae, and Nu'uuli had the most branching coralline algae. Variation between sites was relatively large, as it is every year. It is typical for coral reefs to be very patchy, meaning they have high spatial variation. Spatial variation between sites is much greater than temporal variation, that is, the variation of the same sites over time.

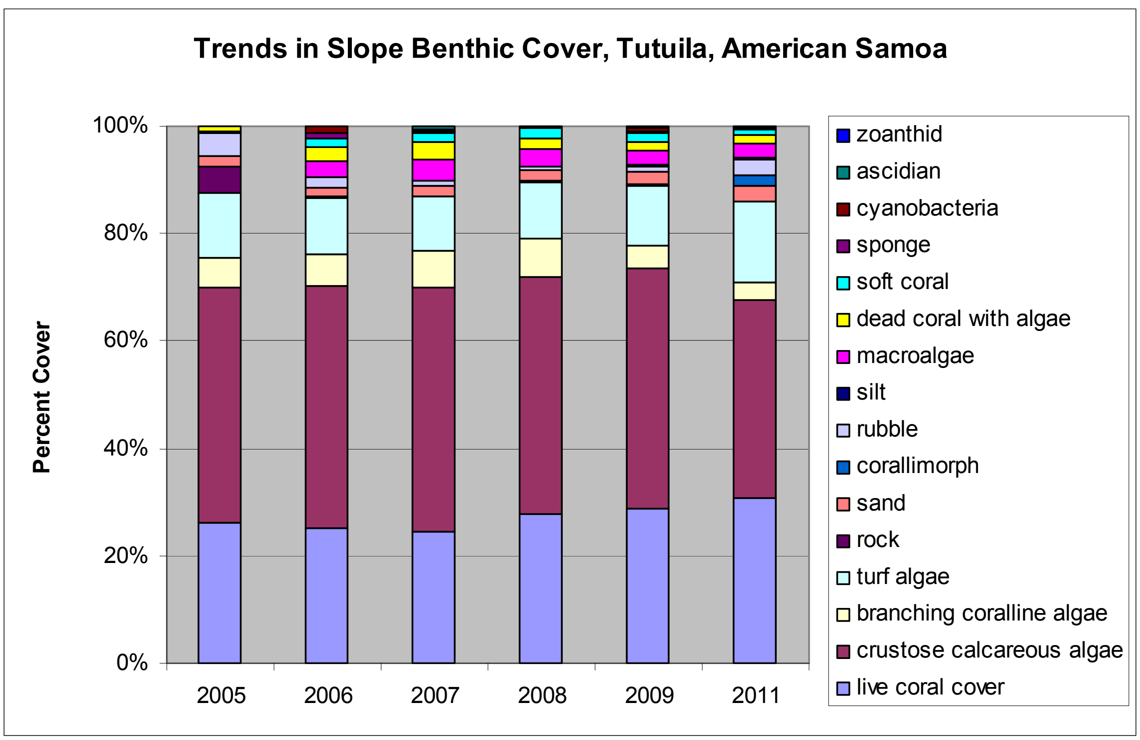
Five different monitoring programs have recorded coral cover averaging around 30% cover around Tutuila (Fenner et al. 2008).

Figure 1. Benthic cover for the 10 sites surveyed in 2011.



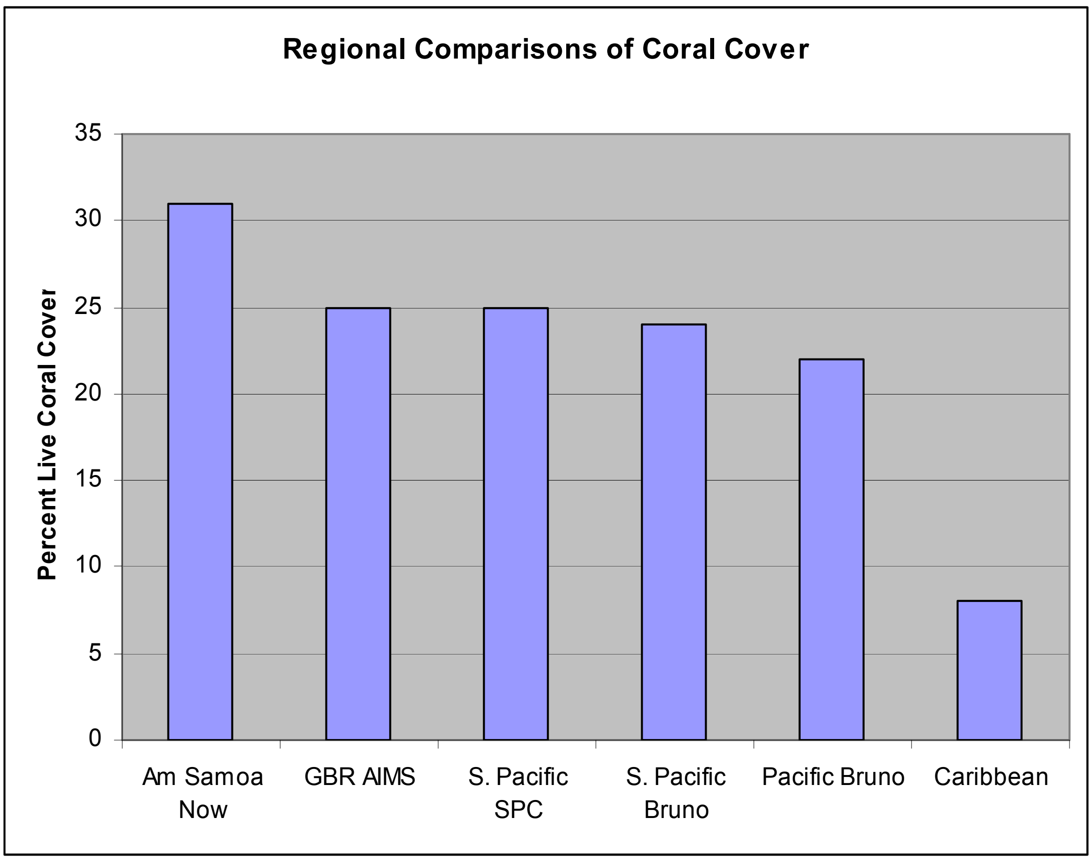
As seen in Figure 2 below, live coral cover was steady over the seven years of the monitoring program, with a slight upward trend in the last three years. Turf increased slightly in 2011 with a decrease in crustose calcareous algae. Since turf and coralline algae have generally been steady over the years, this may not be a real trend. It was only possible to collect data from two sites in 2010 due to boats not working, so that year was omitted. Notice that the variation over time in Figure 2 was much smaller than the spatial variation in Figure 1. This is likely to be partly a matter of scale. That is, variation over individual years of the mean for American Samoa is small, and even variation over the 6 years of this monitoring program has been small. But variation over time periods of several decades is surely larger. In 1978, over 80% of all coral tissue was eaten by crown-of-thorns starfish, so coral cover dropped dramatically then. Spatial variation is large in Figure 1, but presumably if the locations were closer together, the differences would be smaller. If distances between locations were small and time differences were large, then levels of variation would appear more similar. In a sense, the surprise is not that variation is less temporally than spatially, but that the distance over which spatial variation is equal to temporal variation is small compared to the time over which they are equal.

Figure 2.



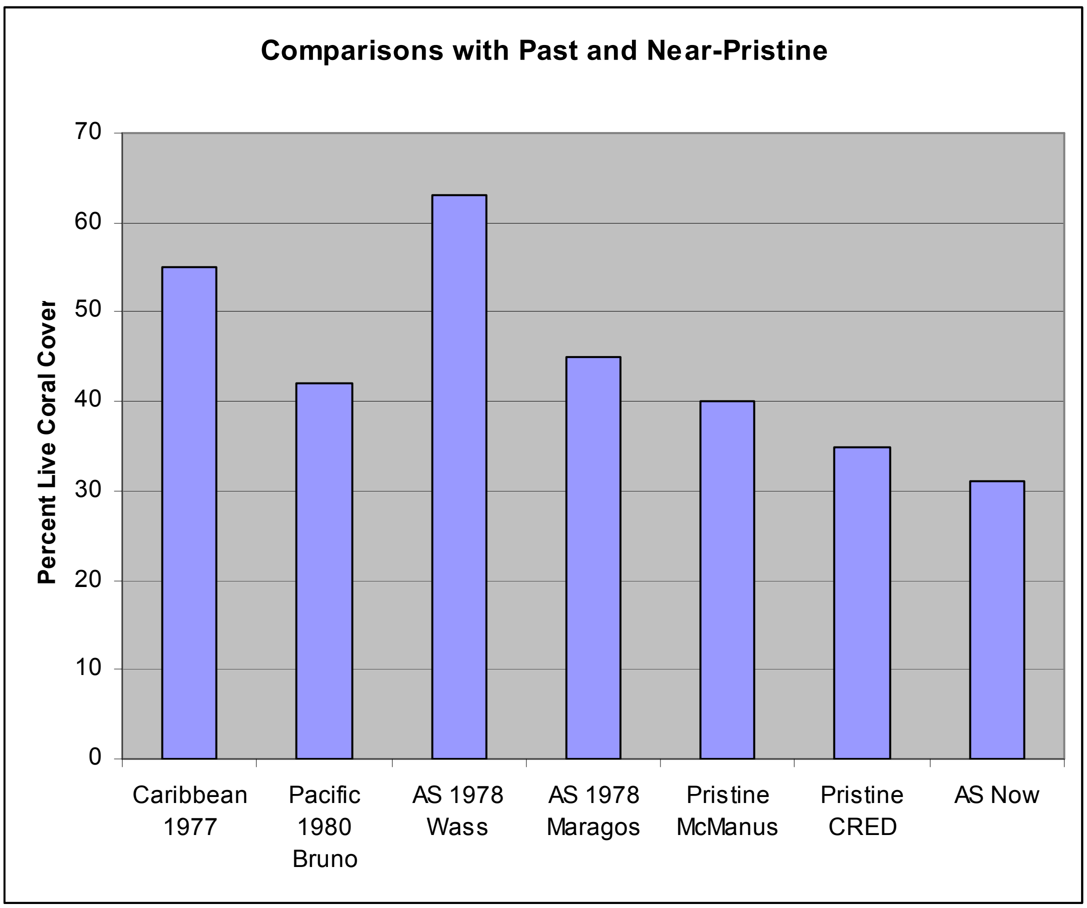
The coral cover on the slopes of American Samoa compare favorably with averages for most areas of the world, as shown in Figure 3. The coral cover on American Samoa is higher than the averages on the Great Barrier Reef, the South Pacific (SPC, 2005; Bruno and Selig, 2007) the whole Pacific (Bruno and Selig, 2007) and especially the Caribbean (Gardiner et al 2003). American Samoa has 31% coral cover compared to only about 8% in the Caribbean. Coral cover dropped drastically in the Indian Ocean in 1998, with places such as the Maldives, Seychelles and Chagos reported to have mortality as high as 90%, but a few other places having little mortality, like Rodriques. Average coral cover figures for the Indian Ocean are not available, but are likely to be low also, surely lower than the Pacific and possibly as low as the Caribbean. The Maldives are reported to be showing recovery, while the Seychelles are not. American Samoa has higher coral cover than most major regions of the world.

Figure 3.



However, coral cover has declined in most parts of the world, and the available information indicates that they were originally higher than the present cover in American Samoa. The Caribbean in 1977 and Pacific in 1980 have both been reported to have had higher coral cover than American Samoa now (Gardiner, 2003; Bruno and Selig, 2007). There are two estimates of coral cover in American Samoa before the outbreak of crown-of-thorns in 1978 ate much of the coral (Wass, 1982; Maragos). Both are well above the present coral cover, but they are estimates not quantitative measures, and may well have been from sites selected to be better than average. A survey by John McManus of the available literature on near-pristine reefs produced an average of about 40% coral cover (McManus et al. 1995), while the Coral Reef Ecosystem Division of NOAA produced an average of 35% cover for the many near-pristine reefs of the U.S. Pacific (Fenner et al. 2008)). All of these reference coral covers are higher than the present cover in American Samoa, but some are not much higher.

Figure 4.



The data presented above are based on transects. Most of the available data on reefs around the world is from transects. However, transects are rarely taken at random locations, and there is evidence that there is a bias toward higher coral cover. When choosing transect locations, areas of low coral cover including sandy patches, rubble, or bare rock, are often avoided. The Reef Check instructions to volunteers direct them to survey the best available reefs in their area, and Reef Check surveys are a large majority of the transects taken in recent decades (but not earlier), biasing recent world average coral cover upward. Another way to survey is by towboard, where a person is towed over large areas of reef. With a towboard, there is no chance to pick the best (highest coral cover) areas, and so the coral cover recorded is generally lower than in transects. But it is more representative of the entire reef and not just the best areas. The NOAA CRED program has gathered both transect and towboard data, and their transect data is presented above. Below, Figure 5 is presented from Vroom (2010) in which the live coral cover recorded by towboard (by a camera that takes pictures automatically) around all of the U.S. Pacific Islands, including remote, near-pristine islands. The American Samoan islands are shown in the far right, with "TUT" being Tutuila. Tutuila had an average of about 17.5% coral cover in the CRED towboard surveys, compared to 35% in the CRED transects (Figure 4). Figure 5 shows that the mean coral cover for islands in American Samoa was lower than the mean for the Pacific Remote Island Areas (PRIA) which are all near-pristine, but higher than the near-pristine islands in the Marianas and Hawaiian chains, which are the islands to the left for each of those two areas in the graph below. Thus, American Samoa is in the mid-range for coral cover at near-pristine reefs in the U.S. Pacific, when measured by towboard.

Figure 5. From Vroom (2010).

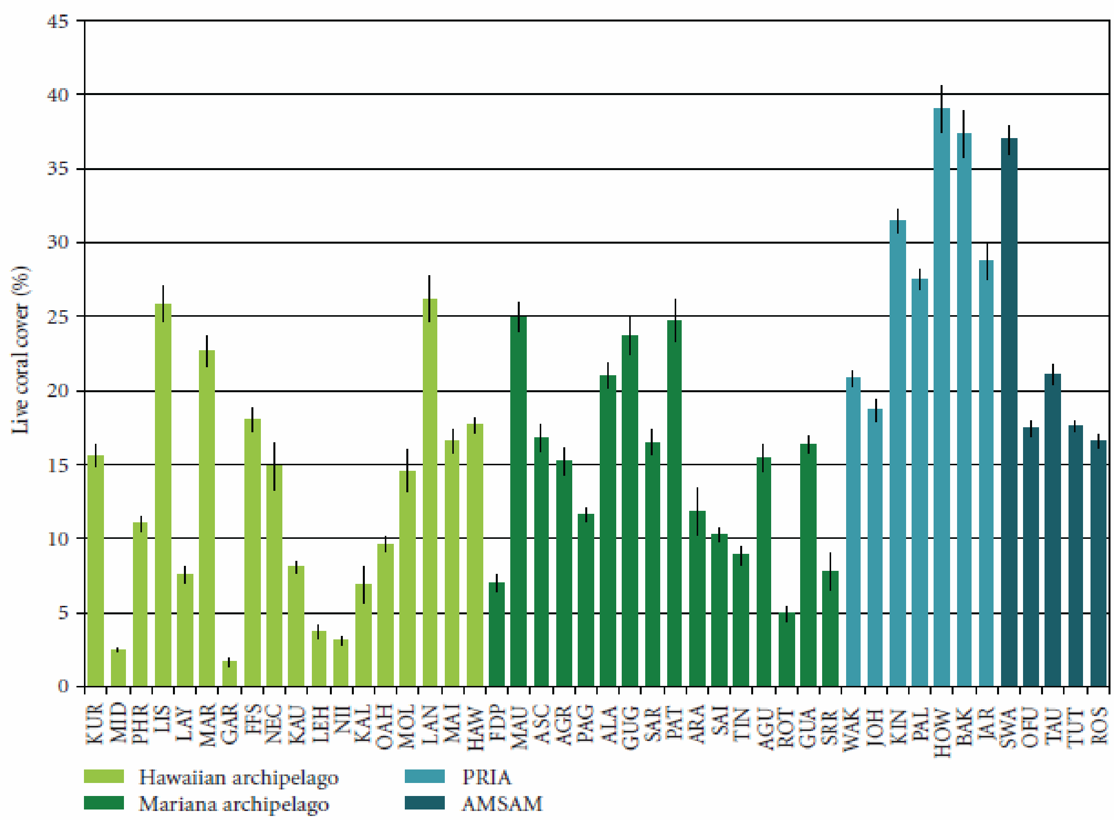
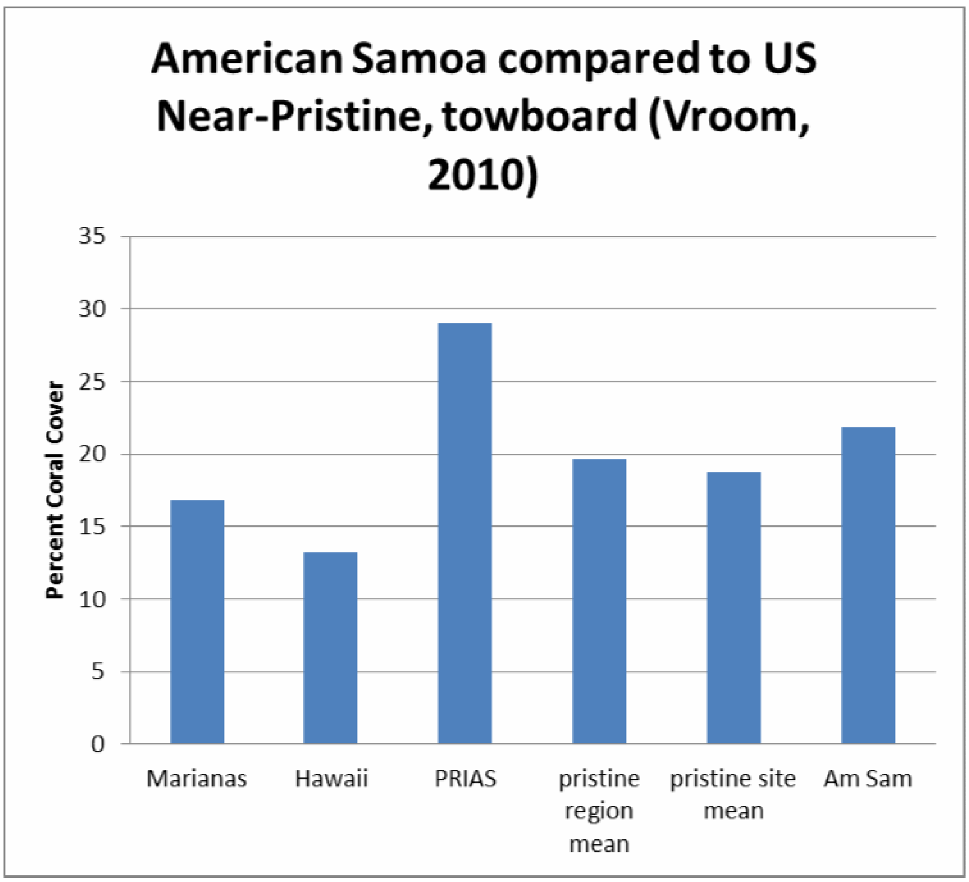


Figure 6 summarizes the information in the previous figure. The mean for American Samoa (all islands) is higher than the means for the Marianas and Hawaii, but less than that for the PRIAS (Pacific Remote Island Areas: Howland, Baker, Jarvis, Palmyra, Kingman, Johnston and Wake Is.). The uninhabited islands in the Marianas and Hawaii are at higher latitudes than American Samoa, and most of the PRIAS are at lower latitudes. All near-pristine islands and reefs are smaller than all but Rose and Swains in American Samoa (which have typical cover for American Samoan Islands). So American Samoa is within the range of variation for near-pristine island areas in the US system. The mean for American Samoa is slightly higher than the means for near-pristine U.S. reefs, taken either by region or by island. This is consistent with the view that American Samoan reef coral cover is in relatively good condition overall.

Figure 6. Mean coral cover from towboard surveys based on Figure 5 from Vroom (2010).



A new publication (De'ath et al. 2012) reports coral cover from the Great Barrier Reef (GBR) from 1985 to 2012 based on towboard data. That data, shown in Figure 7, shows large decreases in coral cover recently, with mean coral cover now about 10%. The Great Barrier Reef has long been considered one of the more pristine reef systems in the world, with Pandolfi et al. (2005) reporting it as near to pristine as the NW Hawaiian Islands. But Tutuila now has about 17.5% coral cover from towboard compared to 10% on the Great Barrier Reef. At the same time, the GBR had about 28% coral cover in towboard surveys in 1985 and the northern GBR which has very little human impact has not declined and still has about 24% cover. Both are higher than Tutuila now. This is consistent with the other information indicating that the Tutuila reefs now have more coral than elsewhere, but not as much as reefs once had.

Figure 7. From De'ath et al. 2012.

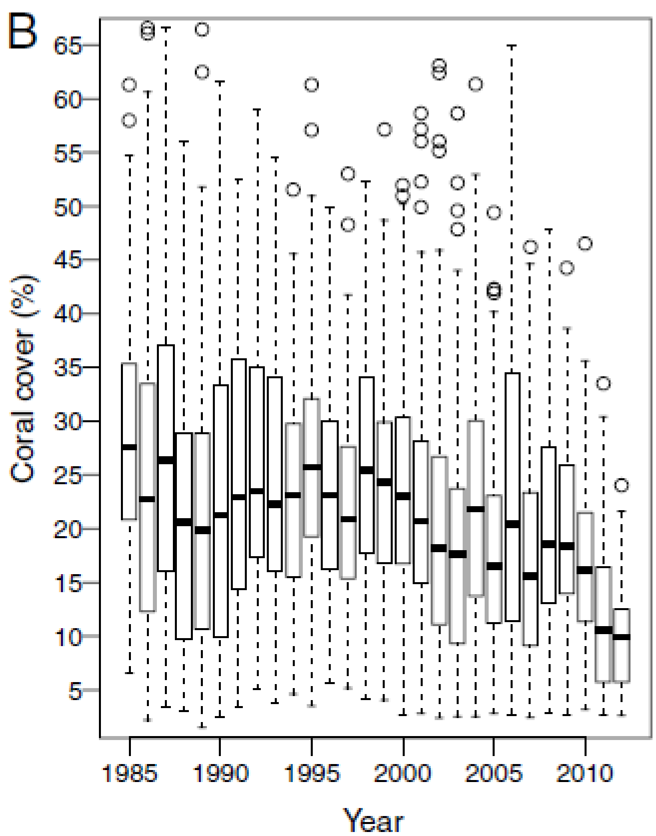
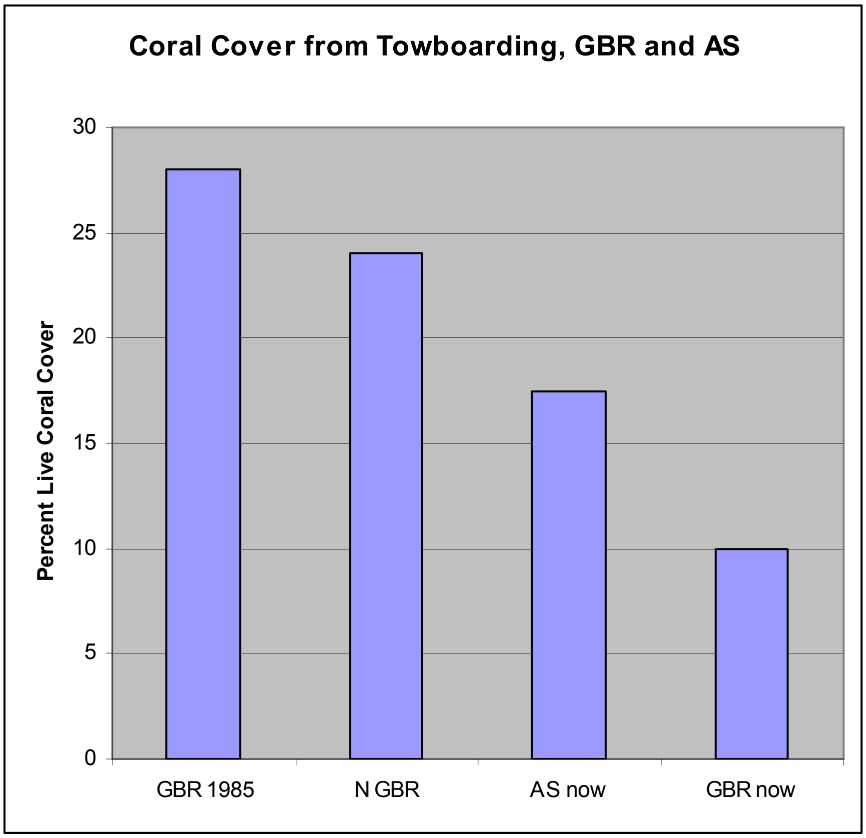


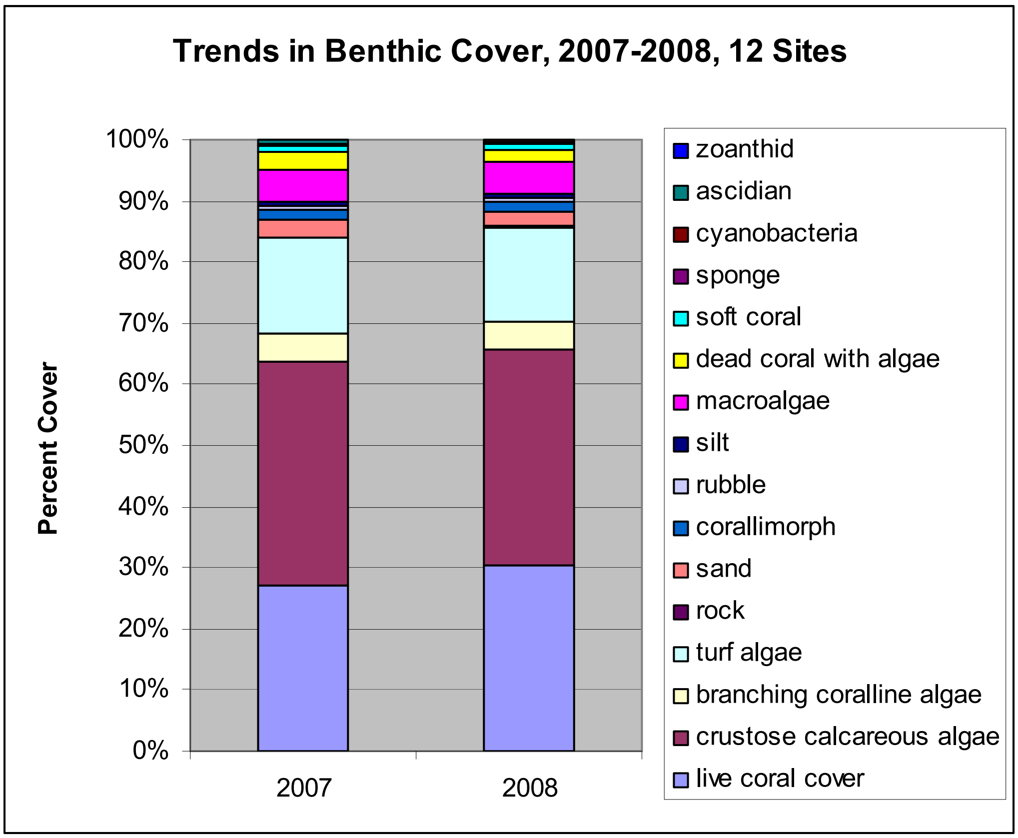
Figure 8 compares the live coral cover recorded by towboarding from the Great Barrier Reef and Tutuila. American Samoa now has higher coral cover in towboard surveys than the Great Barrier Reef as a whole, but less than the northern Great Barrier Reef and the Great Barrier Reef in 1985.

Figure 8.



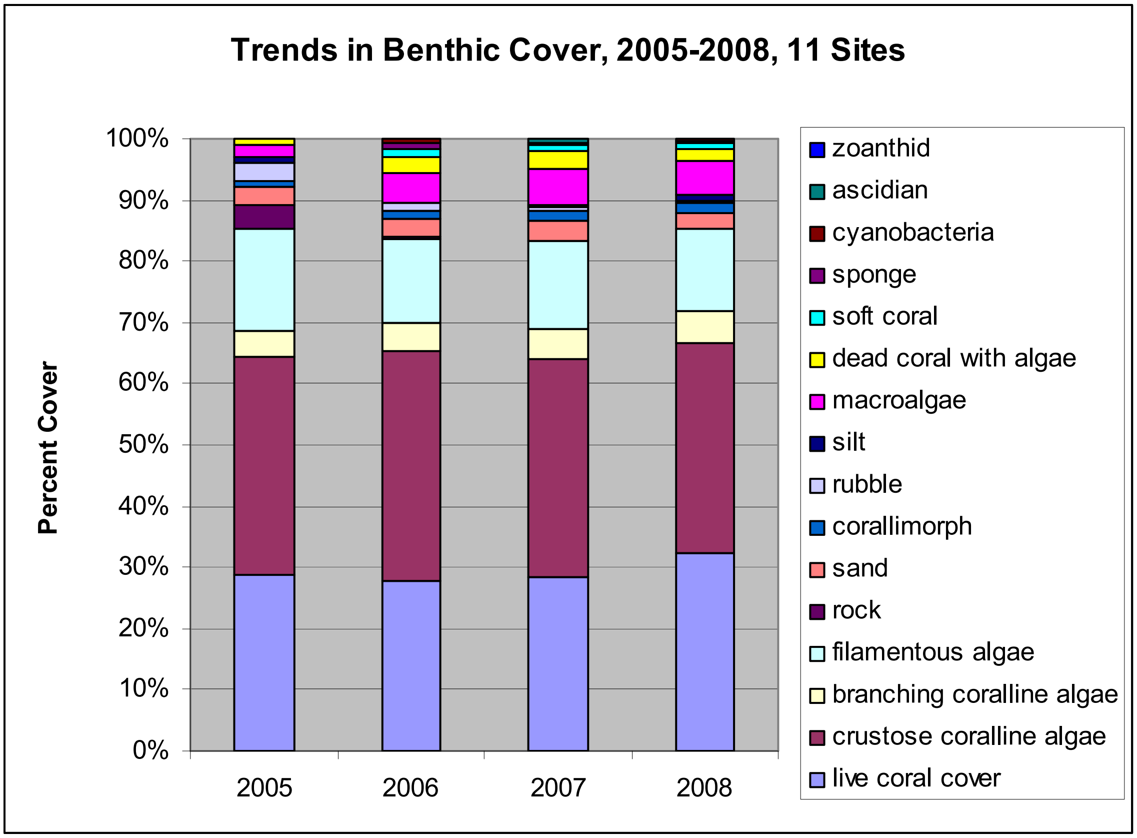
In order to be sure that the trends you see over time are real, you must compare the exact same sites from year to year. Because of various logistical problems, in some years not all sites have been done. So to be sure that the graphs show real trends, you must compare the exact same sites each year. If you do so, you can only compare two years using 12 sites in the present data set, 2007 and 2008, shown in Figure 9 below. There was a slight increase in coral cover recorded between these two years.

Figure 9.



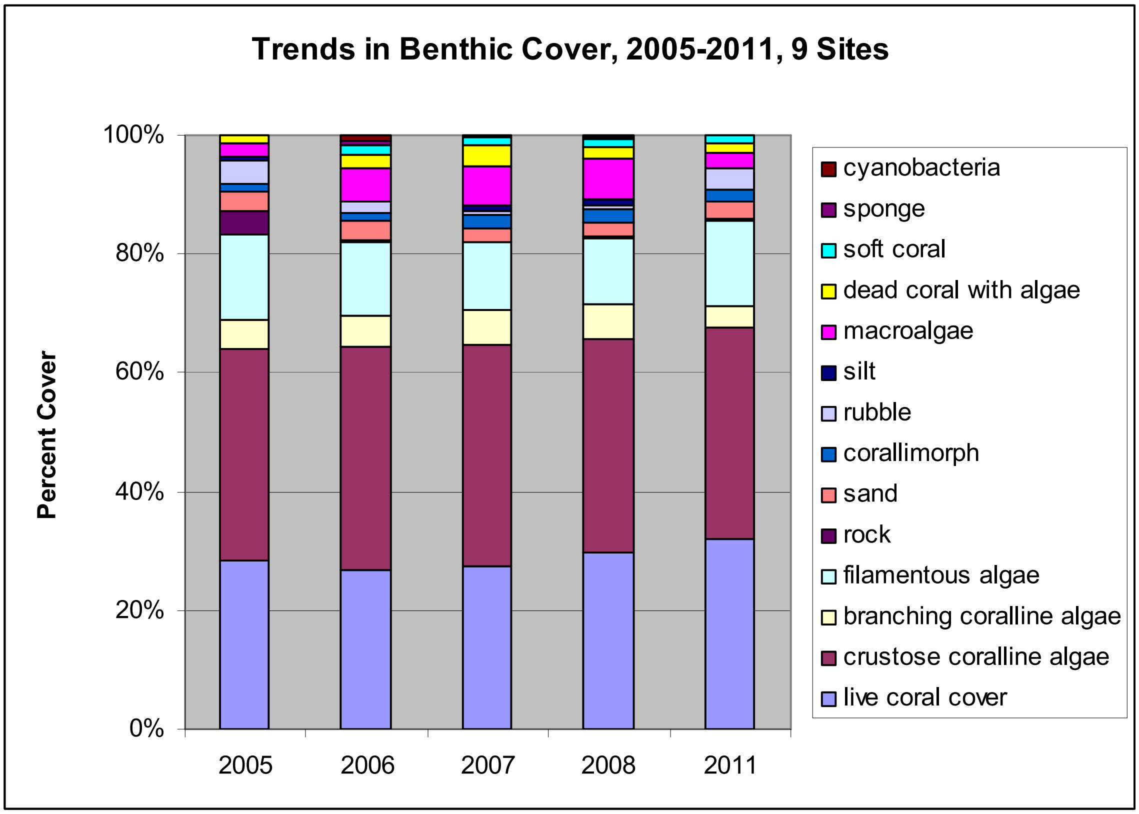
If you relax the requirement for the number of sites to just 11, then you can plot more years that all have data from exactly the same sites, as shown below in Figure 10. There are four years for which data on 11 sites are available, and as the figure shows, there was a slight increase in coral cover recorded at those sites over the four years.

Figure 10.



If the criterion is relaxed further to 9 sites, then 5 years meet the criterion, and Figure 11 below shows trends over the exact same 9 sites, over 5 years. This graph also shows a slight increase in coral cover recorded over this time span.

Figure 11.



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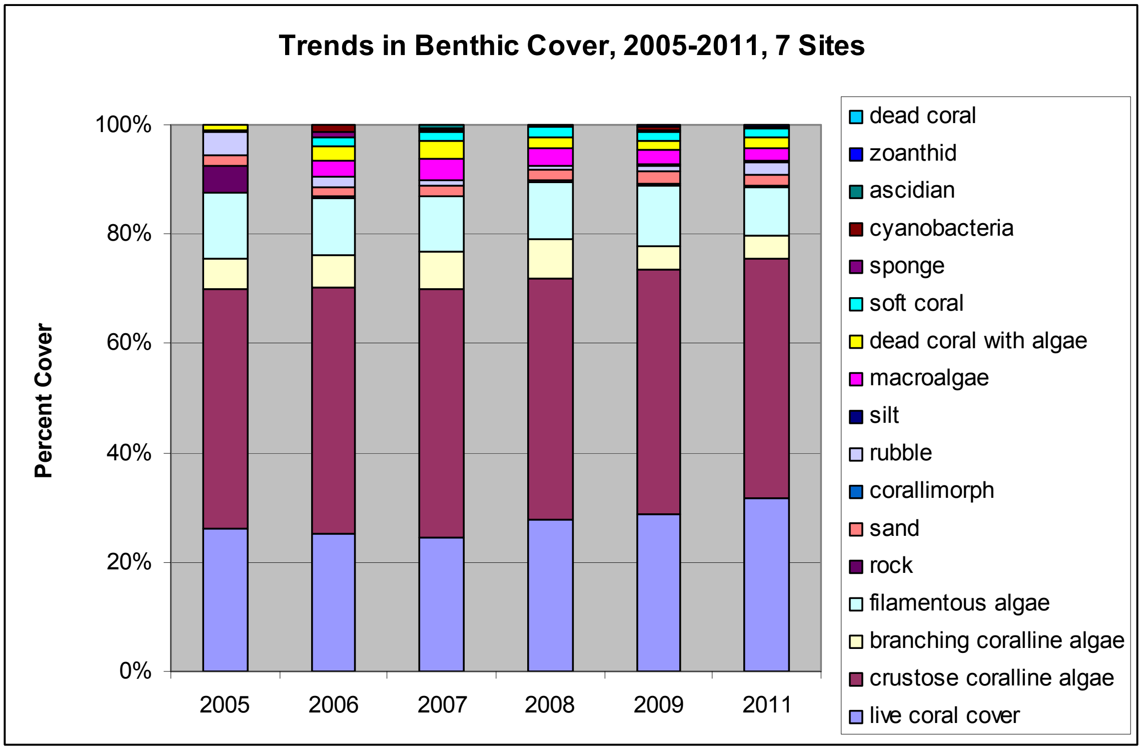
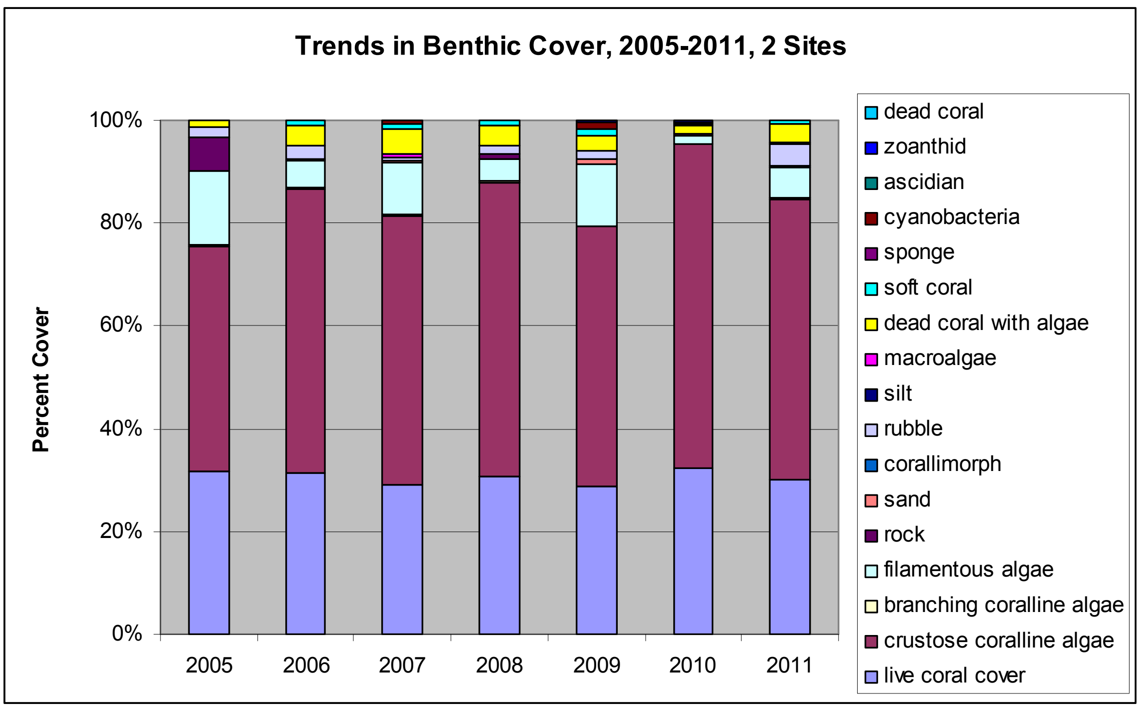
If the criterion is relaxed to 7 sites, then 6 years meet the criterion, and Figure 12 below results. This graph also shows a small increase in coral cover recorded over time.

Figure 12.



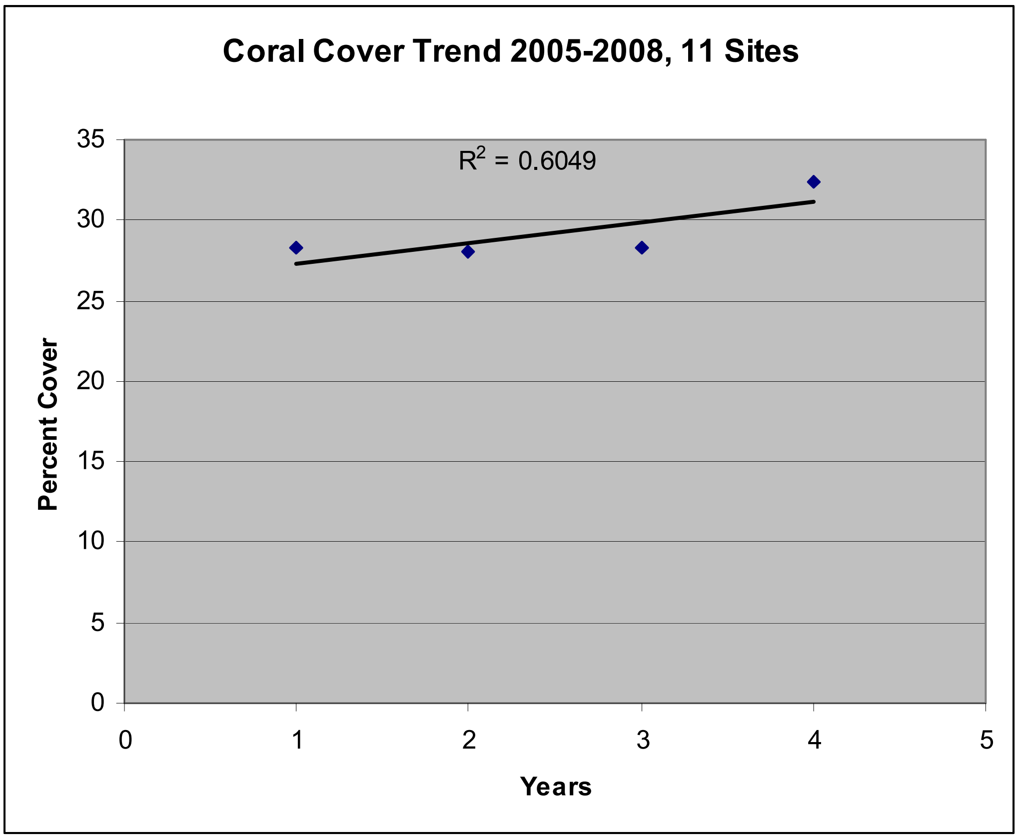
Because in the year after the tsunami our boat was not working for nearly the entire year, in order to compare all years, you can only compare two sites. Figure12 shows trends over all years of the program, based on just two sites. There is no increase in coral cover over this time period in the average for these two sites. However, two sites are such a small number that the findings are much less accurate than for larger numbers of sites. In a way, adding additional sites (which can be seen in the graphs by beginning with Figure 13 and going backwards toward Figure 9), you can see if a small number of sites does very well predicting what a larger number of sites will do. In a sense, it gives an impression of whether the results do a good job in predicting what a larger number of sites will show. It is a way of checking the generality of the findings. It appears that the results from 7 sites do well at predicting the results of 9, 11, or 12 sites, and thus can be generalized beyond the 7 sites. That would indicate that 12 sites ought to be even more secure in the ability to measure the trends in the average for reefs all around the island.

Figure 13.



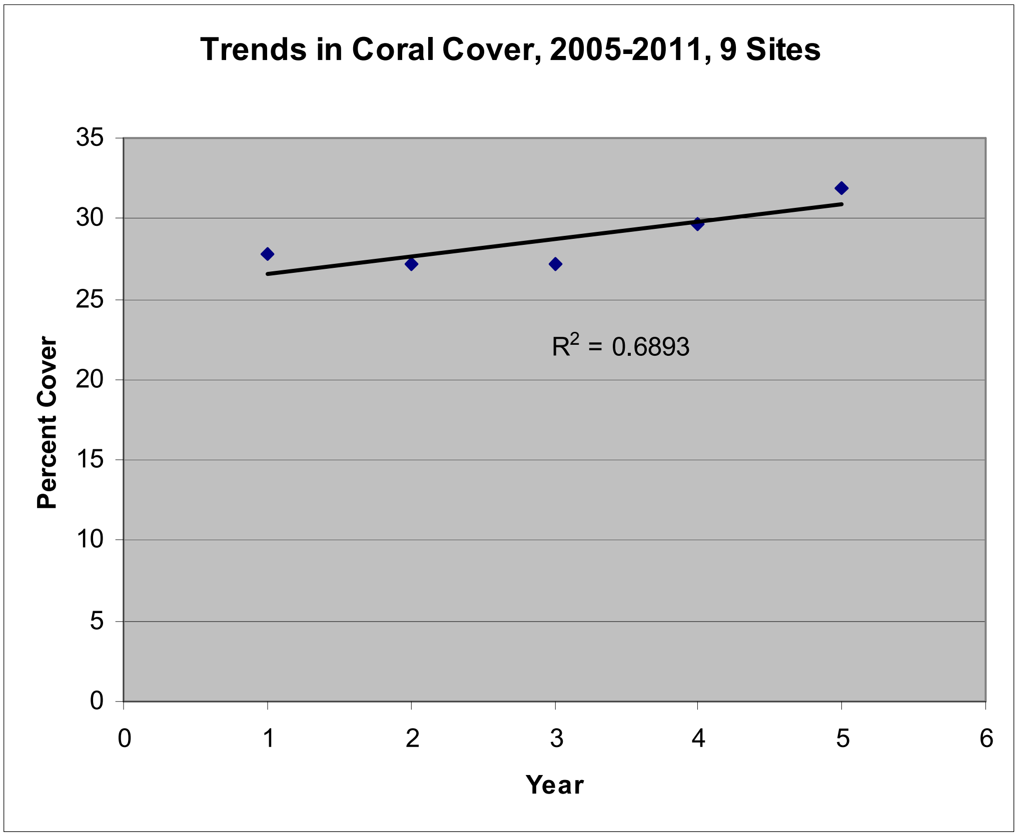
The changes in coral cover shown in Figures 9-13 are not large, but all graphs except for 2 sites show increases. Another way to graph those increases is shown in Figure 14 for 11 sites. This graph has the advantage of being able to put the regression line on it, and to give the correlation of coral cover with the years, which is quite strong, r = 0.7777 (note that r is the square root of R^2 shown in the graph). However, due to the small N, it is not significant ($p > .1$).

Figure 14.



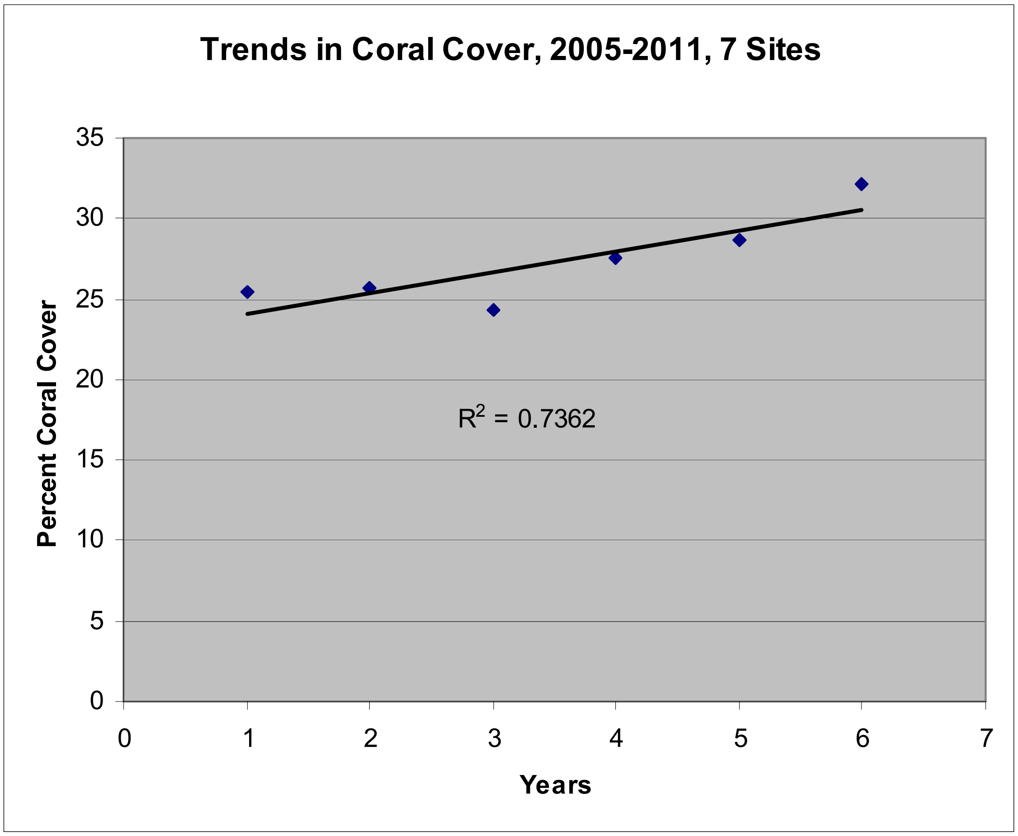
The trend for 9 sites was slightly stronger as shown in Figure 15, r = .8302. This was not quite significant (p > .05).

Figure 15.



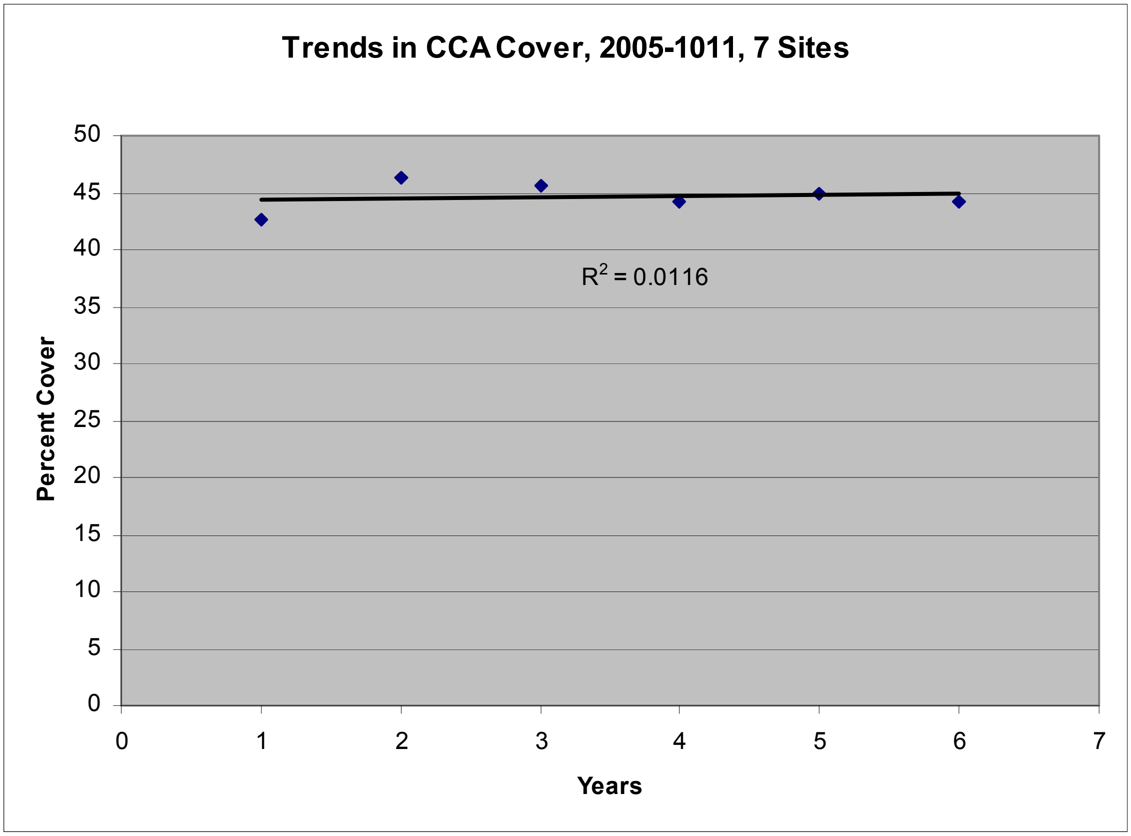
The fit was best for 7 sites as shown in Figure 16, r = .8580. This was significant ($p < .05$).

Figure 16.



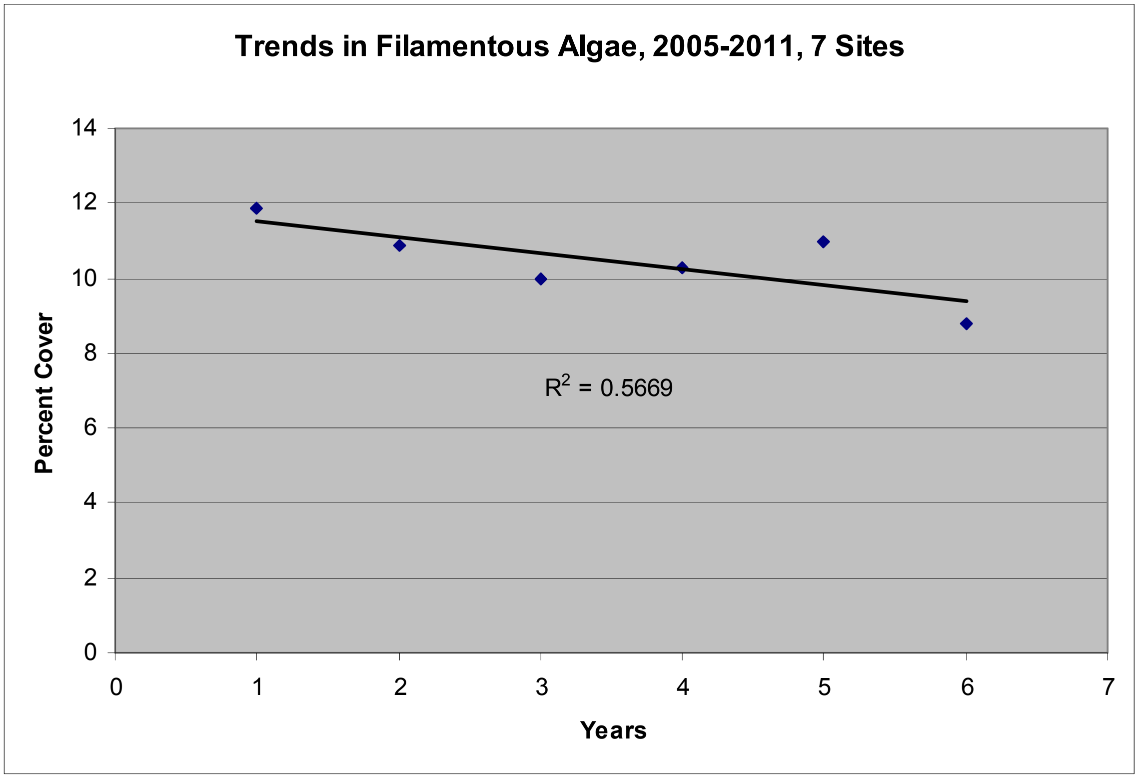
Crustose coralline algae, on the other hand, showed no trend with 7 sites, as seen in Figure 17 below, r = .1077, not significant (p > .2).

Figure 17.



Filamentous algae decreased in the 7 sites as shown in Figure 18, r = .7529, which is significant ($p < .05$).

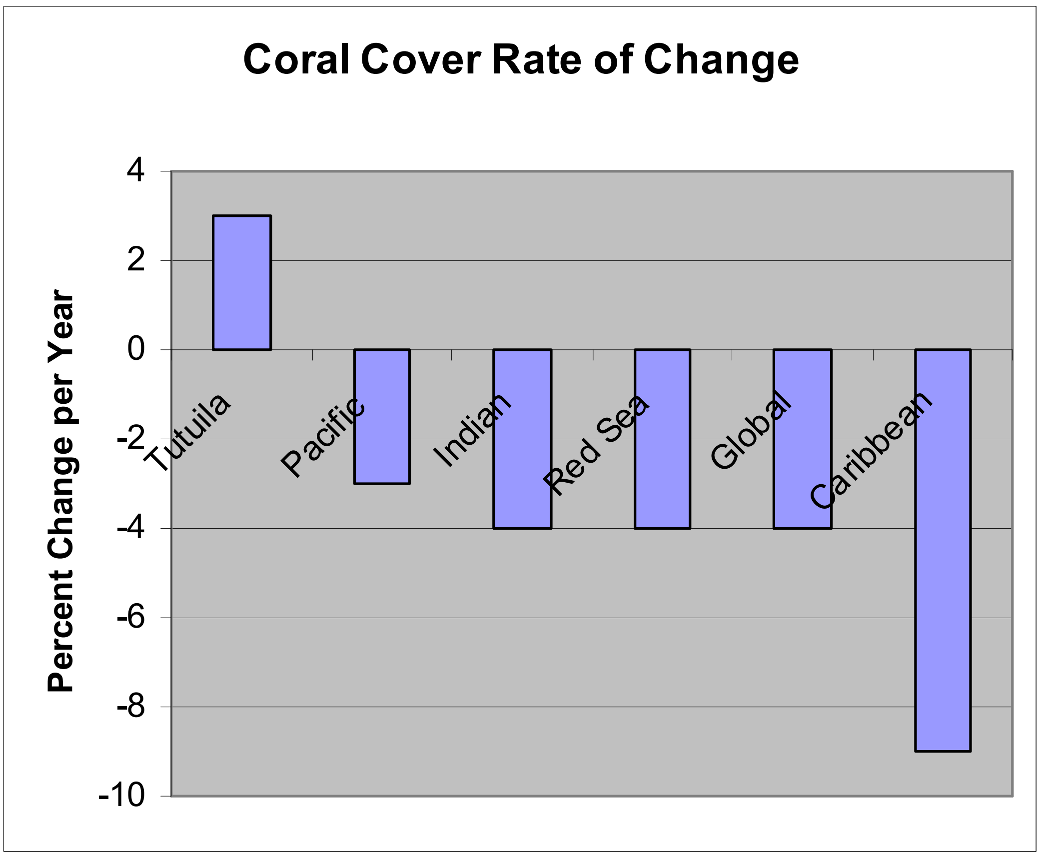
Figure 18.



All major areas of the world's reefs have been reported to have decreased in coral cover (Côté et al. 2006). In contrast, coral cover in American Samoa is currently increasing slightly. The best way to compare rates of change is the geometric mean (Côté et al. 2006). Figure19 compares the geometric means of change of coral cover in Tutuila with averages for major areas of the world reported by Côté et al. (2006). The increase in coral cover in Tutuila supports the view that the reefs there are healthier than the average over much of the world's reefs. Note that the geometric averages are much larger than the linear means of change, which for Tutuila is just 0.75% per year.

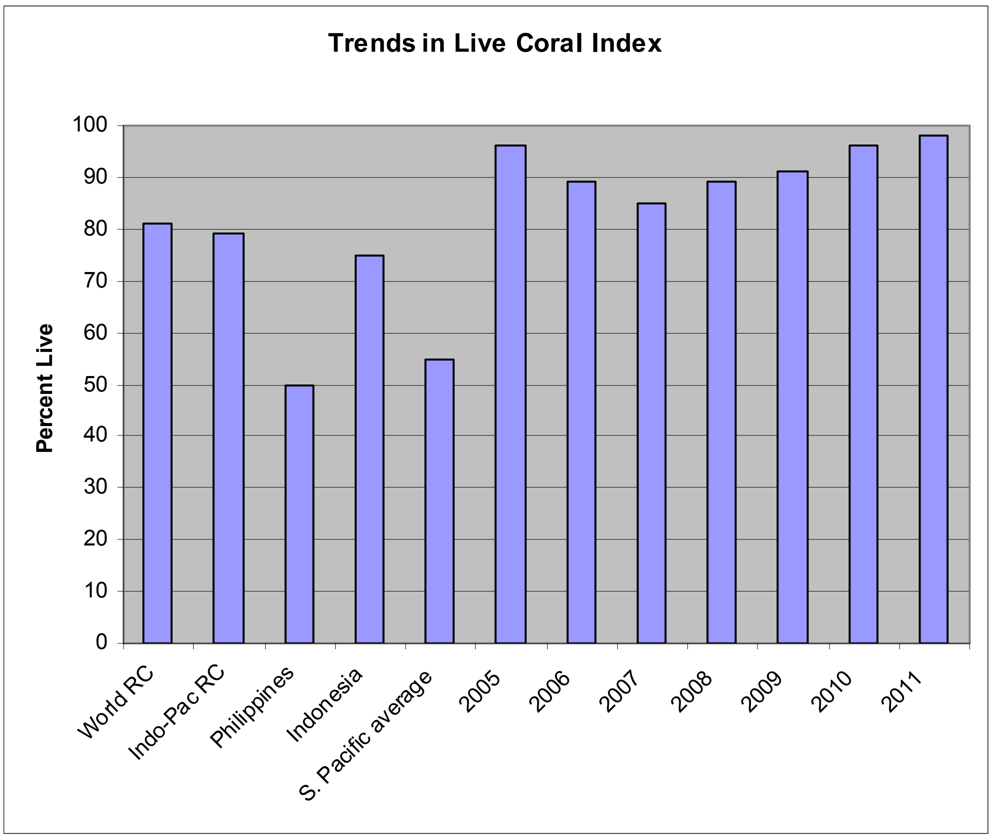
The NOAA CRED program also recorded an increase of coral cover around Tutuila from 2002-2010 (PIFSC, 2011).

Figure 19.



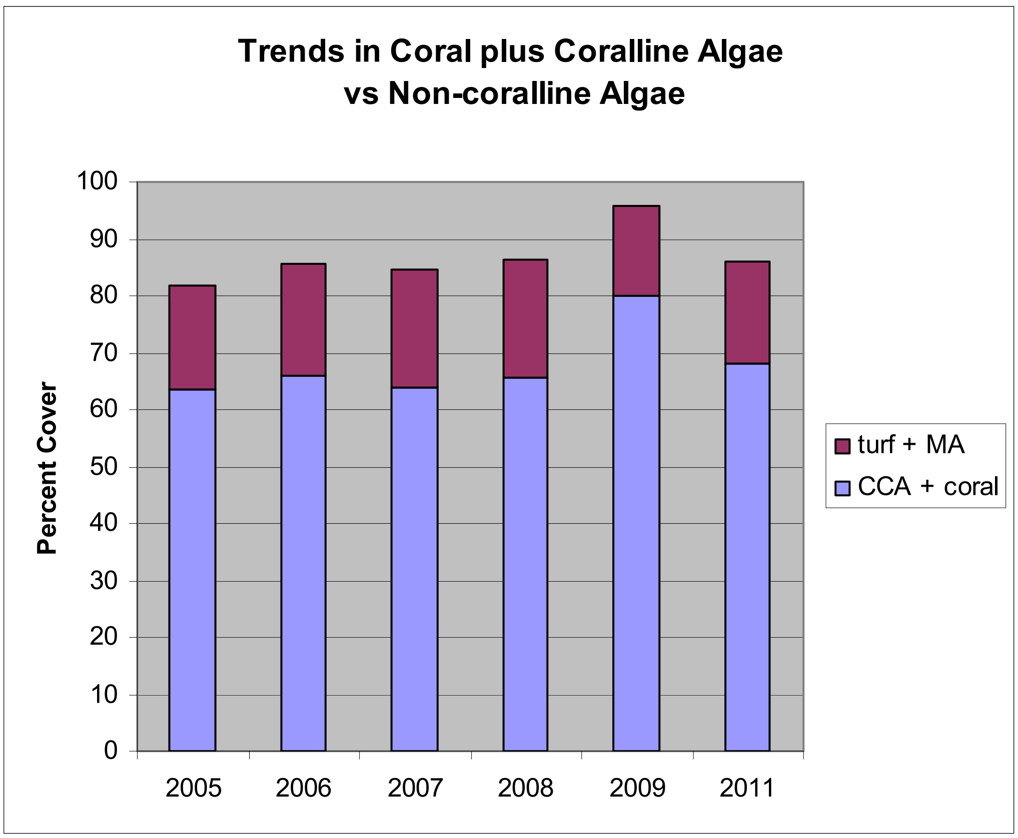
The live coral cover index (live coral/(live coral + dead coral) remains high (Figure 20). There was a dip of unknown cause around 2007, but no overall trend. The live coral index remains above the Reef Check averages for the Indo-Pacific and world and a value for Indonesia (Edinger et al. 1998), and well above a value for the Philippines (Gomez et al. 1994a, b) and the PROCFish average for the South Pacific (Secretariat of the Pacific Community, 2005). The proportion of corals that are alive is an important measure of reef health. There is very little dead coral around Tutuila currently. A reef where most corals are alive is healthy compared to a reef where most corals are dead.

Figure 20.



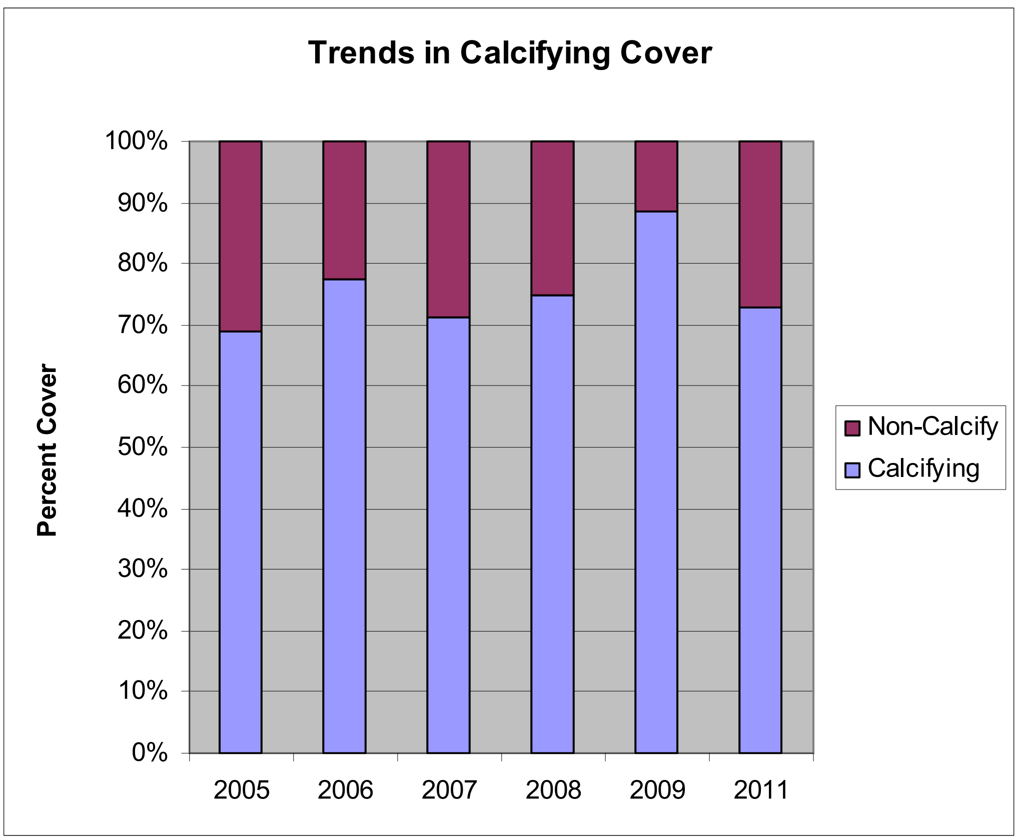
Coral and crustose calcareous (CCA) algae are often considered good for coral reefs, while other algae may be considered bad or at least less good. Figure 21 shows trends in combined categories. The category combining CCA and coral has over 60% cover, and cover has increased slightly over the monitoring period. The turf algae plus macroalgae (MA) category is much smaller, around 20% or less, and shows no trends. American Samoa has a good balance of these categories.

Figure 21.



Some of the macroalgae, such as the green alga *Halimeda* , branching coralline algae *Cheilosporum spectabile*, foliose-encrusting coralline algae *Peyssonnelia* cf. *bornetii* and the brown alga *Padina*, produce some calcium. Thus, they contribute calcium to building the geological reef structure, which is often considered a good thing. *Halimeda* is by far the largest single component of macroalgae on the reef slope, though a few places like our site at Coconut Point have quite a bit of *Cheilosporum spectabile*. *C. spectabile*, *P.* cf. *bornetii* and *Padina* are all lightly calcified and contribute relatively little calcium to the reef, but *Halimeda* is relatively heavily calcified and contributes much more. Crustose coralline algae often occurs under other algae, so the amount of CCA may be underestimated. Figure 22 below shows trends in the combination of coral and all calcareous algae, compared with non-calcareous algae (primarily turf) and any other non-calcifying cover. Over 70% of the substrate is covered with calcifying cover, which should be a good value.

Figure 22.



Trends at Individual Sites

Masacre Bay was added to the original 11 sites in 2007, and we were unable to collect data from it in 2009 or 2010. Figure 23 shows that coral cover was higher in 2011, but this may be because the transect tape was not in exactly the same location.

Figure 23.

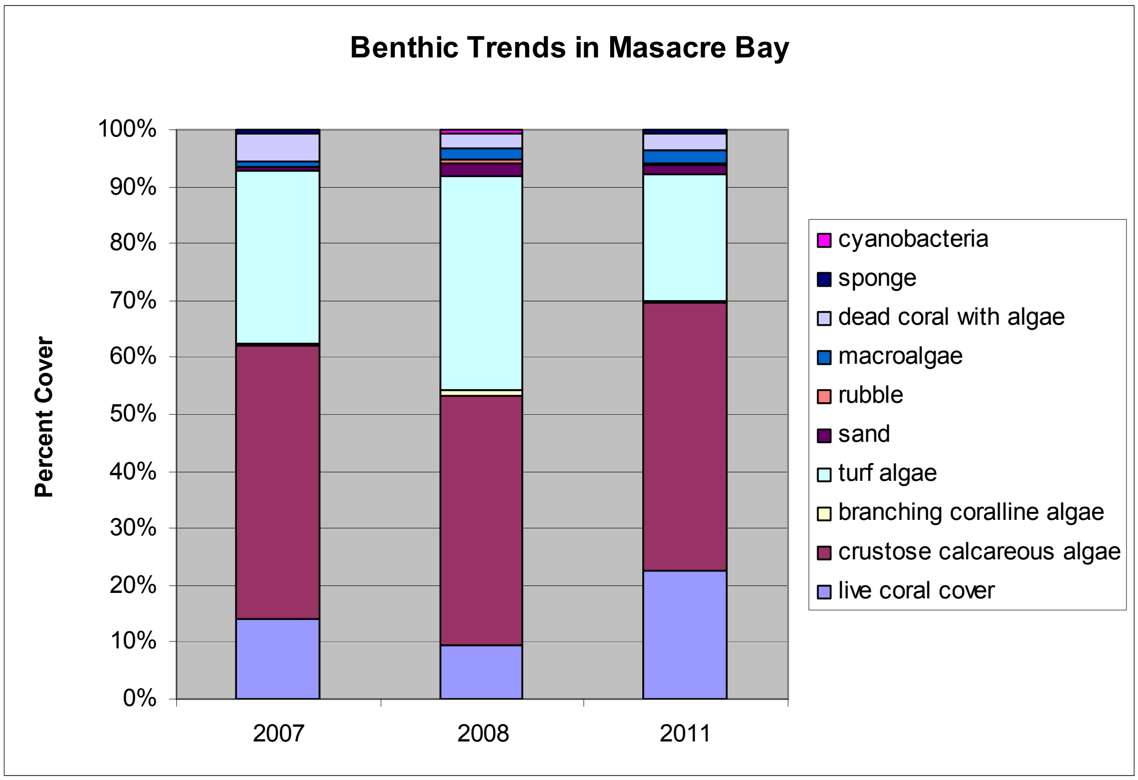
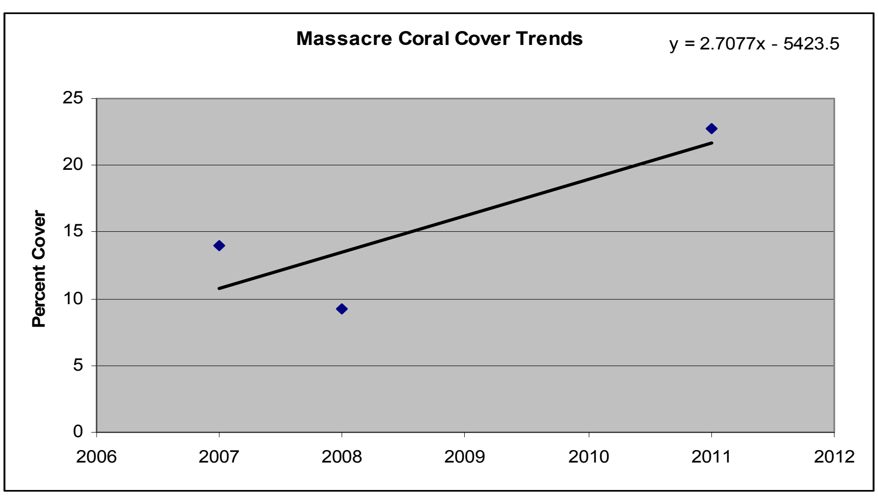


Figure 24. Trends in coral cover with linear trend line and regression equation.



Fagasa shows a trend of increasing coral cover over the entire six year period of monitoring, as shown in Figure 25. At the same time turf decreased.

Figure 25.

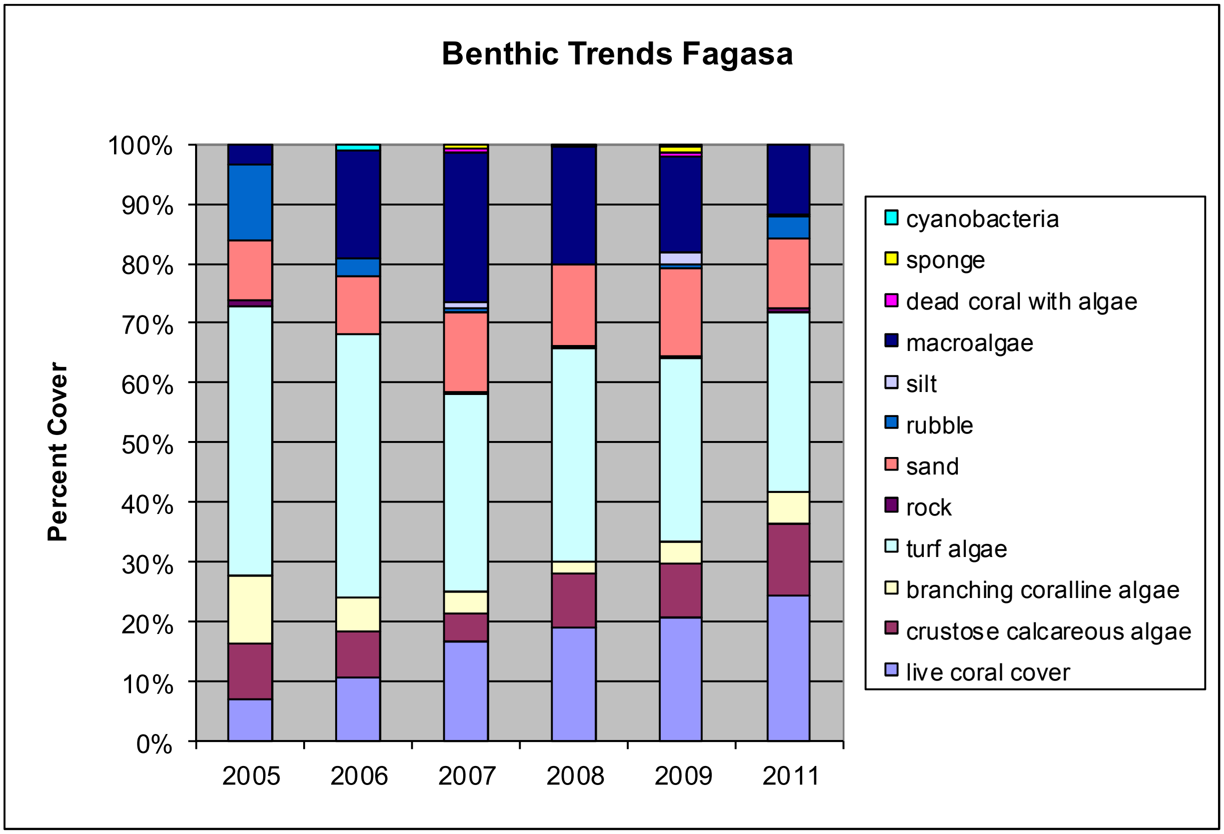
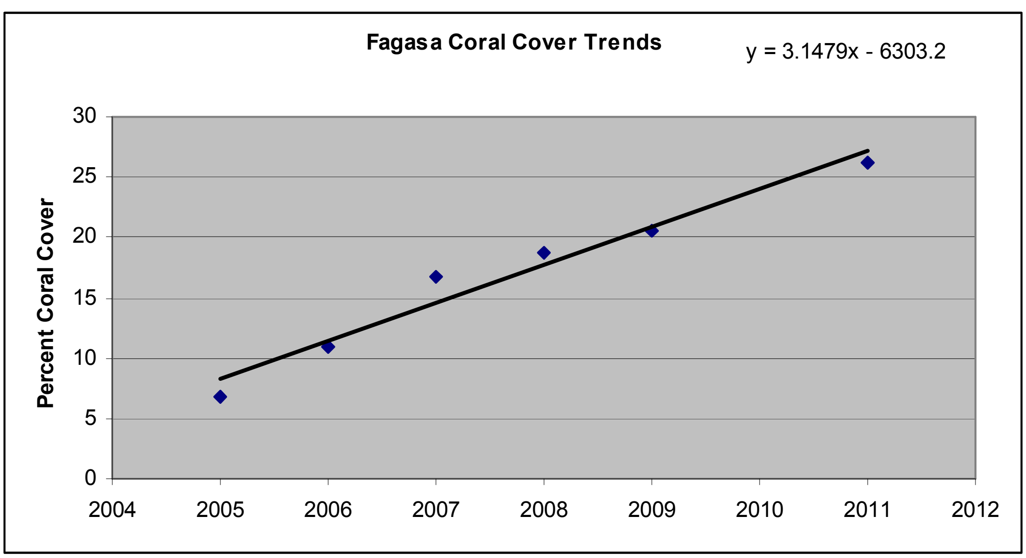


Figure 26. Trend for coral cover at Fagasa with regression equation.



At Tafeu, coral cover gradually increased over the whole six year period of monitoring, as shown in Figure 27. The increase in coral cover came mainly at the expense of decreasing crustose calcareous algae.

Figure 27.

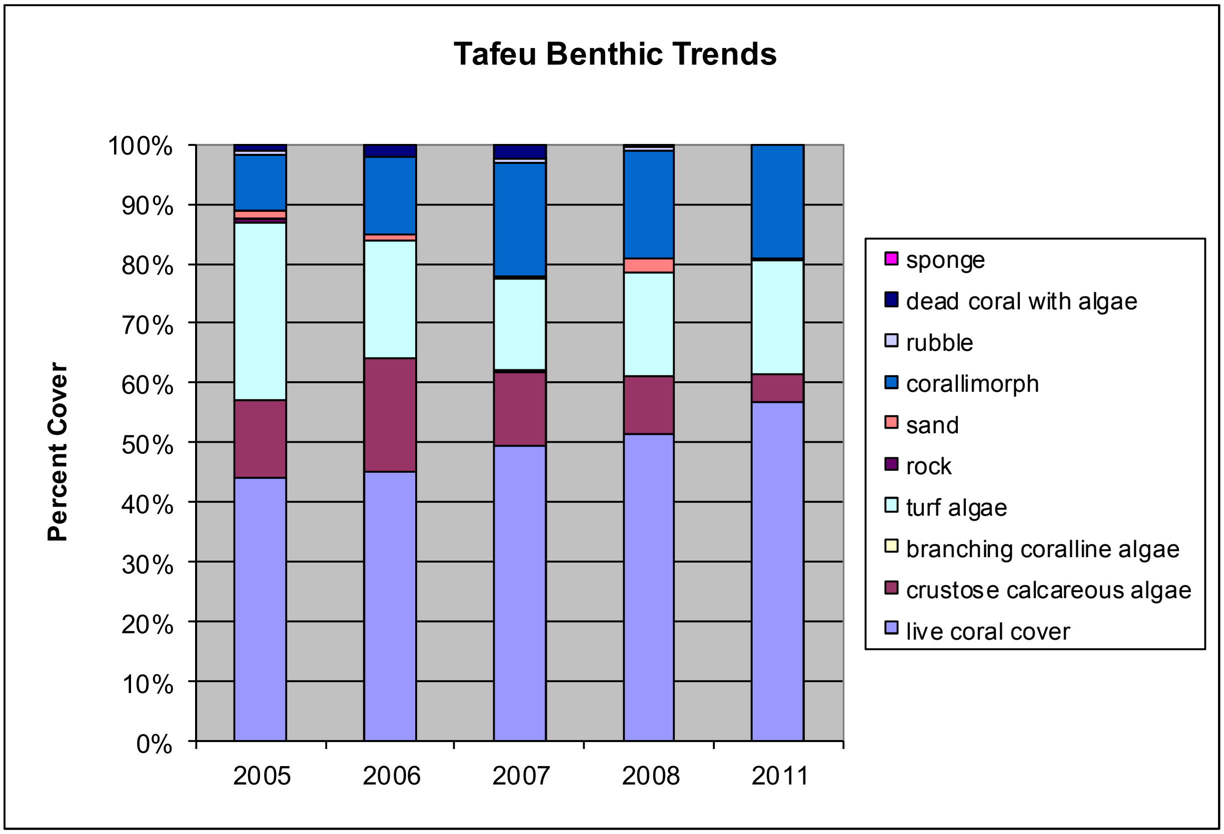
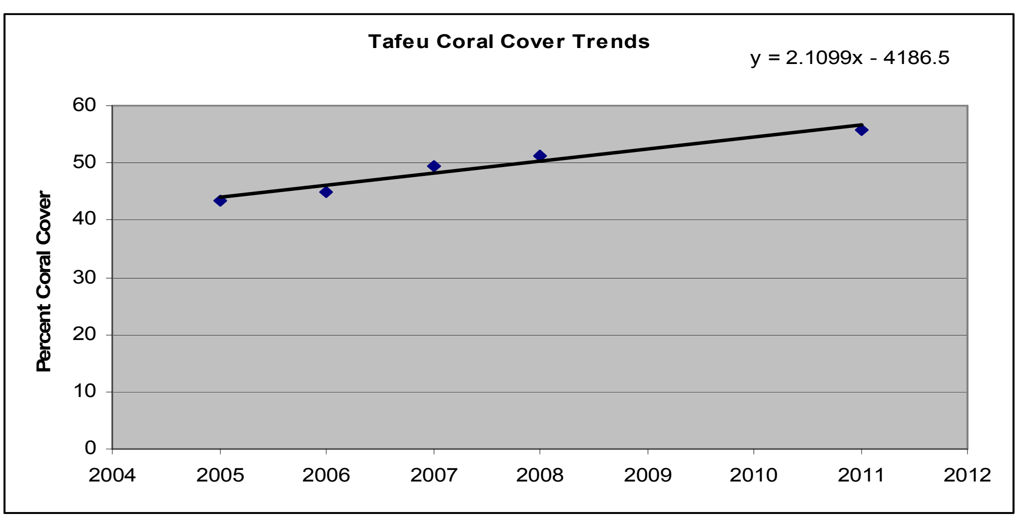


Figure 28. Trends in coral cover in Tafeu with regression equation.



In Vatia, coral cover only decreased slightly over the first four years, but it dropped sharply between 2008 and 2011 (Figure 29). The tsunami of Sept. 29, 2009 reduced live coral cover on the inner half of the bay sharply, and Hurricane Wilma on Jan. 24, 2011 reduced live coral cover on the outer half of the bay sharply. Unfortunately, since we were unable to take monitoring data between these two events (and didn't know the second was coming), data is lacking to determine how much of the recorded drop was due to which event. From observation, that would likely depend on how much of the transects is in the inner bay and how much on the outer bay. The transects roughly straddle the middle of the bay on the south side, so both may have contributed to the recorded decline at the transect site.

Macroalgae increased over the first four years, but was greatly decreased by the tsunami and hurricane.

Figure 29.

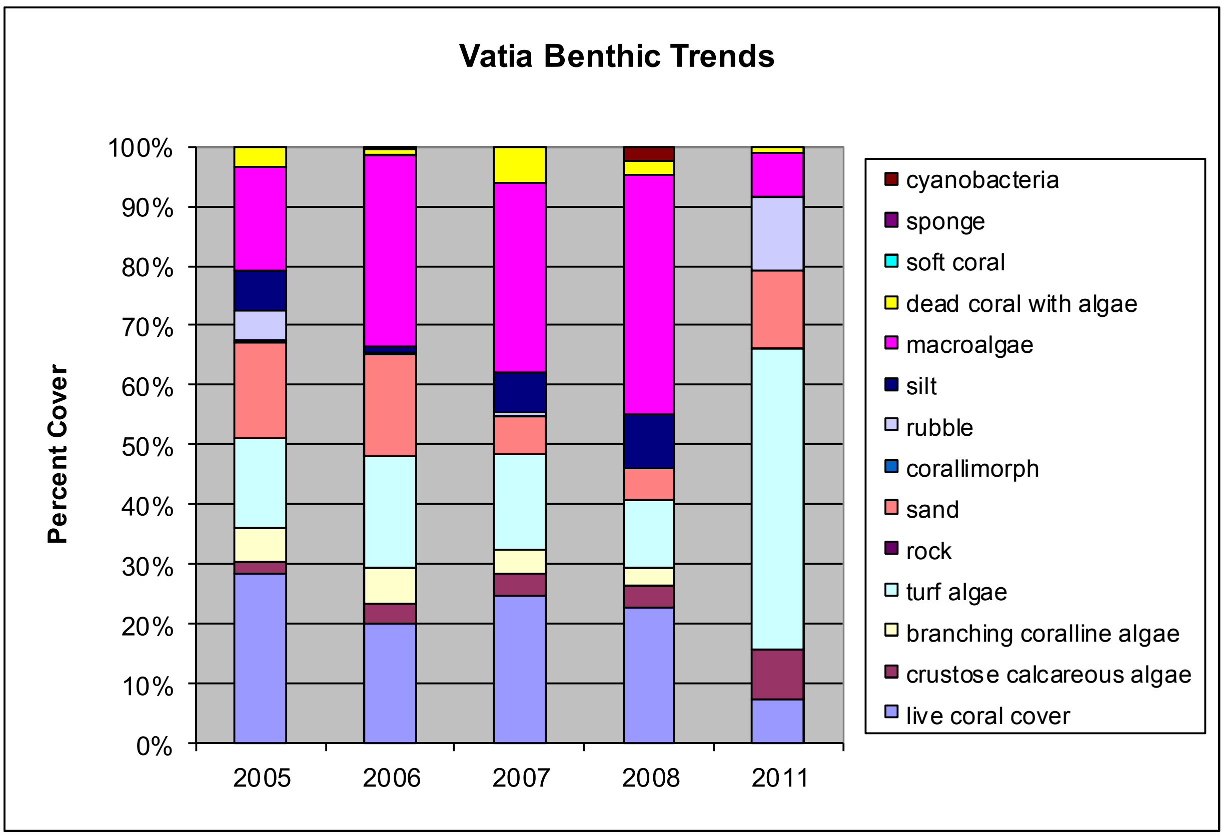
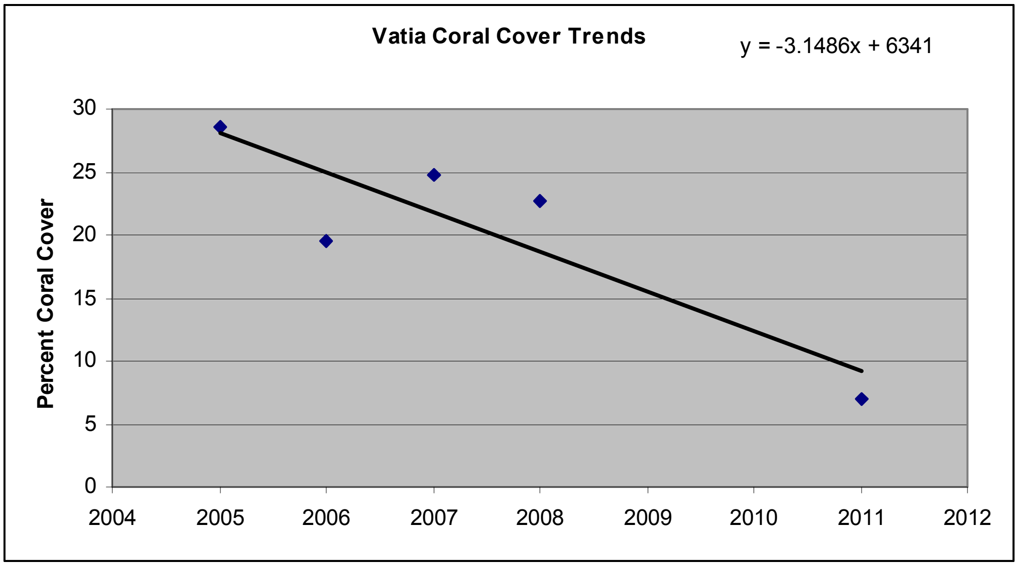


Figure 30. Trends in coral cover at Vatia with regression equation.



At Aunu'u, live coral cover is high, but shows no trend over time. Crustose coralline algae and other cover categories also so no trend.

Figure 31.

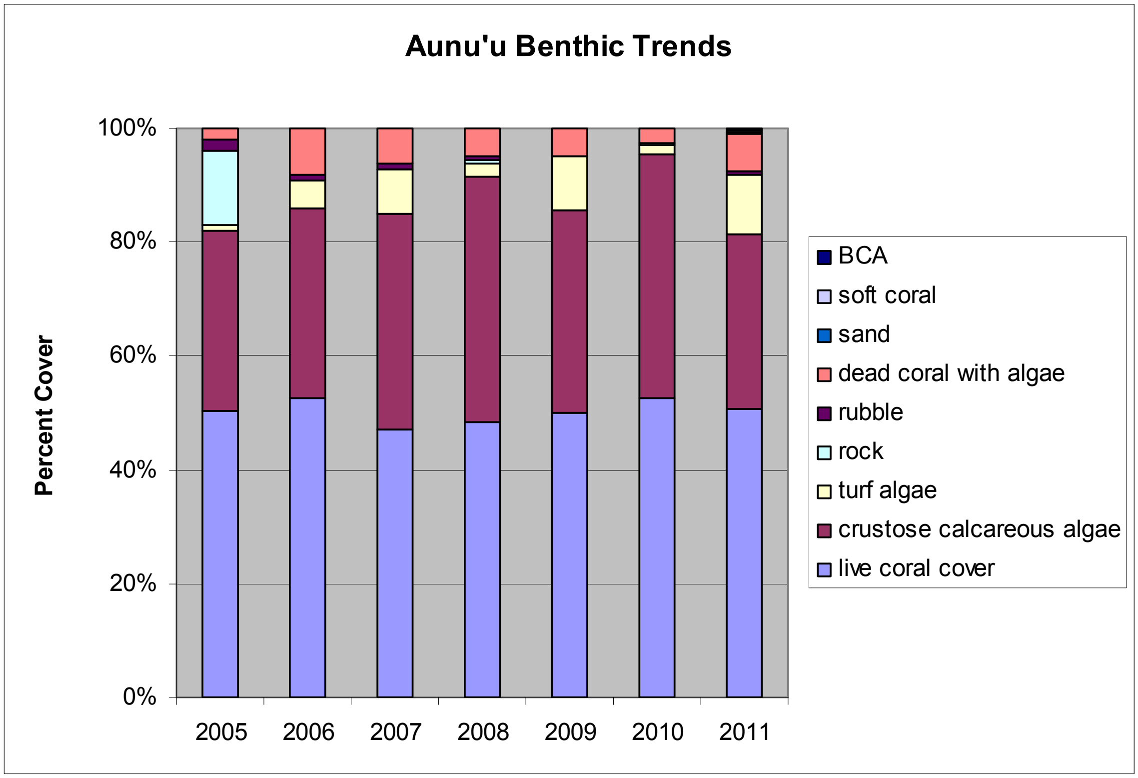
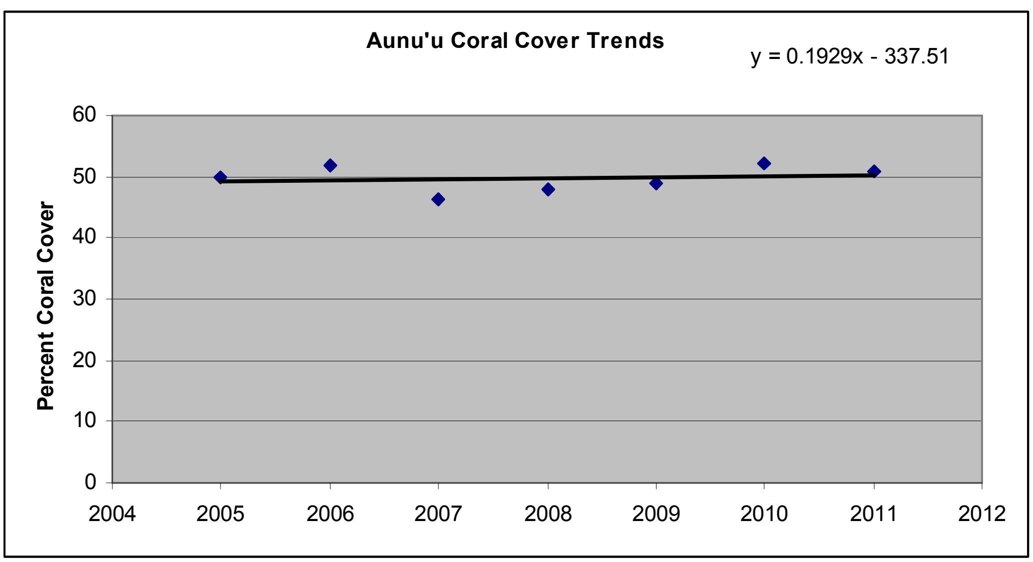


Figure 32. Trends in coral cover in Aunu'u with the regression equation.



Amaua has relatively low coral cover and no trend over time. Crustose coralline algae cover is high and might have increased slightly over time.

Figure 33.

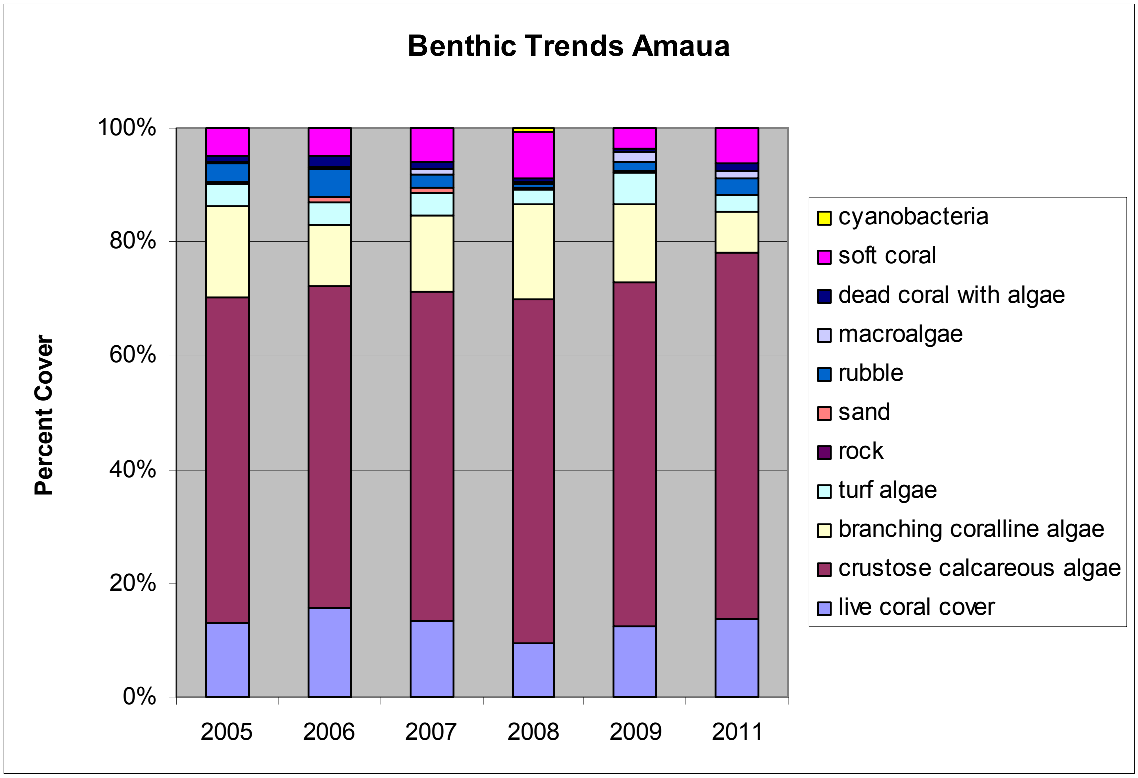
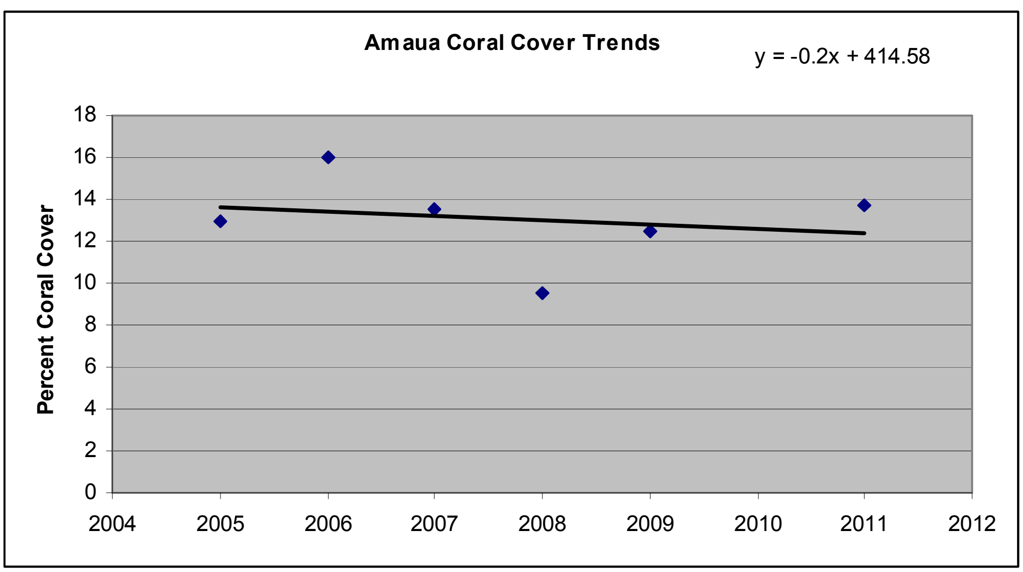


Figure 34. Trends in coral cover in Amaua with the regression equation.



Live coral cover in Faga'alu has remained low and steady for the entire period of the monitoring program. Crustose coralline algae cover has remained high the entire time. Both coral and coralline algae are growing over a bed of rubble from branching coral that appears to be *Acropora*, perhaps *A. nobilis* and/or *A. abrotanoides*. It is not clear what killed that coral, nor when it was killed, since the rubble was already dead and collapsed in 2005 and looked just like it does now. *Acropora* is one of the most sensitive genera of corals to bleaching, disease, crown-of-thorns starfish, and hurricanes, and any of those could have killed the coral that is now rubble. Coralline algae usually indicates conditions that are good for coral, and yet there is no sign of any recovery at all in this area. The rubble is held in place by the coralline algae, and not mobile, so that's not a problem. Deeper on the slope there is high cover of plating corals, *Mycedium* sp., suggesting that growing conditions for corals are currently good. It appears that recruitment is not good enough to produce recovery. It is not clear why recruitment is so low.

Figure 35.

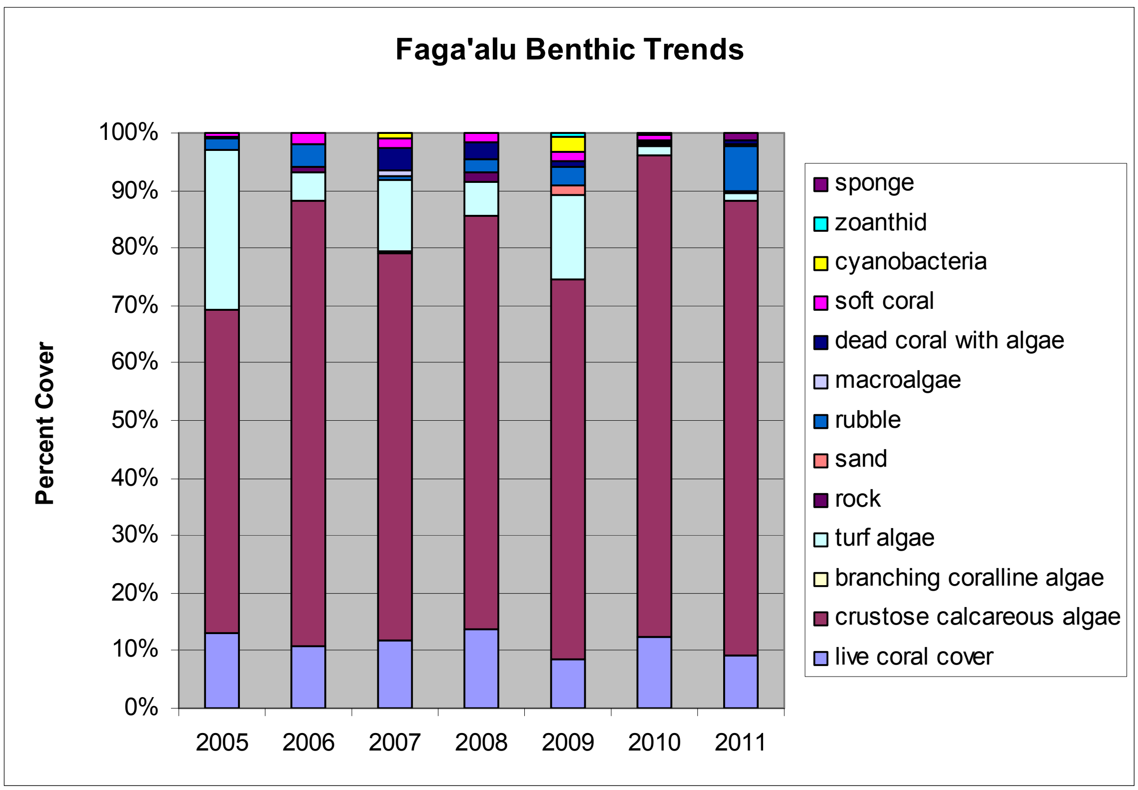
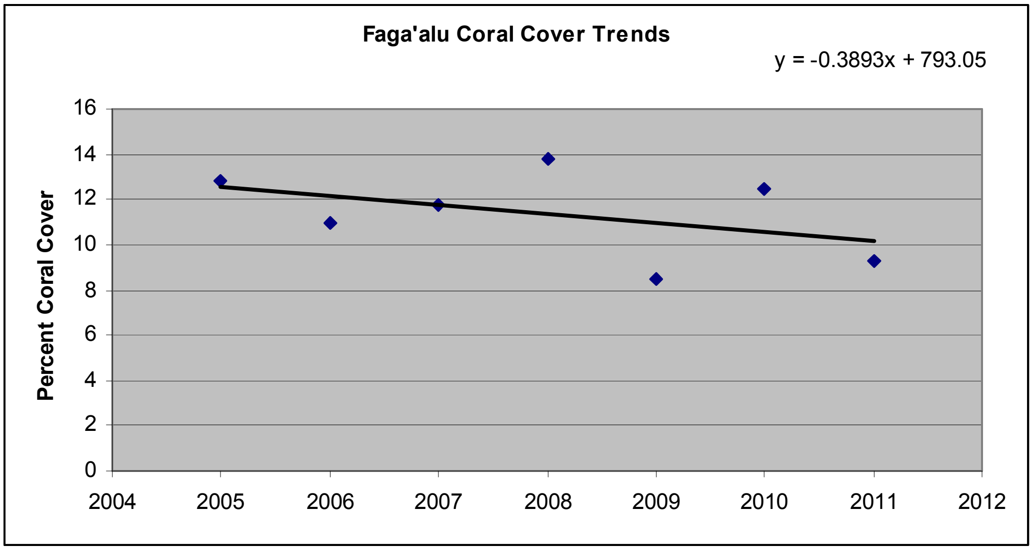


Figure 36. Trends in coral cover at Faga'alu with the regression equation.



Live coral cover at Nu'uuli (Coconut Point) is moderate, and shows no trends. Crustose coralline algae decreased and then increased, while branching coralline algae consisting of *Cheilosporum spectabile* increased and then decreased. It appears that what happened is *C. spectabile*, which is an upright frondose flexible red algae, grew over the crustose coralline algae, covering and hiding it but not replacing or killing it, and then when the *C. spectabile* receded the coralline algae was once again exposed and visible. Why the *C. spectabile* increased and then decreased is not obvious.

Figure 37.

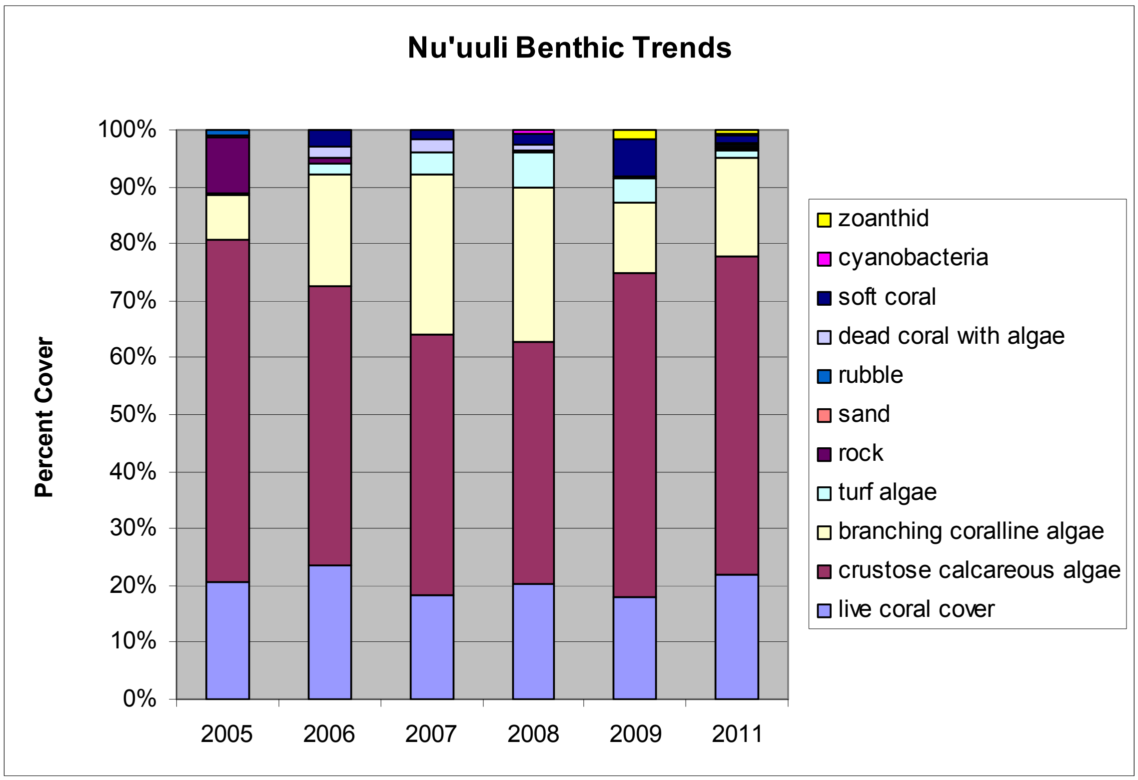
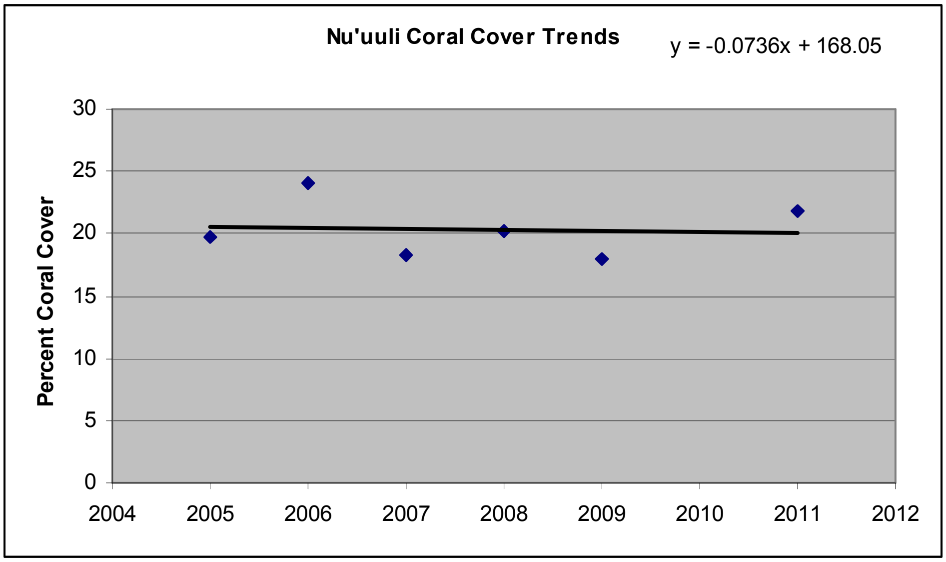


Figure 38. Trends in coral cover at Nu'uuli with the regression equation.



Fagatele Bay has relatively high coral cover. The coral cover recorded decreased in 2006 and 2007, then returned to its former level. It appears likely that the lower coral cover was due to a slightly different transect location. Other than that, the series shows no clear trend.

Figure 39.

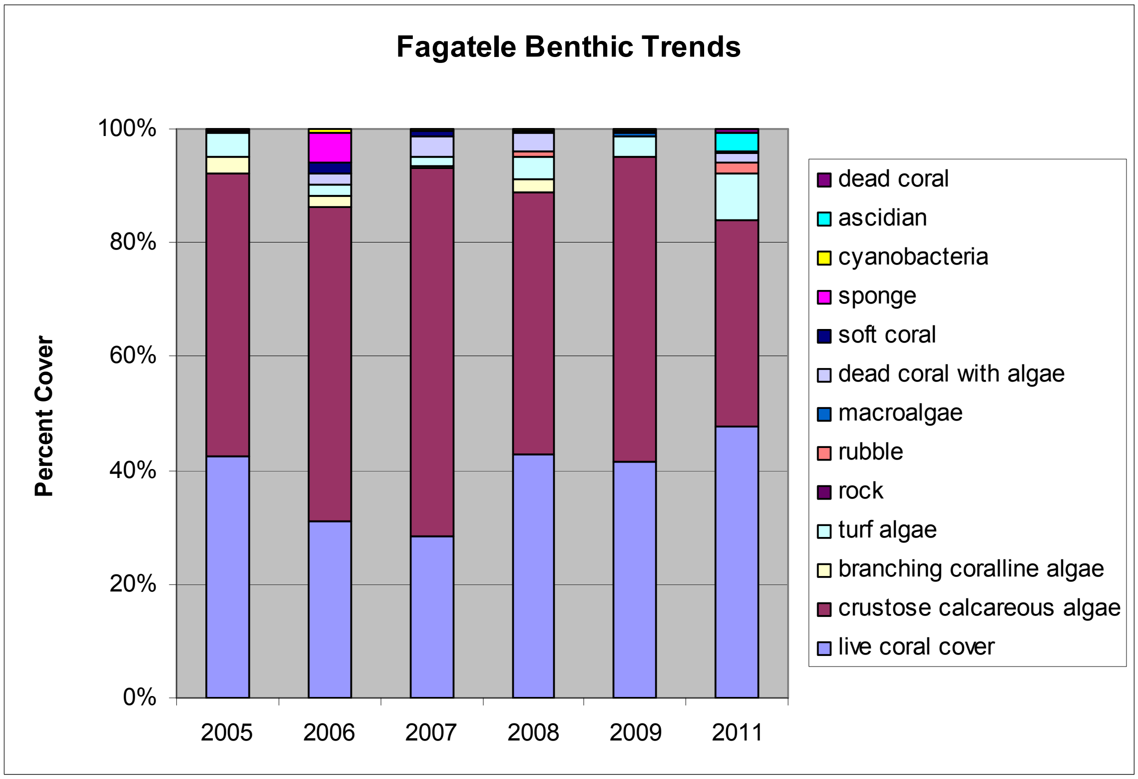
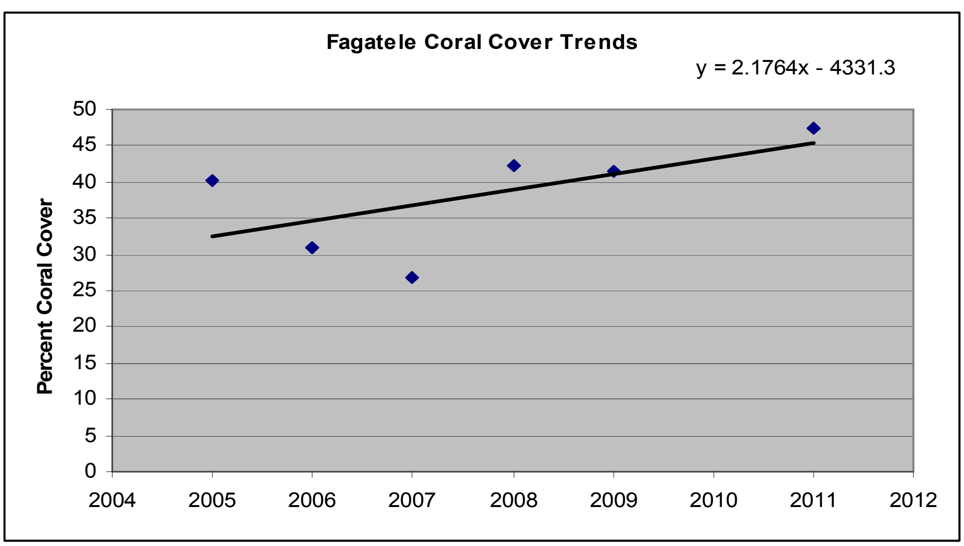


Figure 40. Trends in coral cover at Fagatele Bay with the regression equation.



Coral cover in Leone has been increasing, particularly in recent years. It is now one of the highest coral cover areas in the monitoring program. It is not clear why coral cover is increasing. Coralline algae and other categories have decreased.

Figure 41.

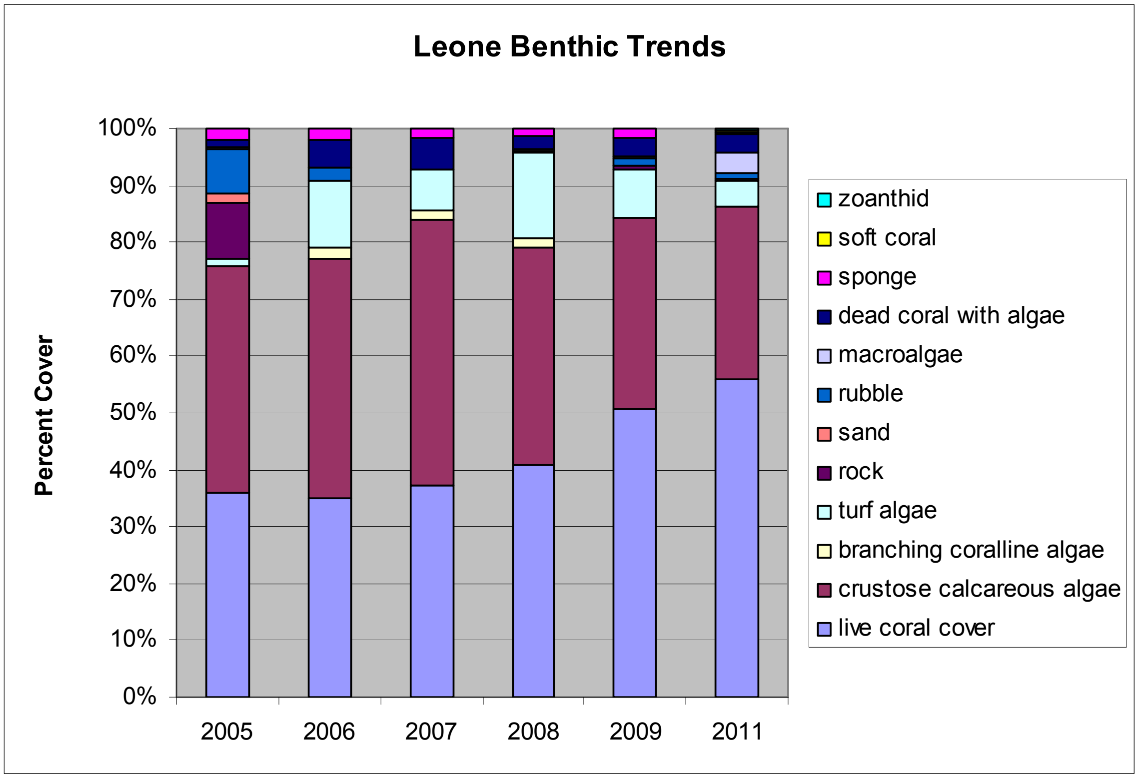
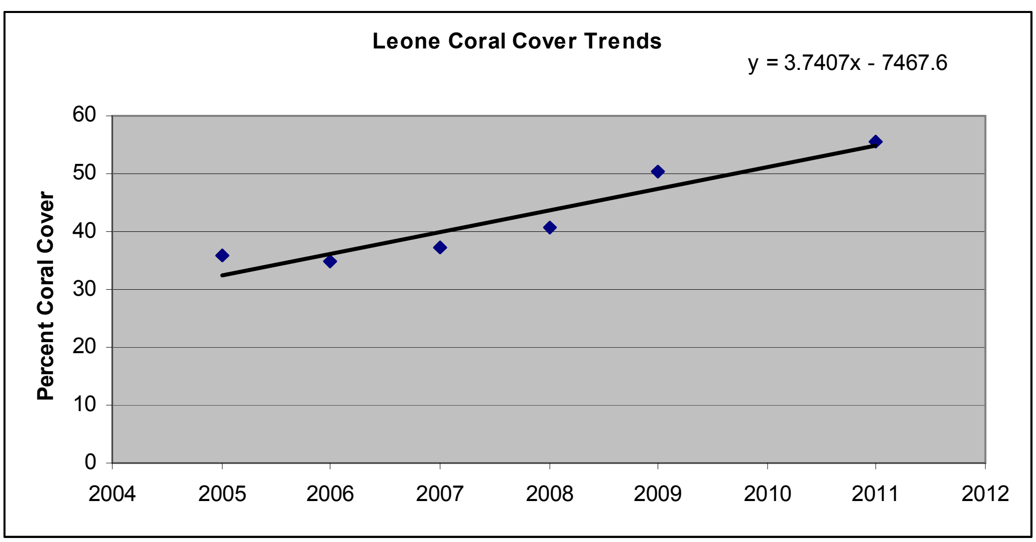
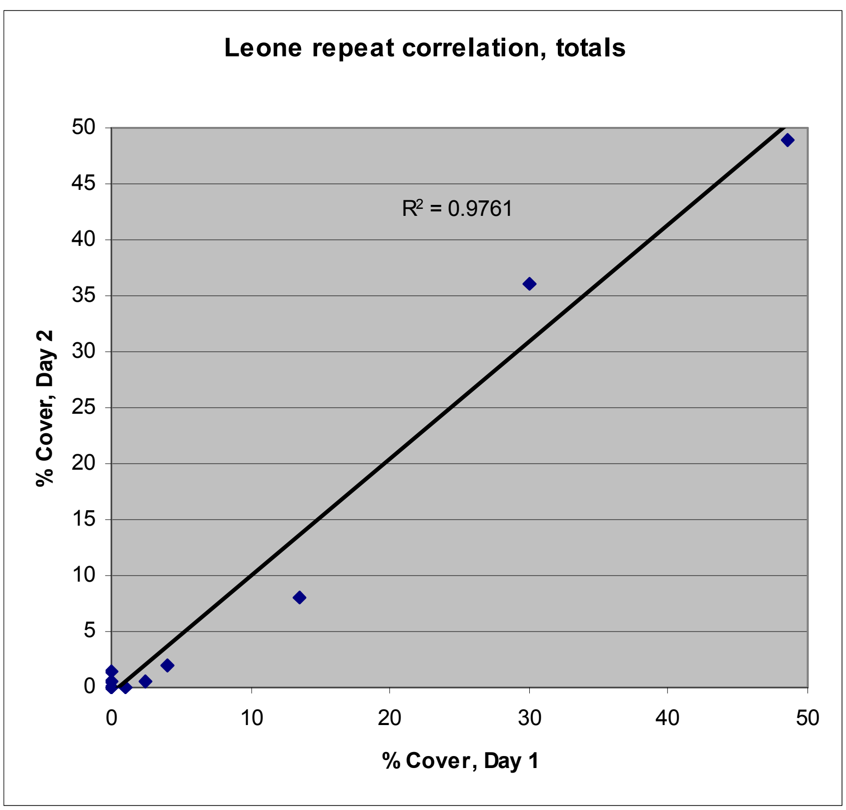


Figure 42. Trends in coral cover at Leone with the regression equation.



A chance opportunity allows a preliminary look at the accuracy of repeat measures of benthic cover. At Leone, the first day in which data was taken in 2011 had surprisingly large surge underwater, stirring up sediment in the water and reducing visibility. Although recording benthic data was difficult due to surge, the low visibility did not hamper data collection. However, for the fish surveyor, the poor visibility made it so that the data collected was based on a much smaller visible area, and thus was not comparable to previous years. After one dive, data collection was suspended for the day. The full data set was collected on another day. The net result was that data from the first two transects were collected twice, and there was not enough time between the two data collection days for any changes in benthic cover. Thus, comparing the two sets of data can provide a direct estimate of variation in repeat surveys, without any actual change in benthic cover. Figure 43 shows the correlation between the average benthic cover values measured in the two transects on the first day with the values recorded on the second day. The correlation is very high, r = 0.9880, out of a maximum possible value of r = 1.0. This was highly significant ($p < .001$). Most points are within about 1% of the same value from one day to the next, but two differ by about 5%. The mean difference per point was 2.38%. So this method can produce high repeat accuracy. The first two transects in Leone have a physical marker for the start of the transects that probably reduces spatial variation in replication, and which other sites do not have. So the repeat accuracy for these transects may be higher than for other sites.

Figure 43.



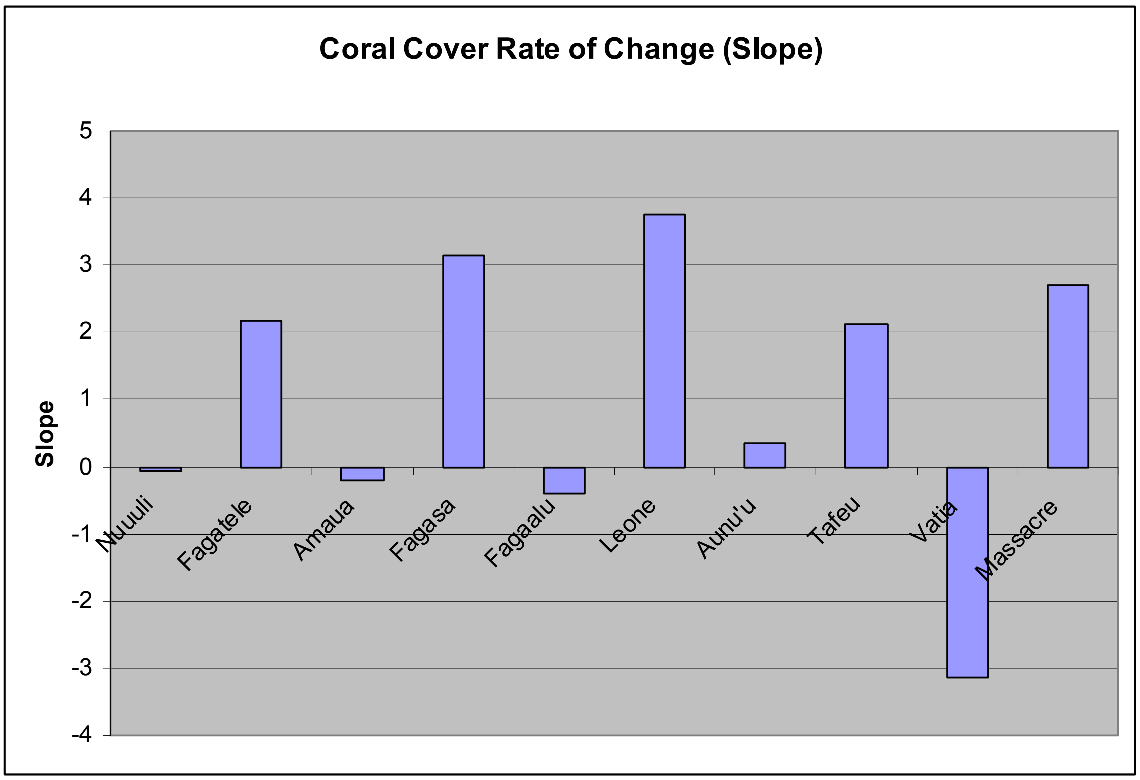
Coral cover at individual sites show either an increase over the study period, are steady, or show a decrease. Table 10 summarizes the different trends at different sites. Just one site showed a decrease, five sites were steady, and four sites showed increases. This indicates that while average coral cover is increasing, some sites show increases and others no change. Reefs on the Great Barrier Reef show a similar pattern (Sweatman, 2011). That seems more likely there, where reefs are much farther apart and events that affect one site seem less likely to affect other sites.

Table 10. Summary of Trends at individual sites.

	decrease	steady	increase
Masacre			X
Fagasa			X
Tafeu			X
Vatia	X		
Aunu'u		X	
Amaua		X	
Faga'alu		X	
Nu'uuli		X	
Fagatele		X	
Leone			X
total number	1	5	4

A more quantitative representation of this is presented in Figure 44. This figure graphs the slopes of the lines in the graphs for each individual site shown above. It shows three categories as well, upward slopes, nearly no slope, and downward slope. The only difference is that Fagatele is shown with a strong positive slope. In Table 10 it was categorized as steady based on the opinion that the second and third years showed lower coral cover because the transect may not have been in the same location. But both considerations lead to the same conclusion, that there are three discreet categories of coral trends with little suggestion of any intermediates. It may be that the lack of intermediates is just a chance occurrence. On the Great Barrier Reef, towboard surveys show a long term decline in coral cover, but most of the decline was confined to a relatively small set of sub-regions, though individual sites showed considerable variation (Sweatman et al. 2011).

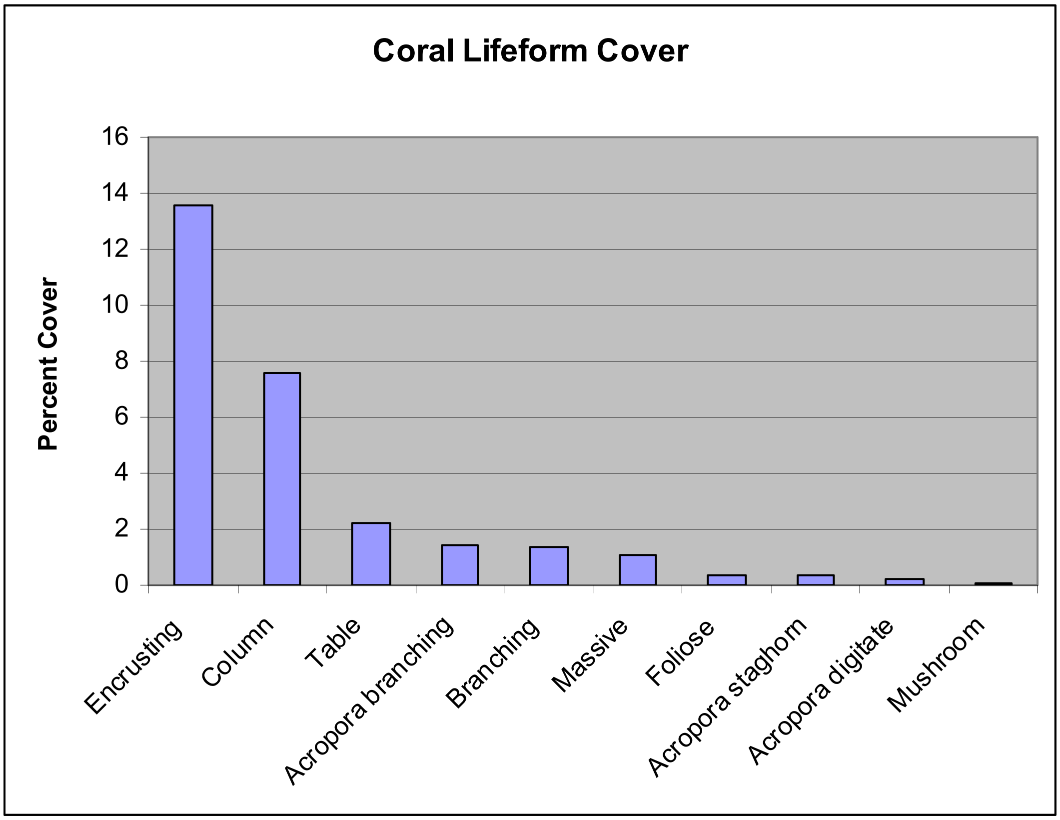
Figure 43.



Coral Life forms

The life forms of corals are their shapes. The mean cover of the different coral lifeforms in transects is shown in Figure 45. Encrusting continues to be the most common lifeform, followed by column, table and *Acropora* branching.

Figure 45.



Genera

Figure 46 shows the mean cover of the most common genera. *Porites* and *Montipora* were the two most common genera, as in past years, followed by *Acropora*, *Pavona*, and *Pocillopora*.

Figure 46.

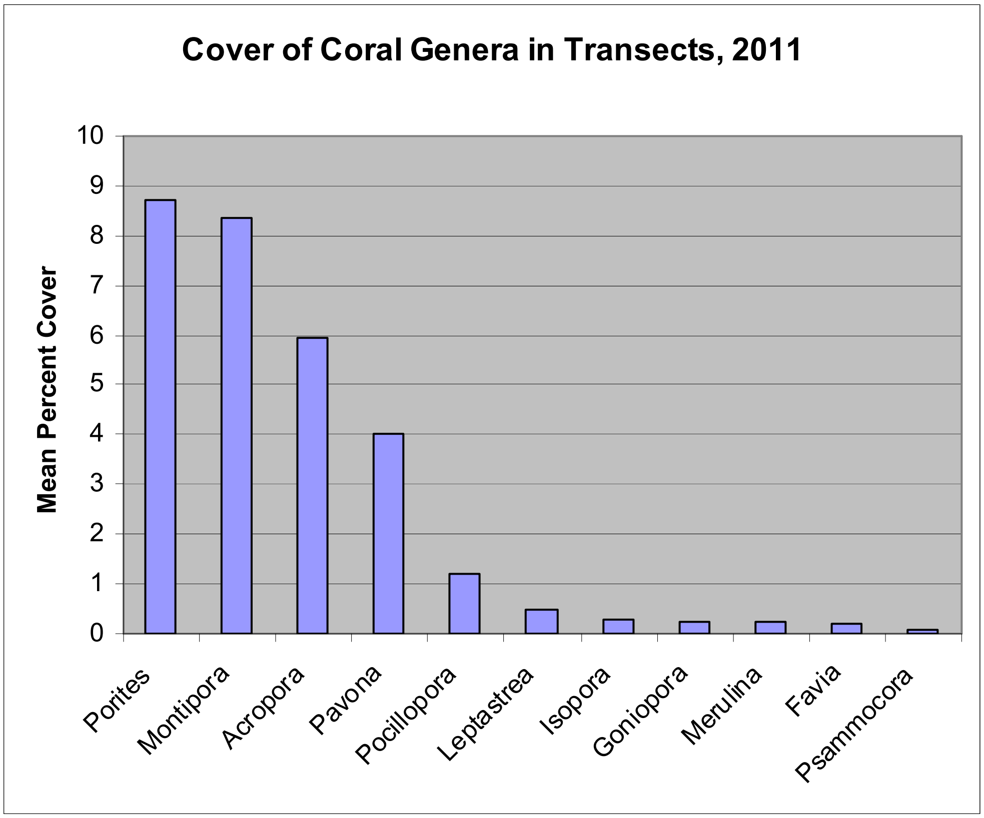


Figure 47 shows trends in the total number of coral genera in all transects. There has been a small decline over the years of this monitoring program, for reasons that are unclear.

Figure 47.

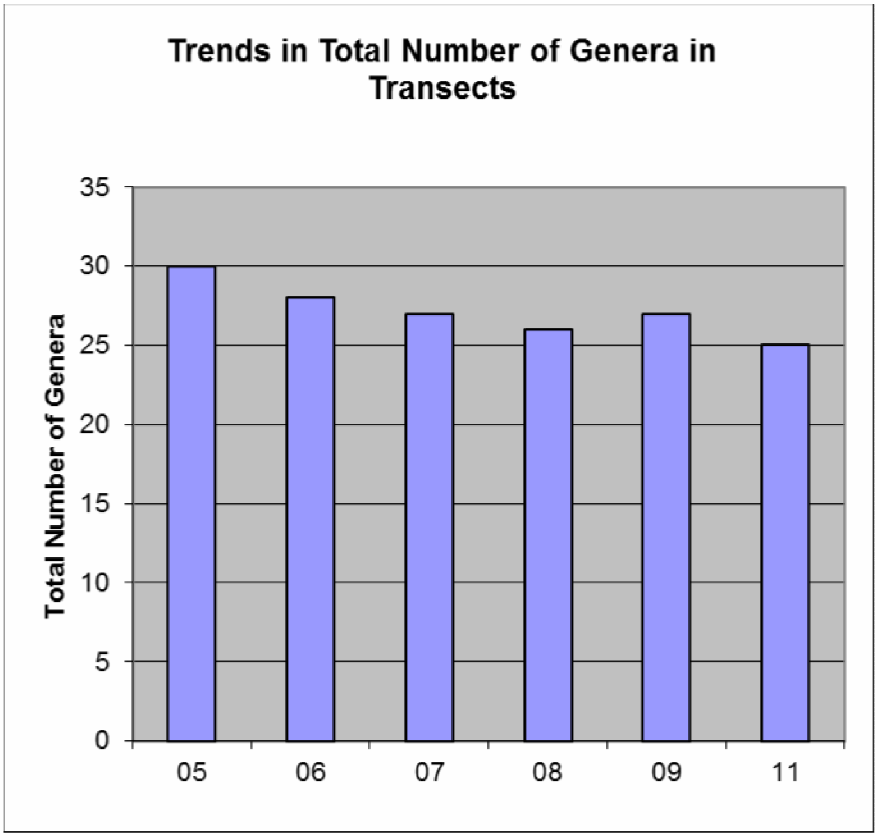
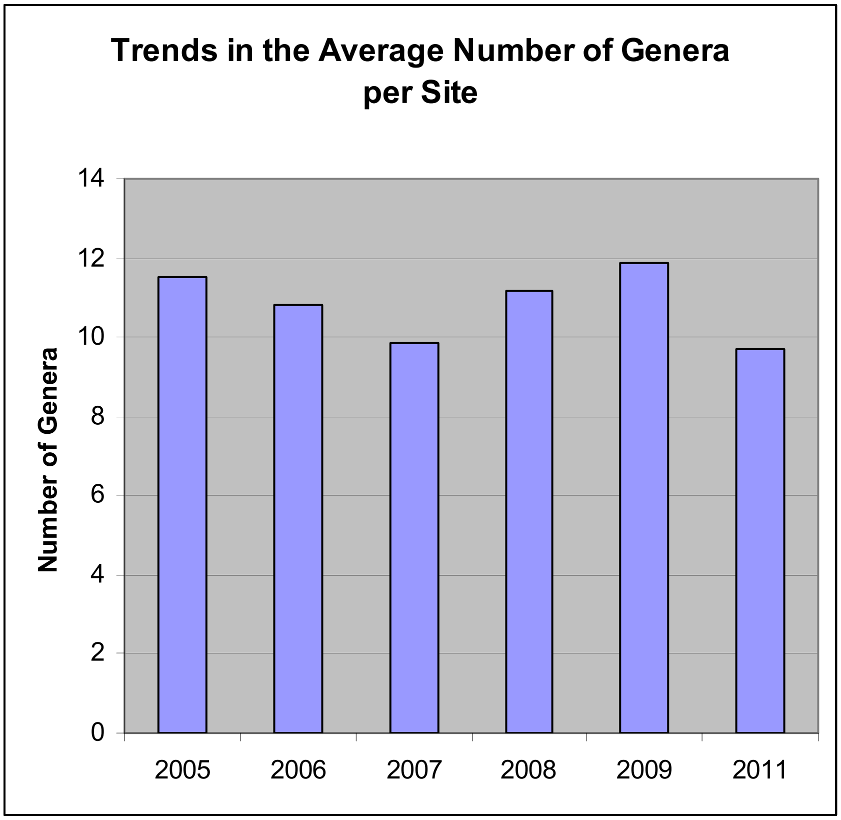


Figure 48 shows the average number of genera per transect. Note that it is a much smaller number than in Figure 32, that is because different sites will have different genera, so the total is larger than the average for individual sites. There appears to be little or no trend.

Figure 48.



Coral Species

Figure 49 shows the cover of the most common coral species in the transects. *Porites rus* and *Montipora grisea* are the two most common species, and *Pavona varians* is the third most common, as in previous years. *Montipora grisea* was referred to as "*Montipora* encrusting" in previous years, because skeleton samples had not yet been examined to confirm its identity.

Figure 49.

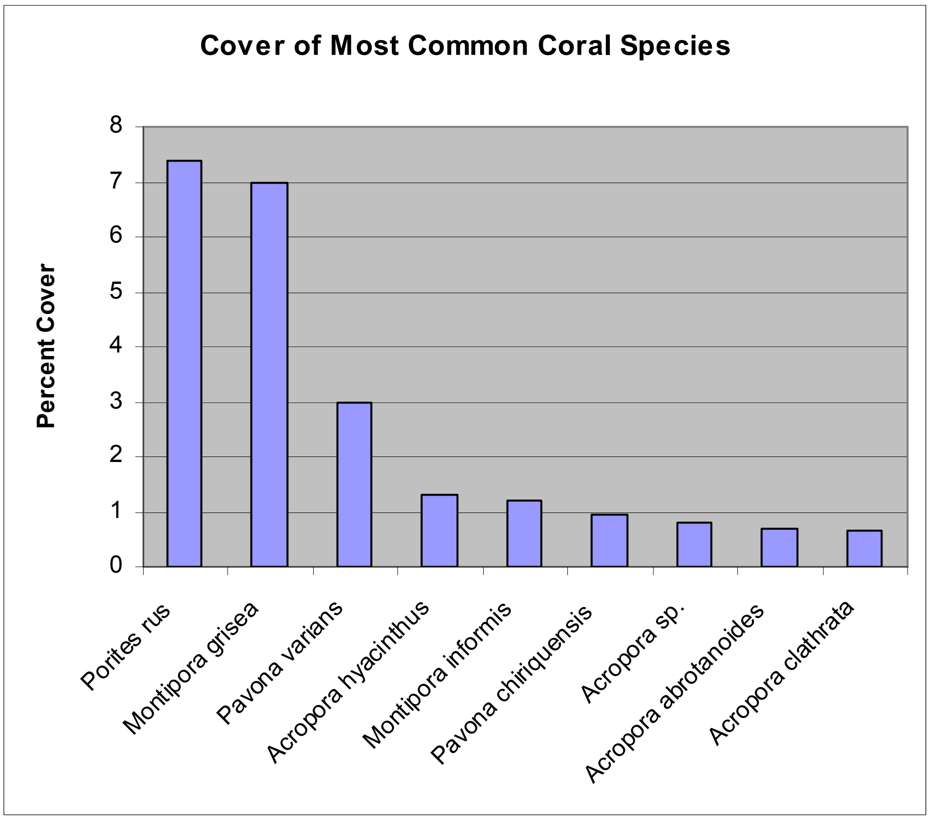


Figure 50 shows trends in the total number of coral species in transects. There appears to be little or no trend, though 2011 was lower than previous years.

Figure 50.

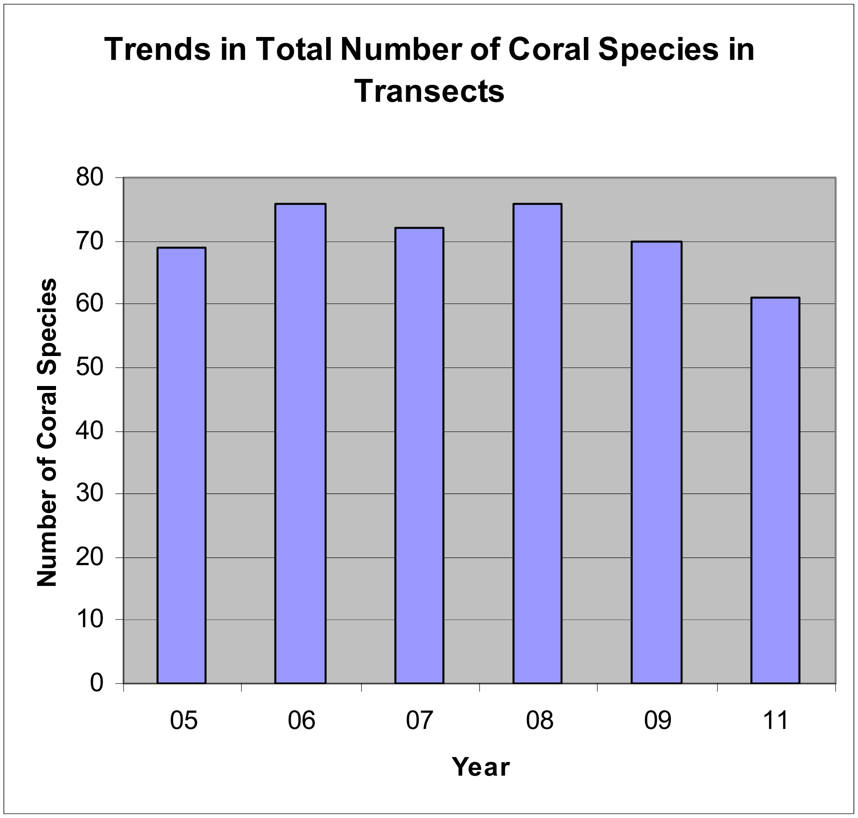


Figure 51 shows trends in the average number of coral species per site. There was no obvious trend.

Figure 51.

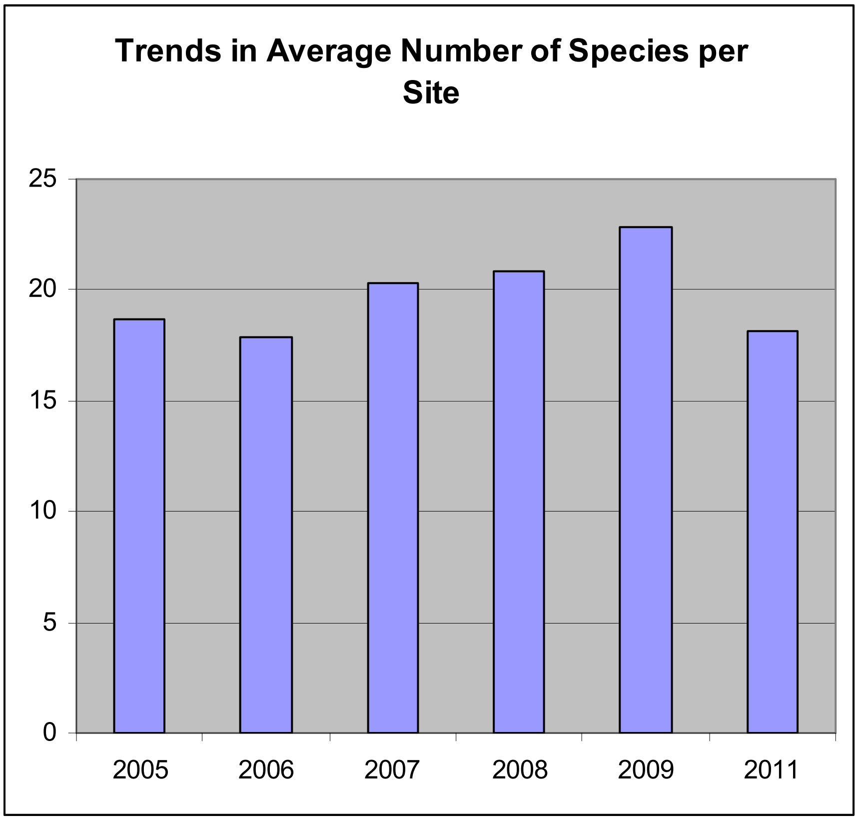


Figure 52 shows that the number of coral species is higher on the south side of Tutuila than on the north side, and that difference has been maintained across the years of the monitoring program. It is not clear why the south side should have more coral species than the north side.

Figure 52.

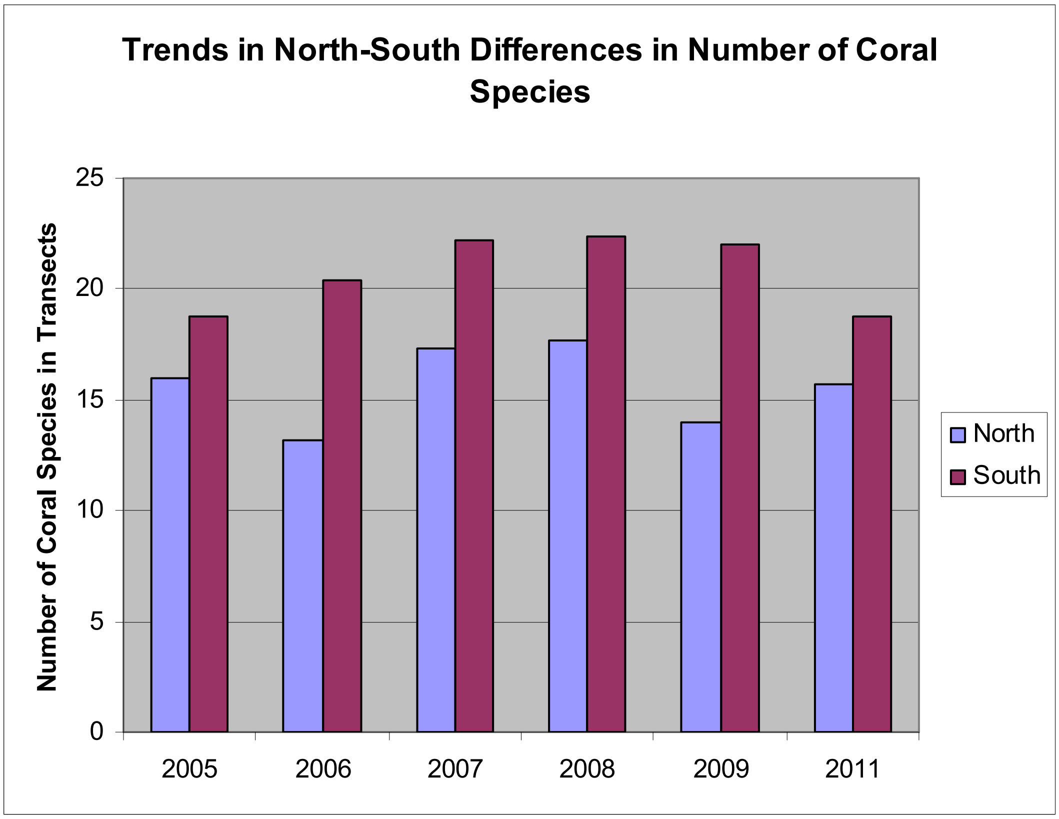
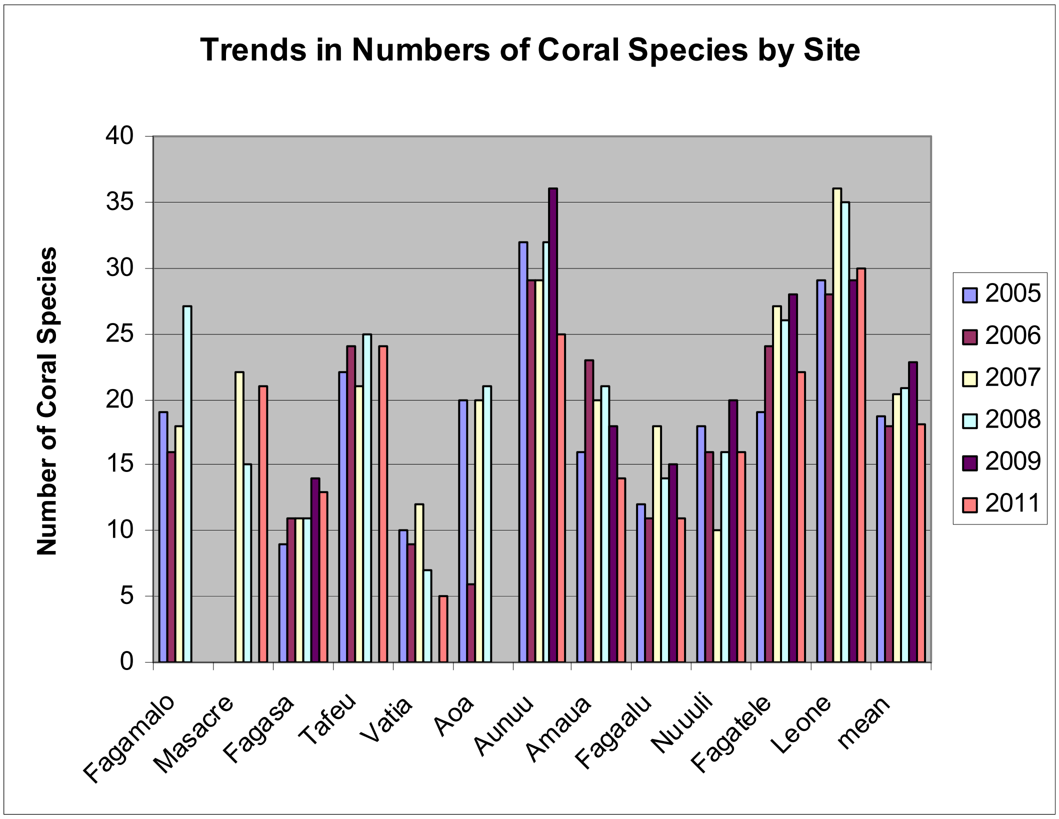


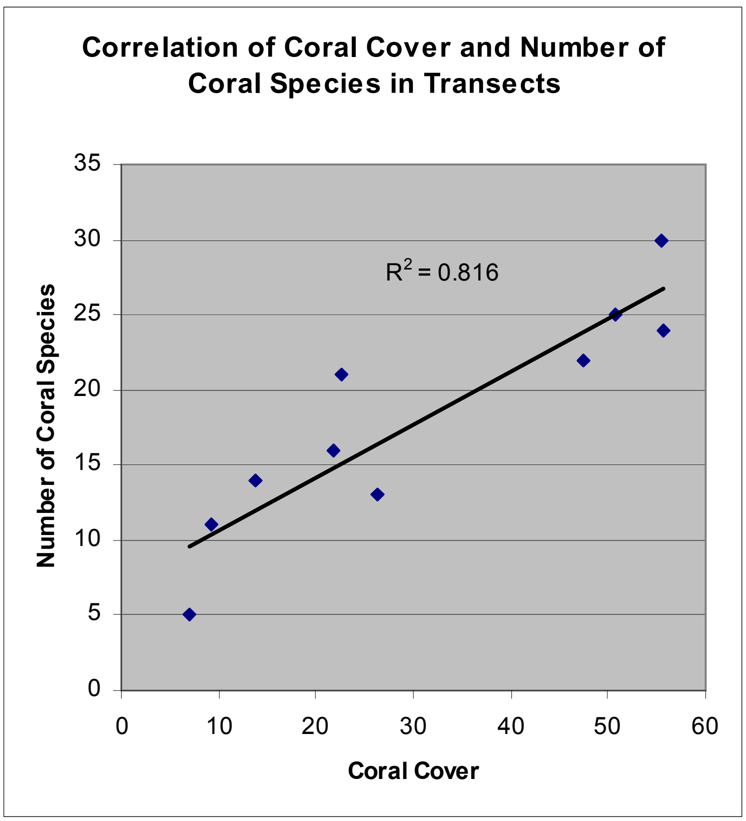
Figure 53 shows trends in the number of coral species by site. The graph shows that not only do some sites like Aunu'u and Leone have higher numbers of species than other sites like Fagasa and Vatia, but those differences are present year after year, in spite of some variation from year to year in the number of coral species found in the transects.

Figure 53.



The sites with high coral diversity shown in Figure 52 are also the sites with the highest coral cover, as shown in Figure 1. Also, the site with the lowest diversity are among the sites with the lowest coral cover. This was explored with a scattergram shown in Figure 54. Figure 53 shows a strong correlation between coral cover and the number of coral species, r = .9033, which is highly significant ($p < .001$). This makes sense, since the number of species will increase with sample size as more coral colonies are sampled. Sample size can be increased by increasing the area recorded, or be increasing the density of corals in a fixed size sample area. In this case, higher coral cover measured in the transect corresponds to a larger sample of corals, and so we expect a larger number of species.

Figure 54.



Coral Biodiversity Data

Biodiversity dives are quite different from transect dives. Instead of laying tapes and recording what is under the tape, an hour is spent on a roving dive, moving upward from the bottom of the reef to the top, recording all the coral species that can be found. This technique covers a much larger area than the transects, but because there is no measure of the area covered, and the numbers of colonies of different species are not recorded, quantitative measures of the abundance of the corals cannot be calculated. Estimates of the abundance of each species are recorded after each dive, on a 5 point scale. So this technique is a way to get data on many more, rare, species by covering a larger area, but produces low accuracy data.

Figure 55 shows the number of coral species found in one hour roving biodiversity dives at core sites, and also at several sites within Pago Pago Harbor. The mean number of species in the core sites (outside the harbor) was 61, and for the sites in the harbor it was 40 (shown more clearly in Figure 41). There was no overlap in the number of species in the two groups. Several published studies (Edinger et al. 1998; De'ath and Fabricius 2010; Houk et al. 2010; De'ath et al. 2012) have reported that coral diversity is lower at polluted sites, and the harbor has certainly had higher levels of nutrients and chemical pollutants than outside the harbor. Thus, it appears that sites within the harbor have lower coral diversity, and the cause is likely to be nutrients and/or chemical pollution. This is the first time this has been reported.

Figure 55.

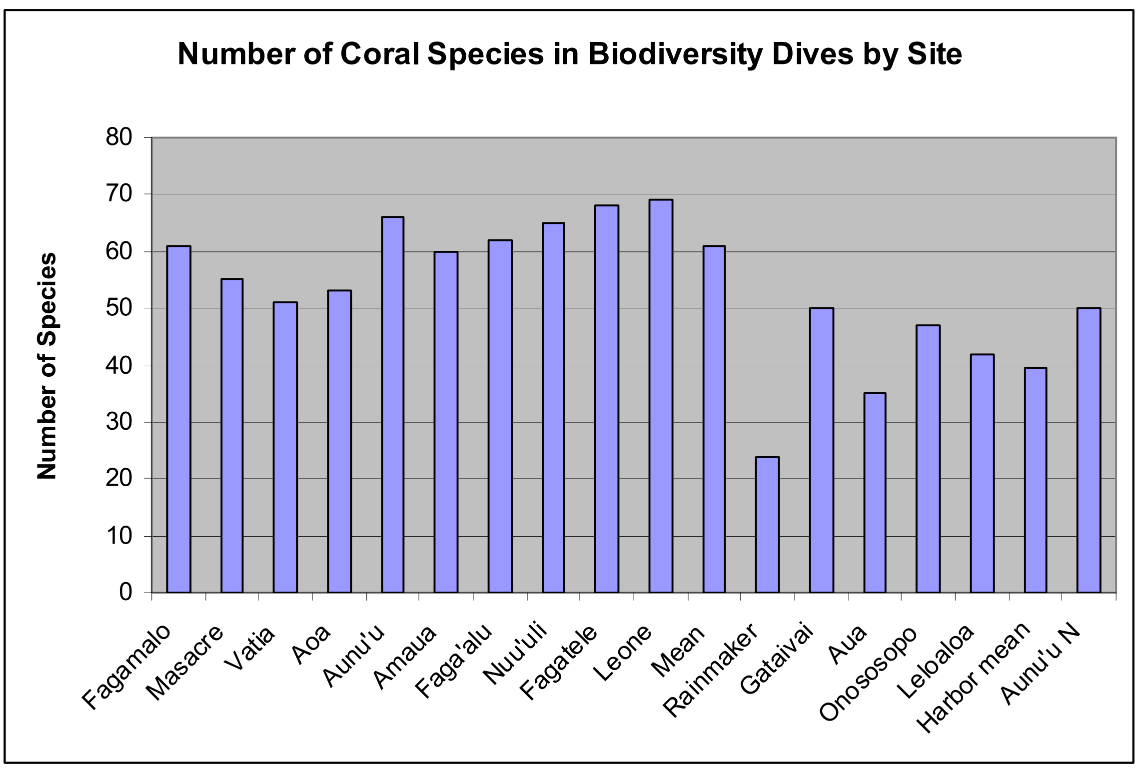
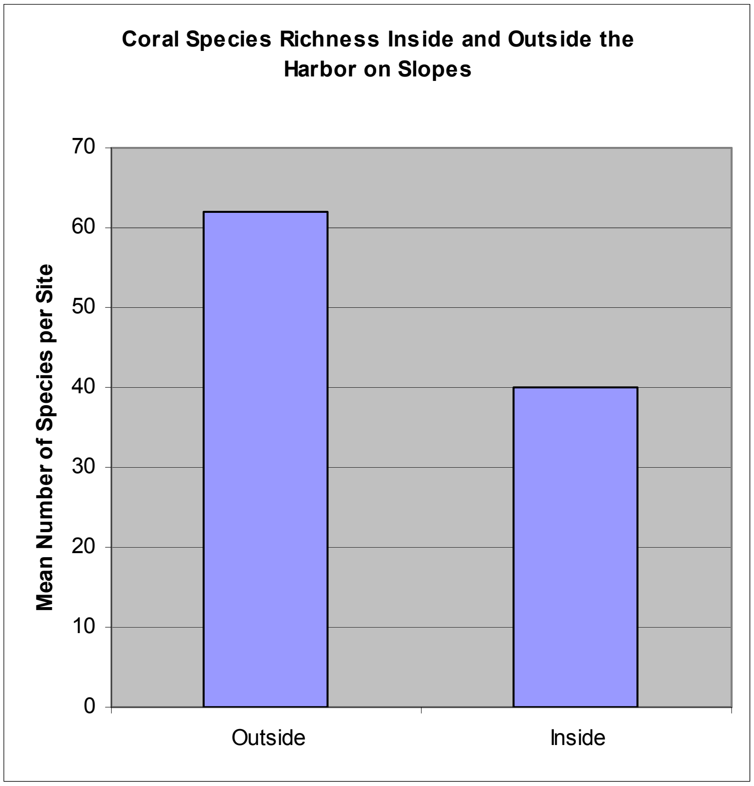


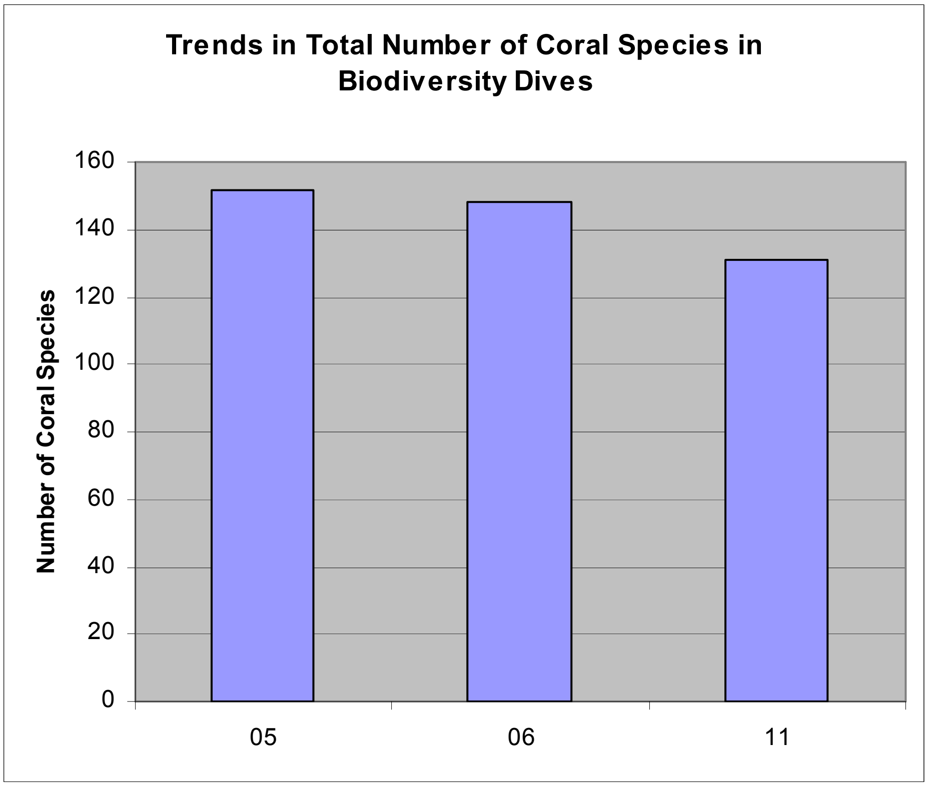
Figure 56.



Coral Species Richness Inside and Outside the Harbor on Slopes
Mean Number of Species per Site
70
60
50
40
30
20
10
0
Outside
Inside

Figure 57 shows trends in the total number of coral species recorded in biodiversity dives, from sites outside the harbor. There appears to be a downward trend.

Figure 57.



The number of sites that were surveyed in biodiversity dives was less in 2011 than in the two previous years that data were taken. The number of coral species recorded increases with increasing area surveyed, so more species should be recorded if a larger area or number of sites (and thus area) are surveyed. In Figure 58, the number of coral species is divided by the number of sites, to equate for area surveyed. Although this graph shows a decline, it is not very large.

Figure 58.

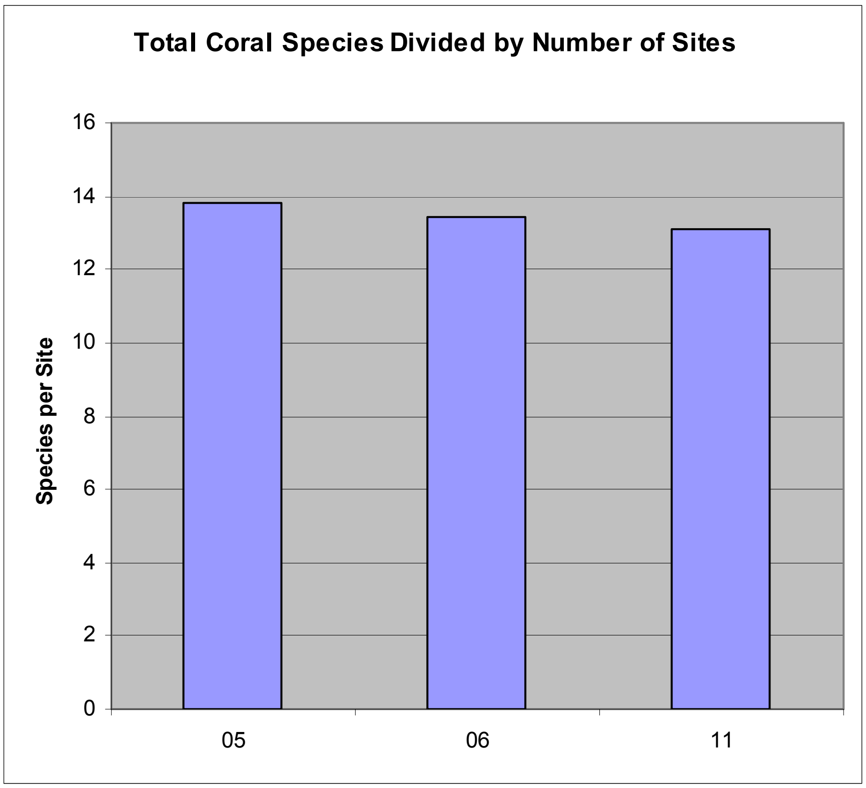
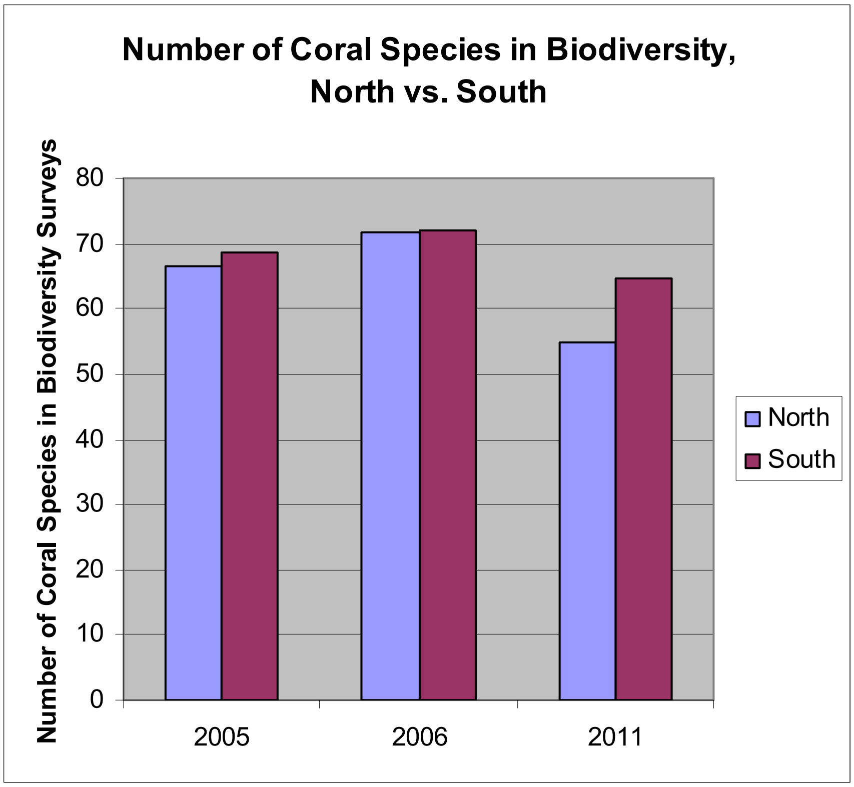


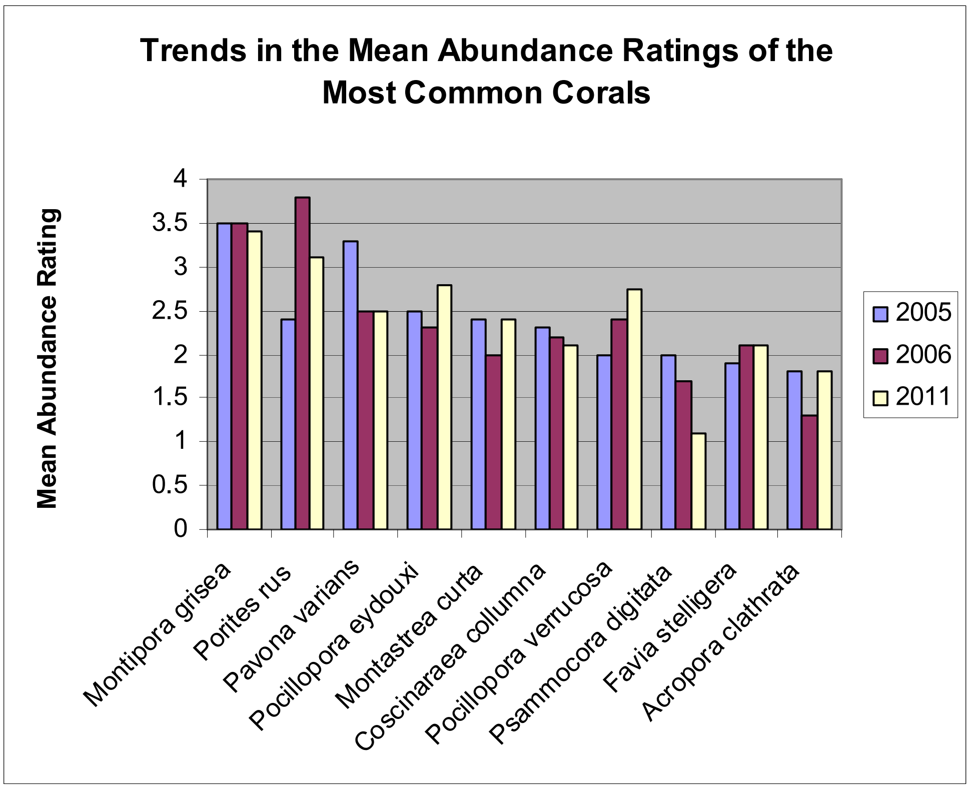
Figure 59 shows trends in the mean number of coral species per site found on sites on the north side with the mean number found on the south side. Larger numbers of species were recorded on the south side than the north each year, much as with the number of species in transects. It is not clear whether there is an overall trend or not.

Figure 59.



In Figure 60, trends in the mean abundance ratings of the most common coral species are shown. The three most common corals, *Montipora grisea*, *Porites rus*, and *Pavona varians*, were also the three most common species of corals in transects (Figure 34). This strengthens the conclusion that these are three of the most common species around Tutuila. It appears that much of the variation from year to year is random. Further, it seems likely that much of the annual variation is sampling error not real changes in abundances.

Figure 60.



Invertebrates

Figure 61 shows the number of invertebrates per unit area, averaged over all sites.

Figure 61.

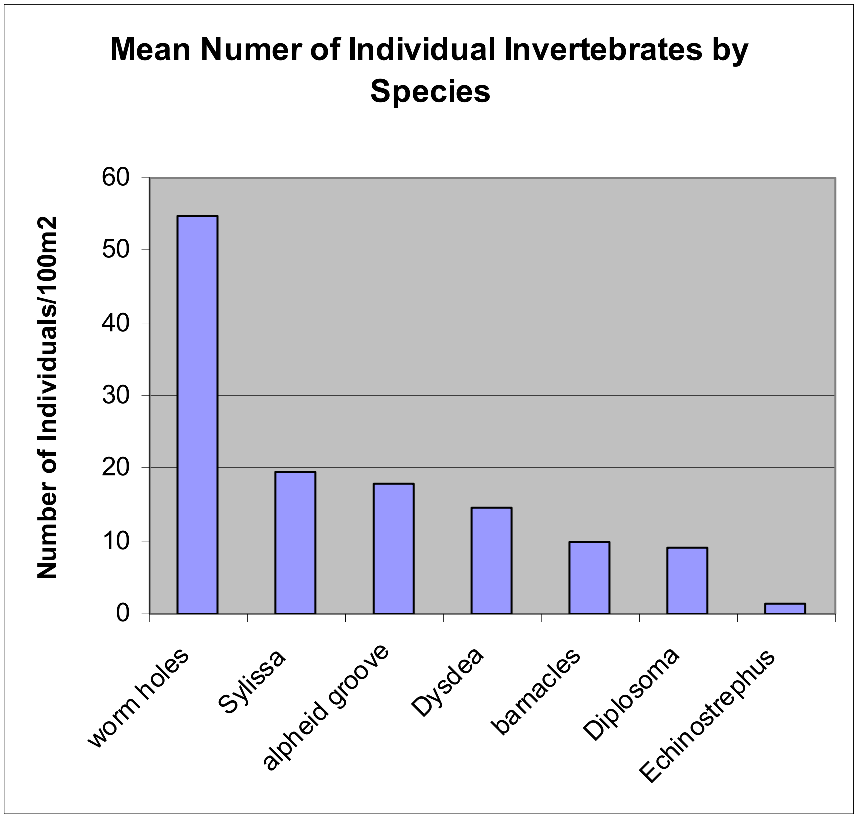


Figure 62 shows the mean density of invertebrates over time. The total number of invertebrates recorded increased each year. However, this is quite unlikely to represent actual increases in numbers of visible invertebrates. More likely it reflects an increasing ability of the recorder to find invertebrates in the belt transect. Invertebrates are widely spaced on most of these reefs, of very different types, and a "search image" is necessary to find them. In other words, it helps to know what you're looking for. Worm holes only were noticed in 2009, and in 2011 the number recorded increased greatly. Again, this is due to increasing recognition of these invertebrates.

Figure 62.

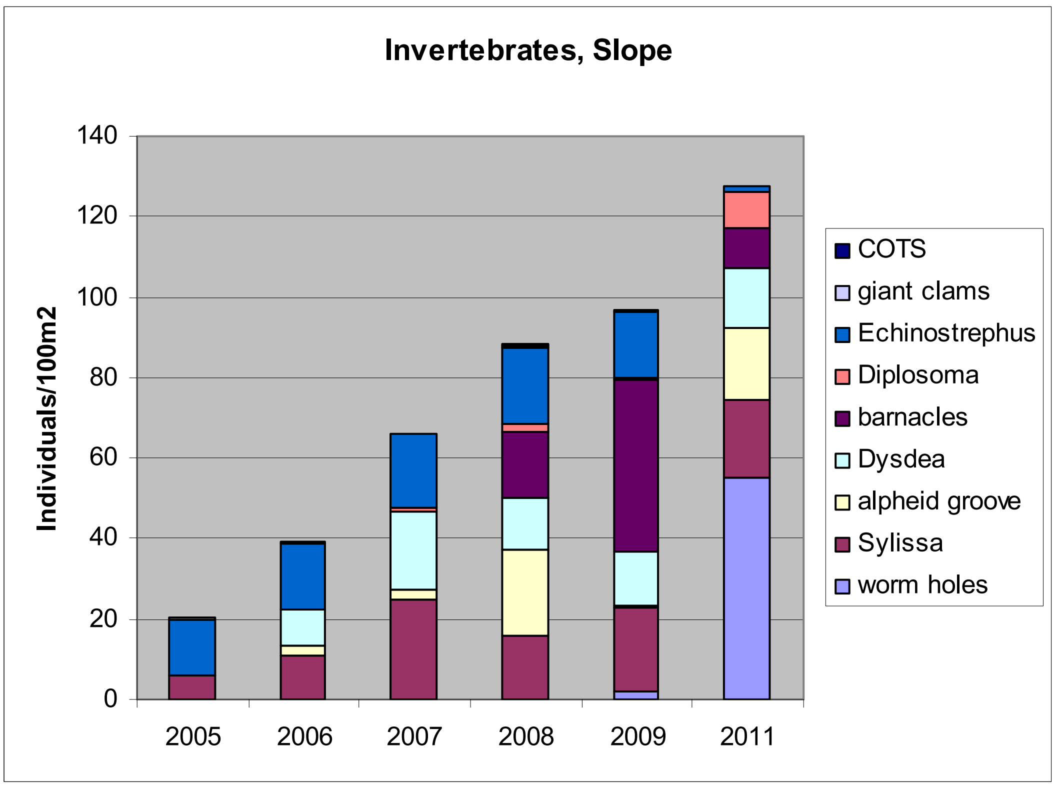
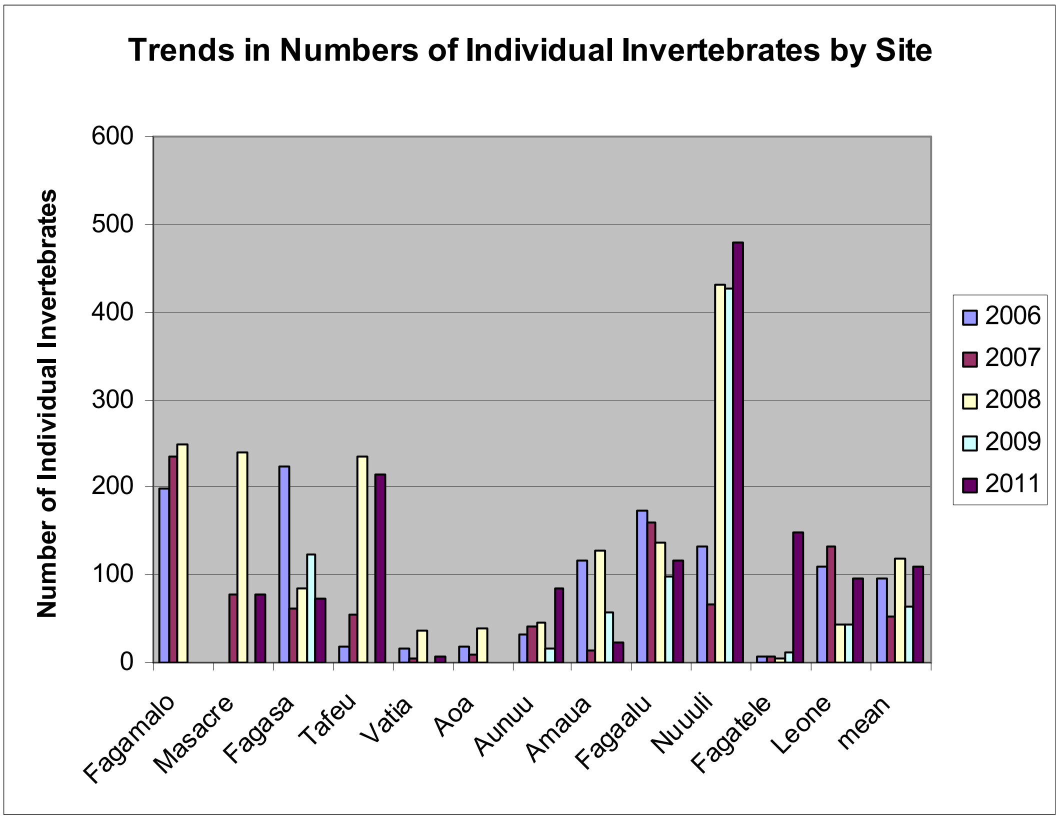


Figure 63 shows trends in the numbers of invertebrate individuals at each site. Some sites are quite consistent, so for instance, Vatia, Aoa, and Fagatele have low levels of invertebrates consistently. Nuu'uli had a sudden large increase, but the cause is not clear. It seems unlikely that this is a real change in invertebrates, more likely it is a new category of invertebrate added to those that were looked for, which was common there.

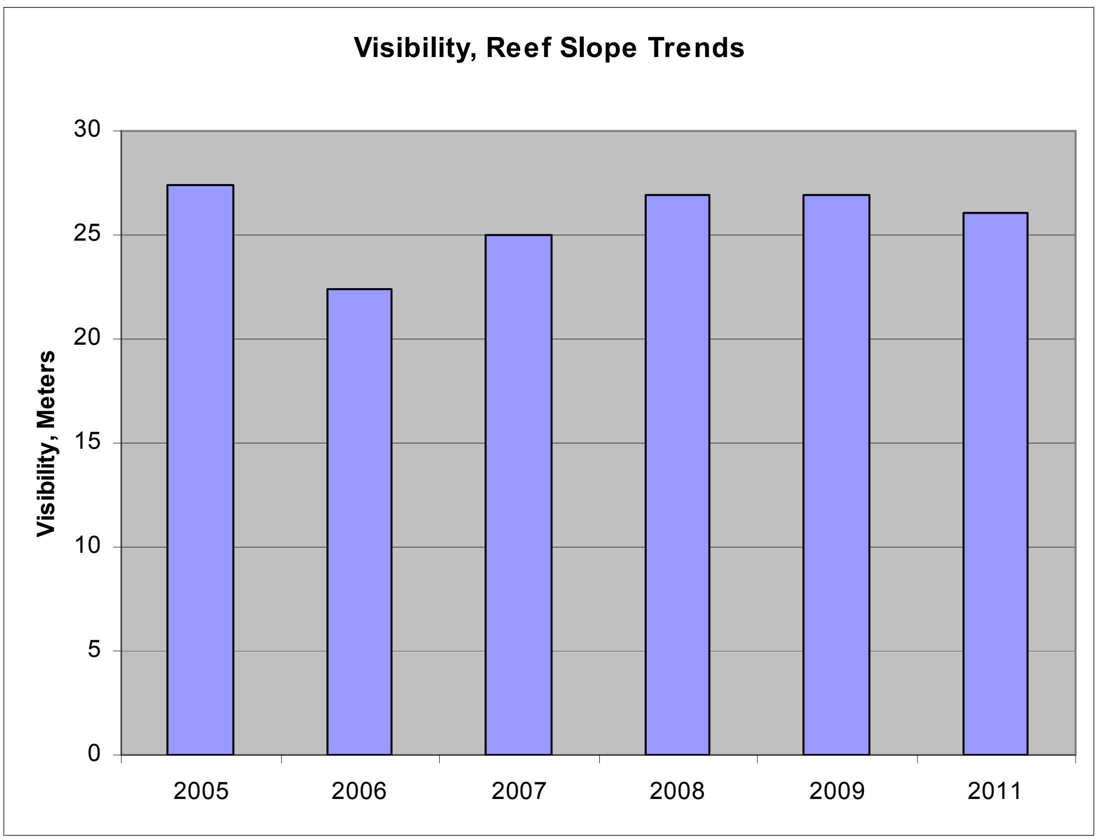
Figure 63.



Water Quality: Visibility

Visibility is a relatively easily obtained indicator of water quality. Low visibility is caused by such things as sediment and plankton, both of which are indicators of poor water quality. A large study of indicators of water quality on the Great Barrier Reef reported that water clarity is the best single indicator of water quality (Fabricius et al. 2012). Visibility estimates were taken using the transect tapes and sighting the end of the tape. The tape was stretched horizontally out from the reef. Figure 64 shows trends in mean visibility on the reef slope sites. There is no increasing or decreasing trend apparent. Water clarity is relatively good on the reef slopes, much better than in the harbor, but not as good as out at the banks where influence from the island is much less.

Figure 64.



Reef Flats

Reef flats are not often monitored, because most attention is now focused on reef slopes, and reef flats are almost neglected. The first scientists who studied coral reefs had to study reef flats, because that was the only part they could get to, since they didn't have SCUBA gear. But now with the advent of SCUBA gear, attention is usually focused on reef slopes. Reef flats generally have lower coral cover that reef slopes, because exposure to air kills corals on reef flats that grow too high. This is the reason reef flats are flat, because corals that grow too high are exposed to air too long and die, while corals in deeper spots survive and continue to grow upward, and thus low spots tend to get filled in and high spots cannot grow any more. Low tides do most of the killing of corals, in a process much like mowing a lawn, and which is quite natural; it has been going on for millions of years. In periods when there are no unusually low tides, coral cover on reef flats increases (Brown et al. 2011; Scopélitis et al. 2011). Sea level is rising at about 3 mm per year, and over a decade or more can provide a little more depth for corals to grow, and could allow more live coral cover on reef flats, at least until global-warming caused mass coral bleaching kills the corals (Fenner, 2012). Reef flat areas can be measured by remote sensing, but reef slopes cannot because you can't see reefs in deep water from above the water surface. Reef flats are now estimated to have between about four and 12 times as much area as reef slopes, globally (Vecsei, 2004). Thus, reef flats are an important part of coral reefs. In addition, because they are subject to some disturbances like low tides and trampling which don't affect reef slopes, and are closer to sources of human disturbance on land like sediment and nutrients (Field et al. 2011), reef flats need to be monitored as well as reef slopes. There is a significant area of reef flats in American Samoa.

The cover of benthic organisms on reef flats was measured at 11 sites. All sites were outer reef flat, except at Amaua, where surf makes it too dangerous to record coral on the outer reef slope. Coral cover is generally lower on inner reef flats than outer reef flats. The results are shown in Figure 65. As on the reef slopes, there was a considerable amount of variation from site to site. Mean coral cover was 31%, the same as on the reef slope. The highest cover was at Gataivai, followed by Fagamalo and Fagasa, and the lowest cover was at Leone, followed by Amaua and Vatia.

Figure 65.

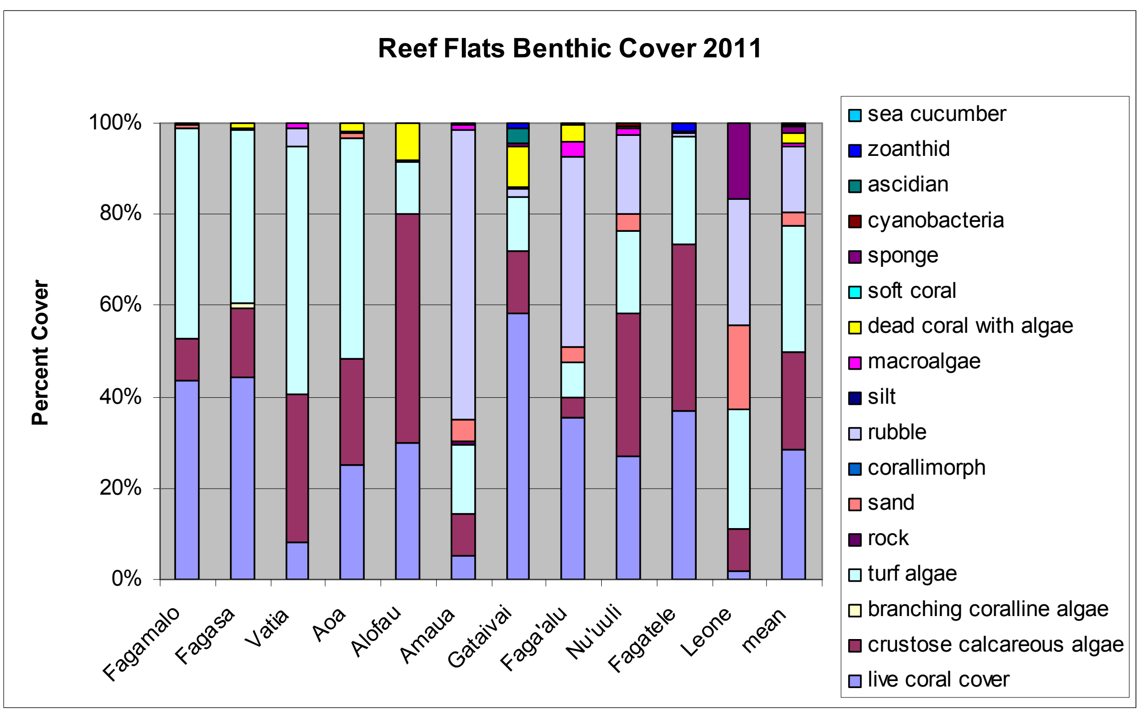
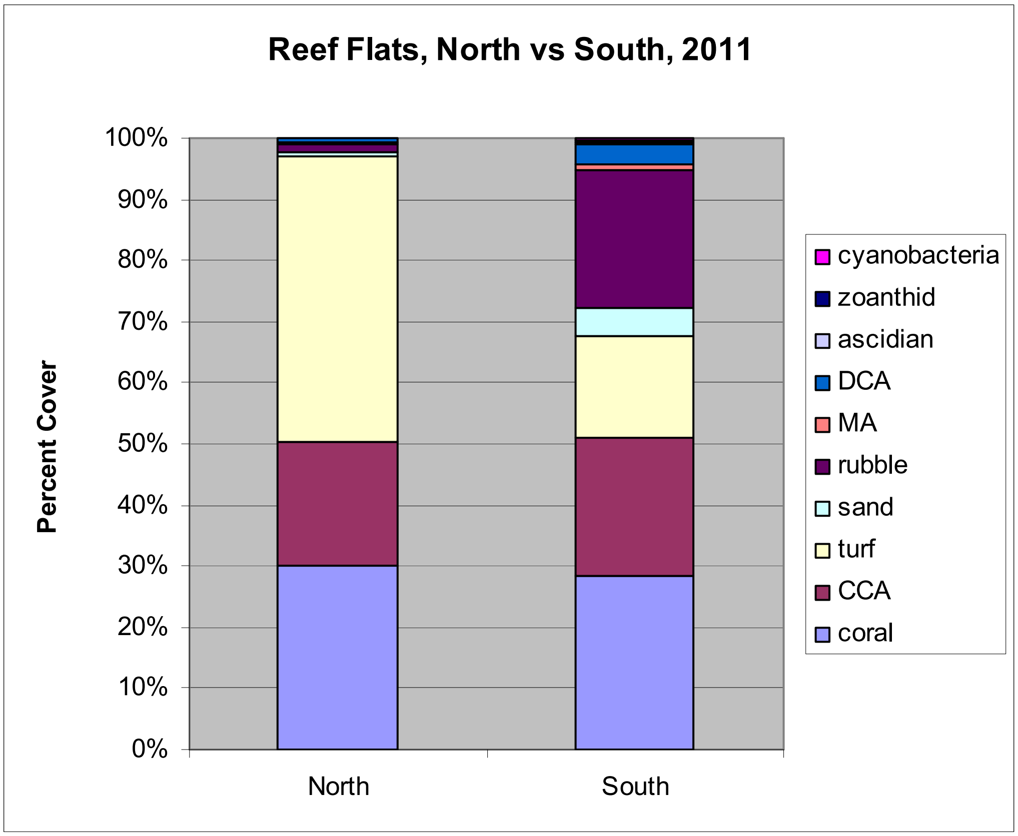


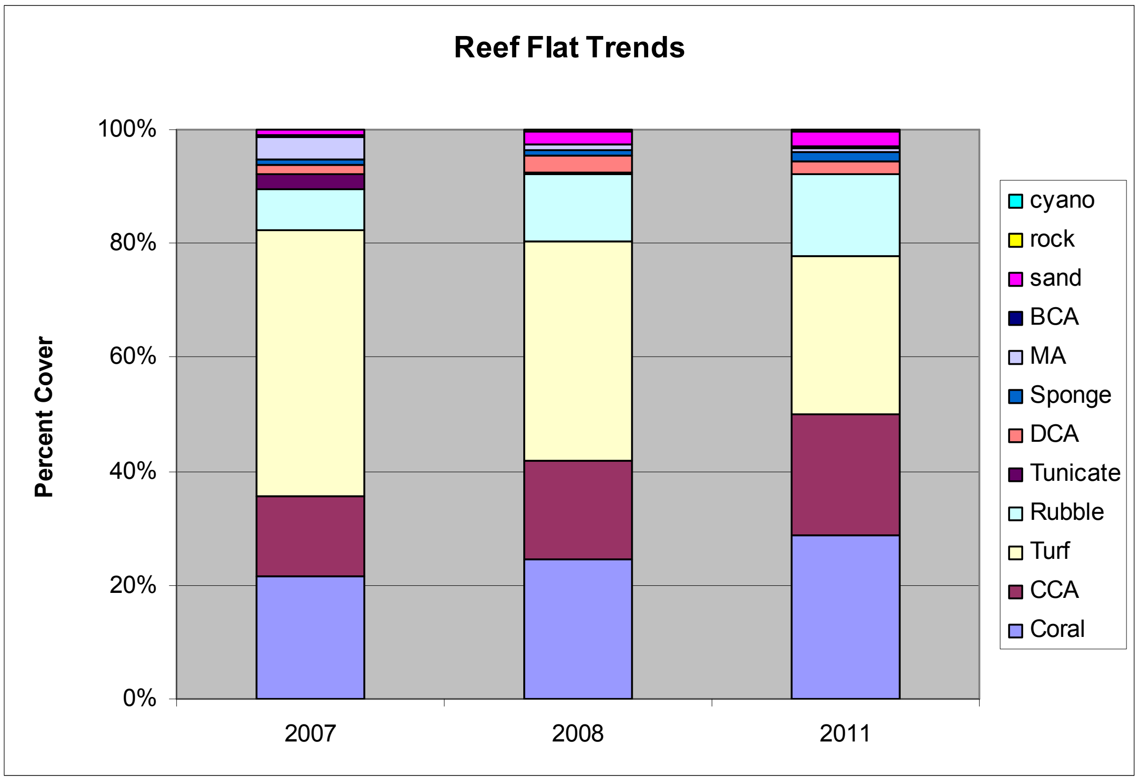
Figure 66 presents the mean cover for reef flats on the north and south sides of the island. Coral cover was almost the same on the north side and the south. Turf was much higher on the north side, and rubble was much higher on the south side. It is not clear why that is the case, though turf is also higher on the slopes on the north side than the south side.

Figure 66.



The trends in average cover on outer reef flat sites are presented in Figure 67. Coral cover, coralline algae and rubble increased, and turf decreased. The increase in coral cover on reef flats coincides with the increase in coral cover on the slopes. This should be approached with some caution, since it is more difficult to relocate sites on reef flats since there is no slope that restricts the location to a particular depth in one dimension. Still, it suggests a trend in a good direction.

Figure 67.



The live coral index was calculated for the reef flat just as on the reef slope. Figure 68 shows the trends in the live coral index on the outer reef flat. The live coral index was high like on the reef slopes, and there was little or no trend. This indicates relatively healthy reef flats.

Figure 68.

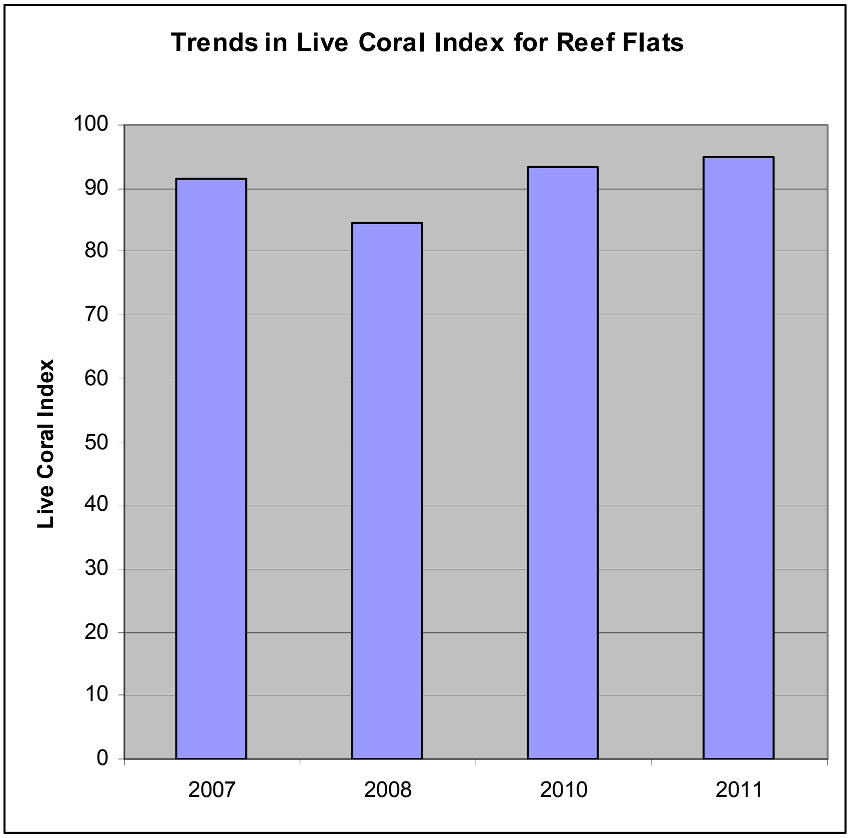


Figure 69 shows trends in the amount of coral plus crustose calcareous algae versus turf plus macroalgae, on the reef flats. Coral and crustose coralline algae are considered good, macroalgae bad, and turf mixed or neutral. Coral plus crustose calcareous algae increased, while turf plus macroalgae decreased, though most of the change is only in the last year. It is not yet clear whether this is a real long term trend. The amount of coral plus crustose calcareous algae is less than on the reef flats, with 40-55% cover on the reef flats but 60-70% on the reef slopes.

Figure 69.

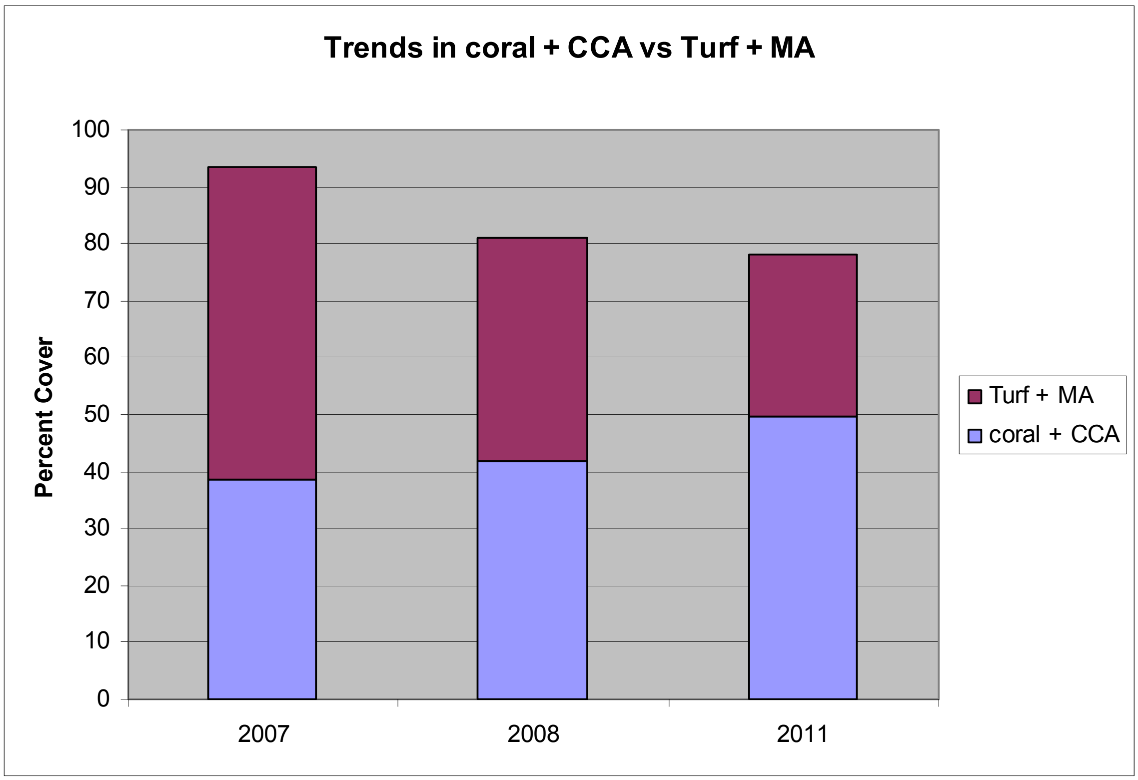


Figure 70 shows a comparison of the same benthic categories for reef slopes and reef flats for 2011. Reef slopes have a larger cover of coral + crustose calcareous algae (CCA), while reef flats have a larger cover of turf + macroalgae (MA). But even reef flats have a fairly large cover of corals plus CCA.

Figure 70.

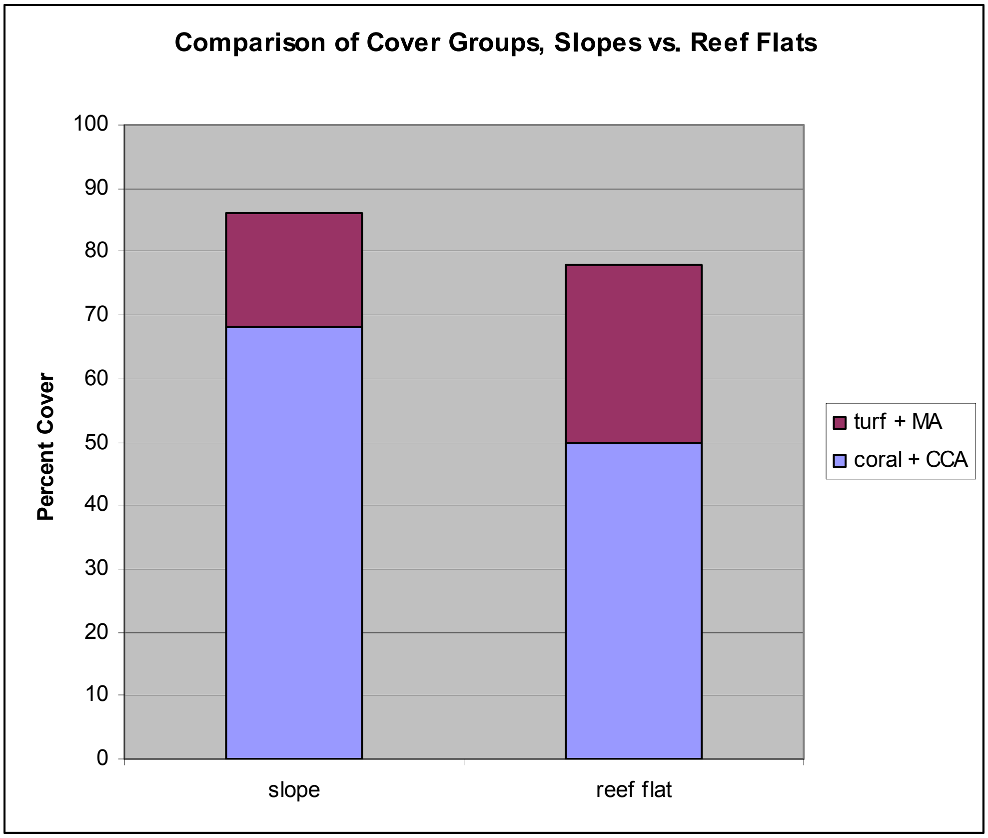


Figure 71 shows the trends in calcifying and non-calcifying cover on reef flats. The primary differences with the previous groups are that the calcareous group includes *Halimeda* macroalgae, and the non-calcareous includes all cover that is not calcifying. The amounts of *Halimeda* are generally small, and the pattern is very similar.

Figure 71.

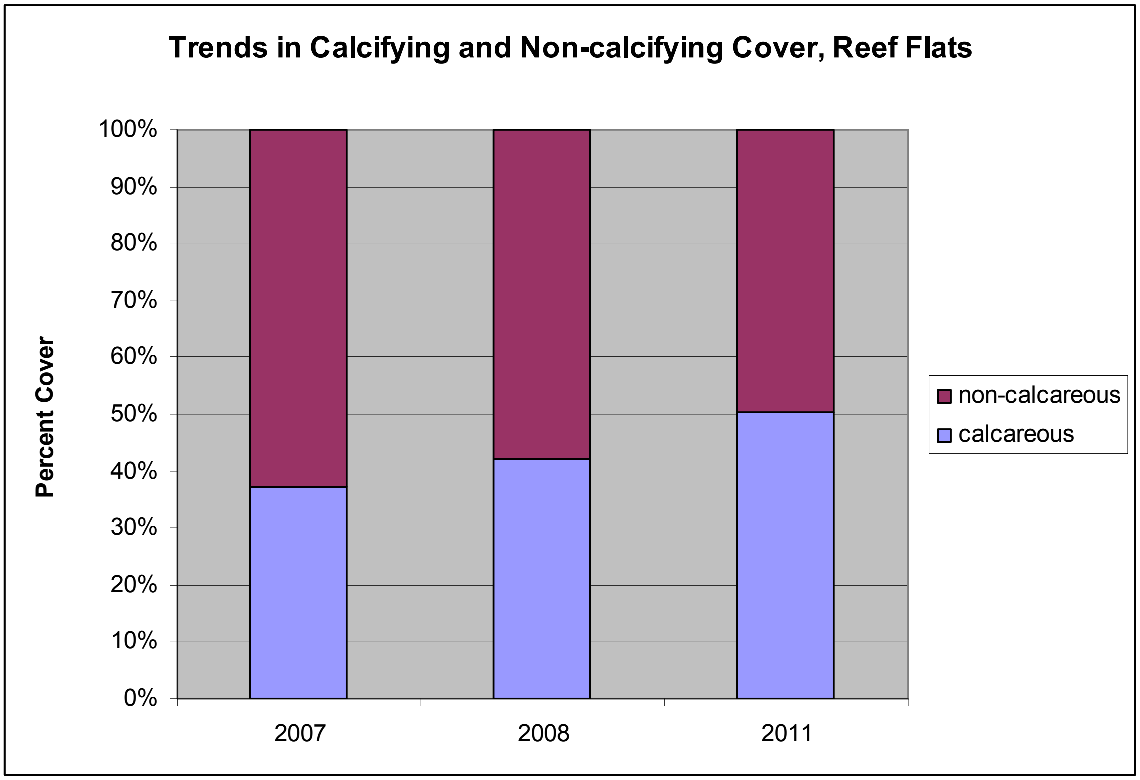
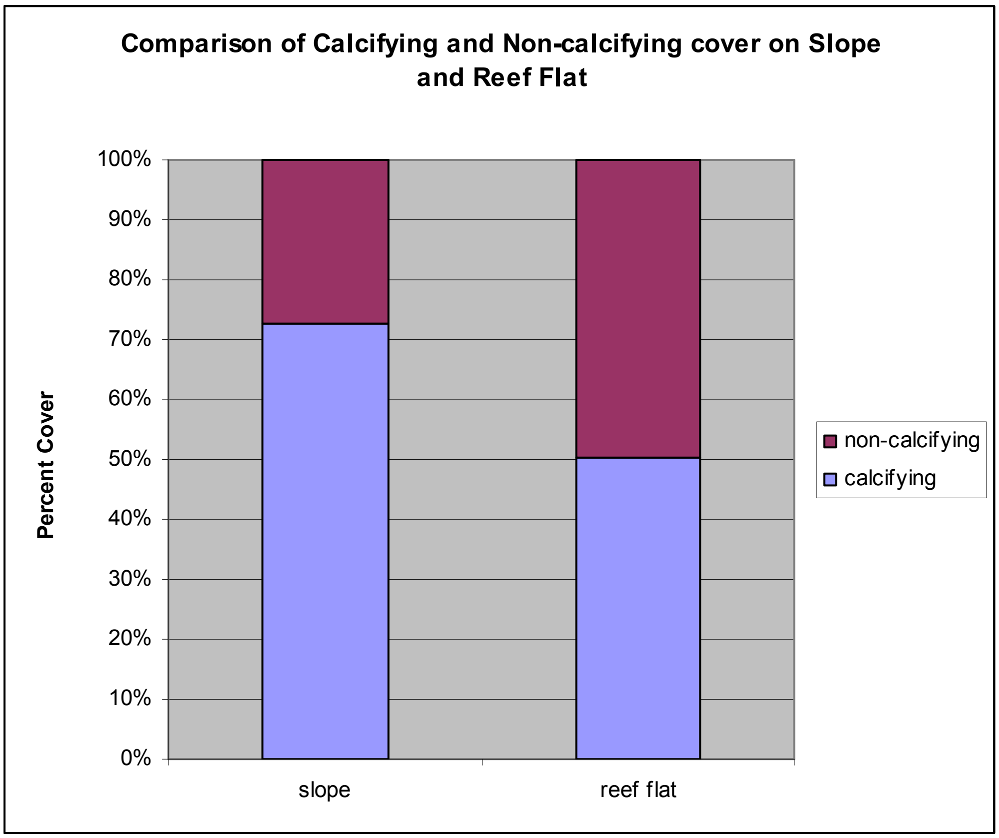


Figure 72 shows a comparison of the calcifying and non-calcifying cover on the reef slopes and reef flats. As with the previous measure, calcifying cover on the slope is higher than on the reef flat, and non-calcifying is higher on the flat than the slope. The amount of calcifying on the reef flat is still fairly good. The primary reason that calcifying on the reef flat is lower, is that low tides kill coral on the reef flat. This is natural.

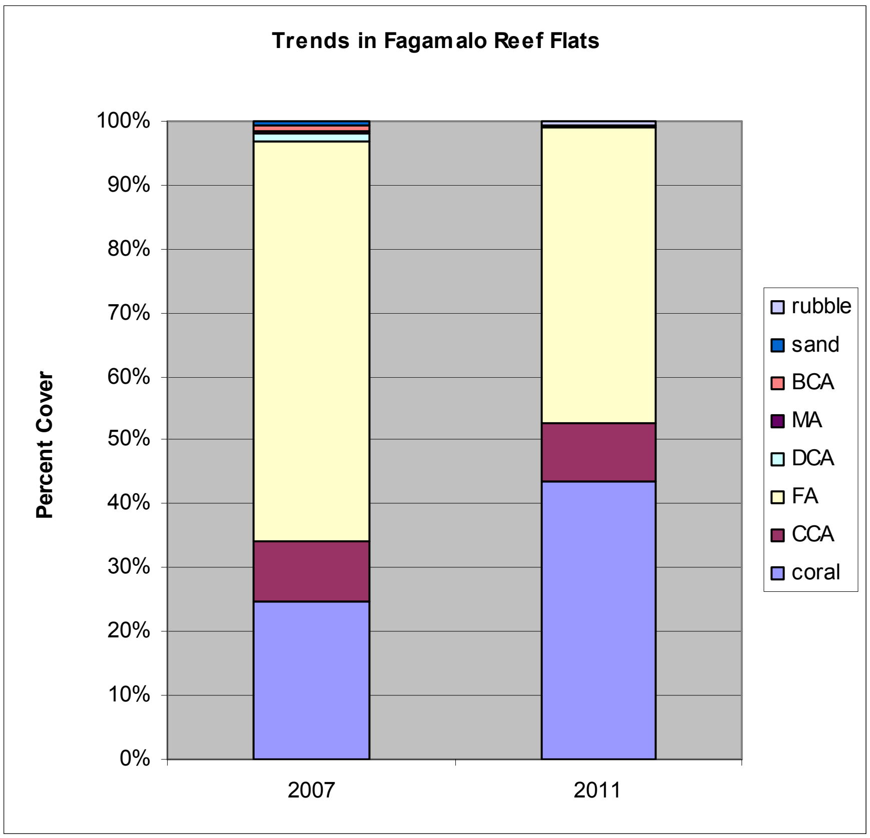
Figure 72.



Trends at Individual Sites

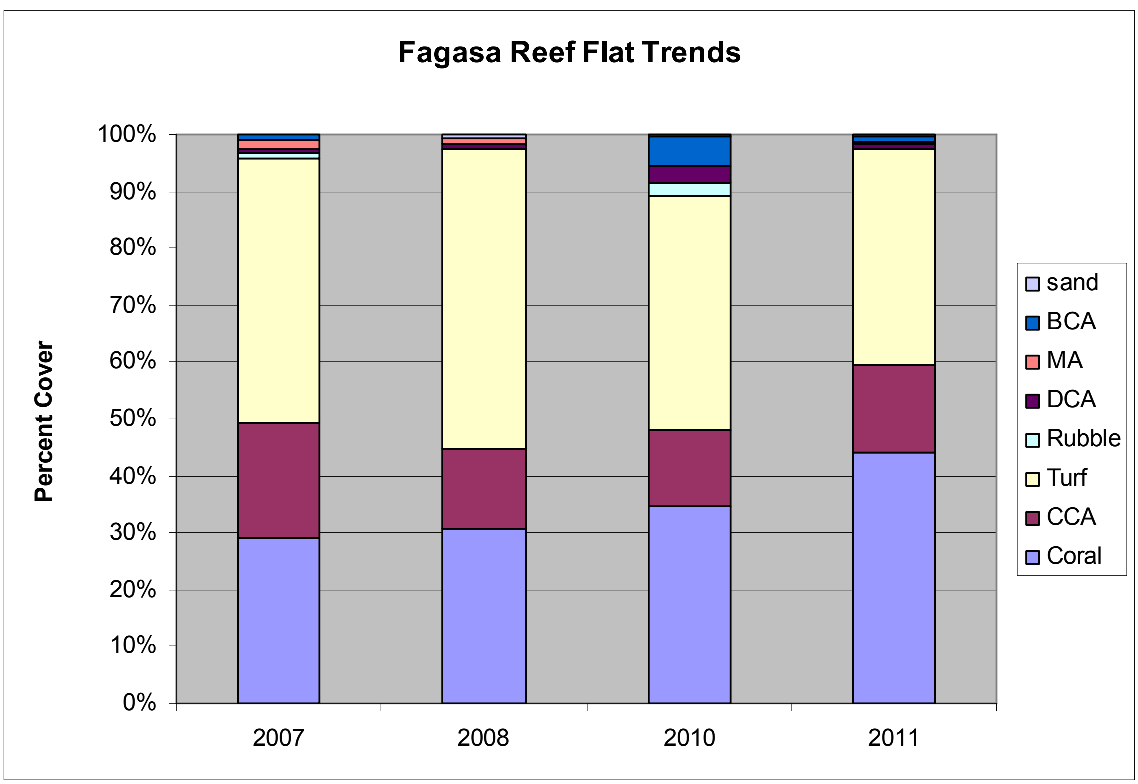
Trends for the reef flat at Fagamalo are shown in Figure 73. Coral cover increased considerably, and turf decreased. However, in 2007 the surf was rough and it wasn't possible to see clearly where the tapes were on the reef. In 2011 it was very calm and the reef flat was seen clearly, but the tapes may well have been in a different location than in 2007.

Figure 73.



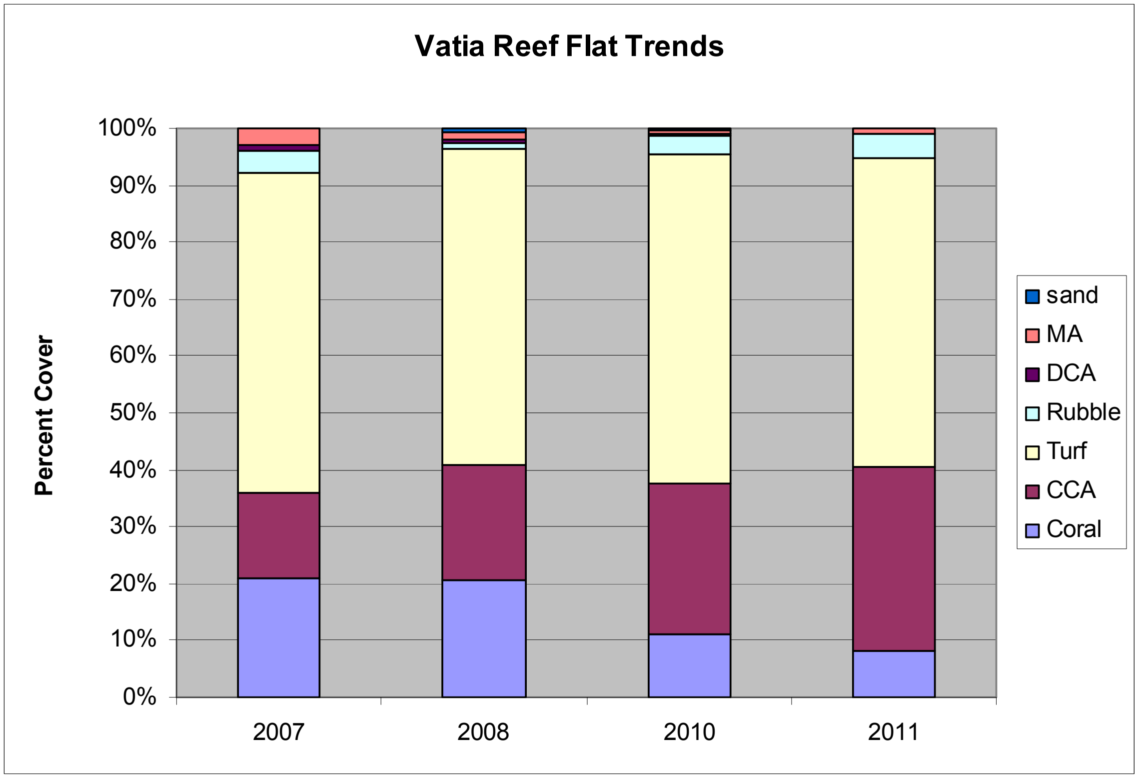
Trends in cover on the reef flat at Fagasa are shown in Figure 74. There was no change from 2007 to 2008, but then increases in coral cover in 2010 and 2011. The transects are taken near the outer edge of the reef flat which is where the most coral is. This was the site of the settlement of many table corals (*Acropora hyacinthus*) around 2007, and continues to be a settlement site of smaller numbers of table corals. The tsunami on Sept. 29, 2009, washed many pieces of cloth onto the reef flats, and many were caught on these table corals, which have a shape that catches them, as well as being very sharp so that the cloth catches on them and doesn't come off easily. In the weeks after the tsunami, a major effort was mounted to remove cloth from these young table corals, and the cloth was removed from hundreds. In the following years, all of the young tables were seen to have survived, except about 4 which still had cloth on them and were completely dead. There is one section of the table corals that had reached a diameter of about 30-40 cm, and was back from the edge of the reef flat. 100% of that group was dead after a low tide event, while those near the edge survived. It appears that at the edge, wave splash kept the tables wet and alive while farther back they dried out too much and died. The transect tapes are too near the edge of the reef flat to cross the dead table area. The area of dead tables is a small part of the whole population of young table corals. Some of the live tables are now big enough to be running into each other as they grow. In any case, the increase in coral cover recorded appears to be largely due to the young table corals growing larger.

Figure 74.



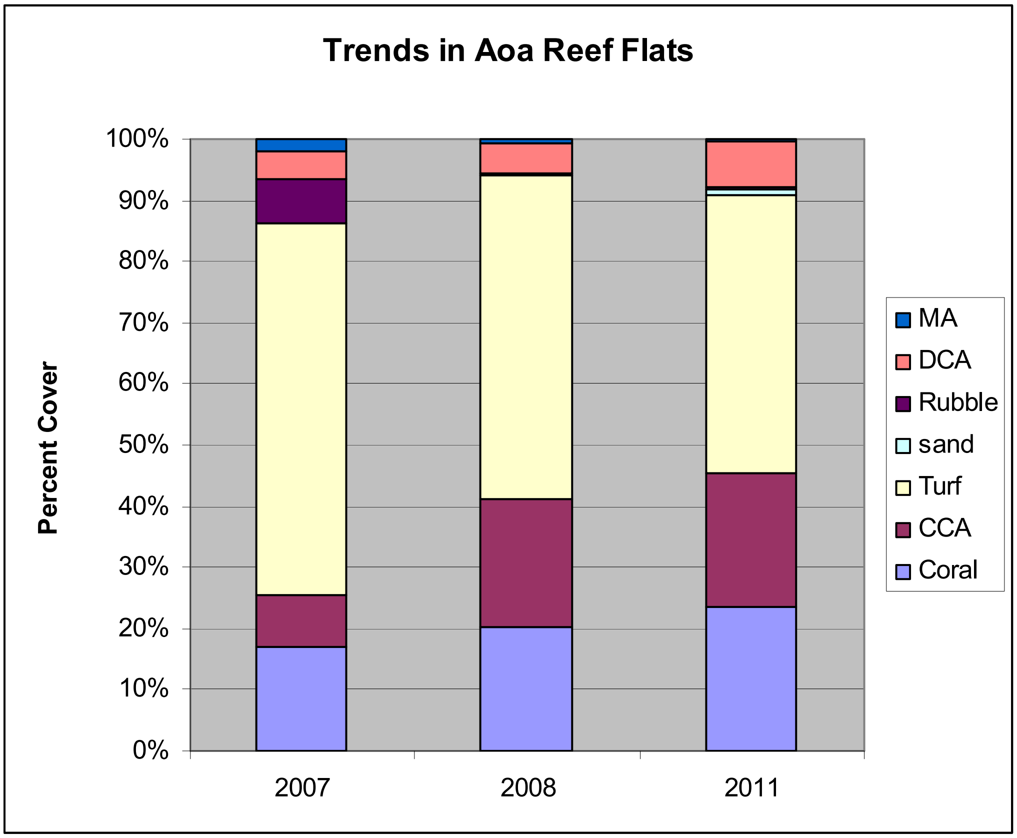
Trends in the cover of the outer reef flat at Vatia are shown in Figure 75. Coral cover was steady from 2007 to 2008, then dropped suddenly between 2008 and 2010, and then decreased slightly in 2011. The tsunami on Sept. 29, 2009, heavily damaged the reef slopes on the inner part of the bay, with damage decreasing with distance from the head of the bay. Hurricane Wilma then damaged the outer part of the bay. The reef flat corals showed some signs of damage as well. So the decrease from 2008 to 2010 was very likely due to the tsunami and/or hurricane.

Figure 75.



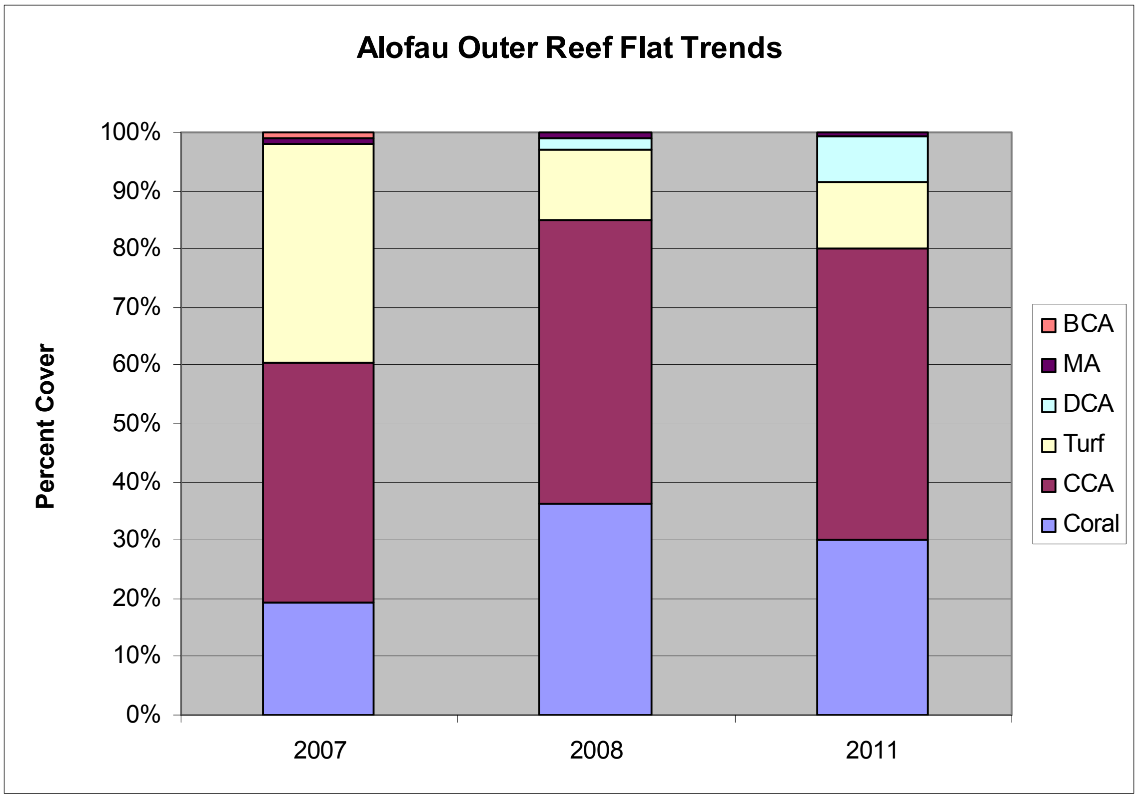
Trends in cover on the outer reef flat at Aoa are shown in Figure 76. Coral cover increased steadily, crustose coralline algae increased, and turf decreased.

Figure 76.



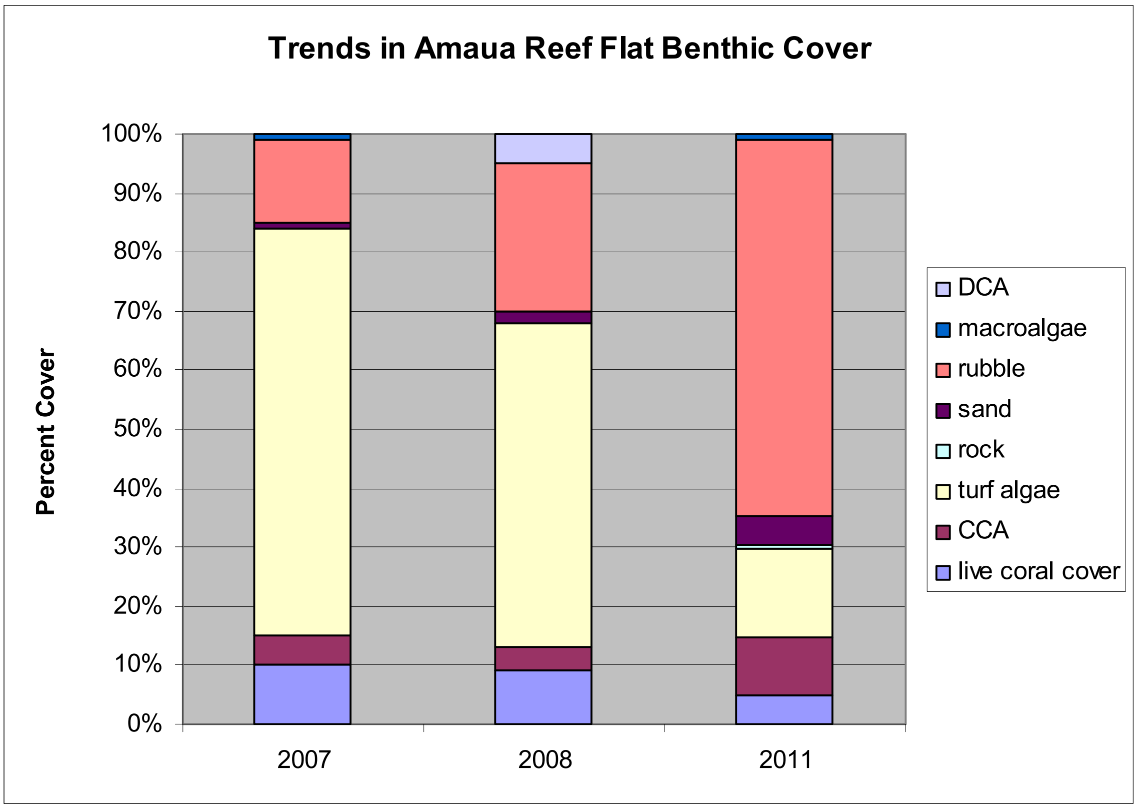
Trends in benthic cover on the outer reef flat at Alofau are shown in Figure 77. The recorded coral cover increased from 2007 to 2008, and then decreased in 2011. This is likely due to changes in the exact location of the transect tapes. Visually, there does not appear to have been any changes in the amount of live coral cover over this period.

Figure 77.



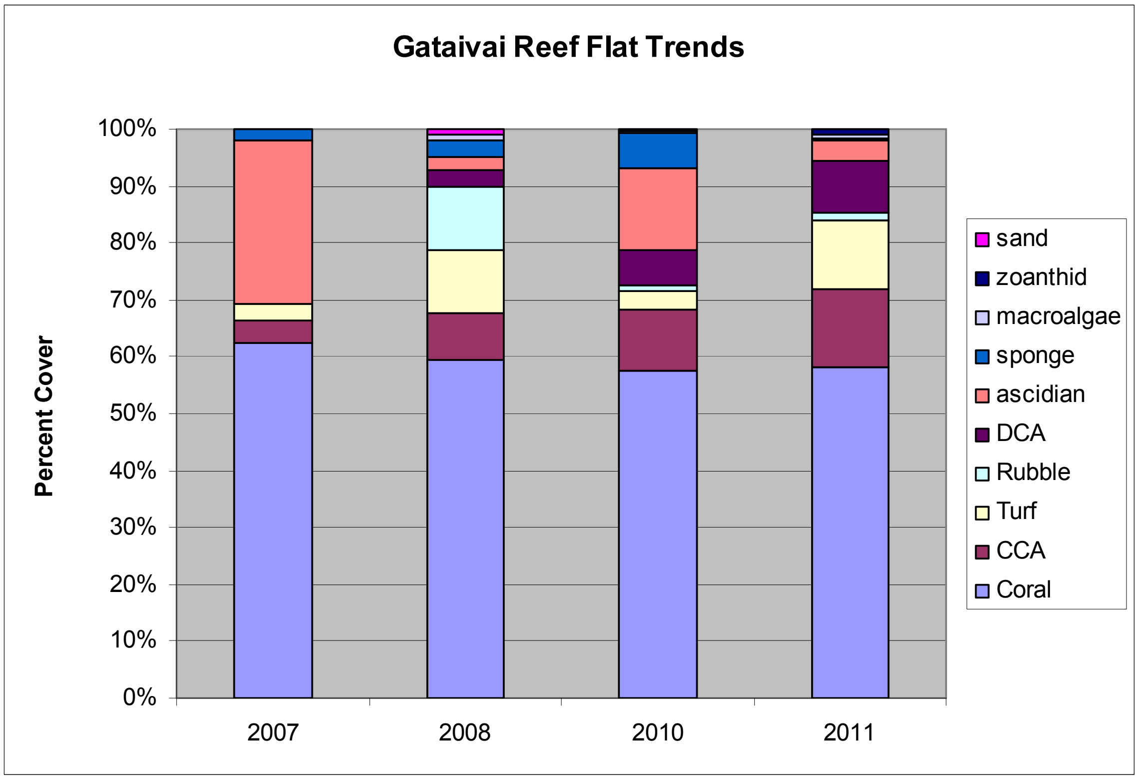
Trends in benthic cover on the inner reef flat at Amaua are shown in Figure 78. Coral cover decreased, mainly from 2008 to 2011. Turf algae decreased greatly and was replaced with rubble. Although the replacement of turf by rubble might be real, there is a good chance that it is due to a shift in the criteria for these categories. Amaua has rubble covered with turf, but the turf is thin. It is largely a judgment call whether to record it as rubble or turf. The decrease in coral cover is not easily seen, and it is not clear why the amount recorded has decreased, it could be changes in transect tape location or real.

Figure 78.



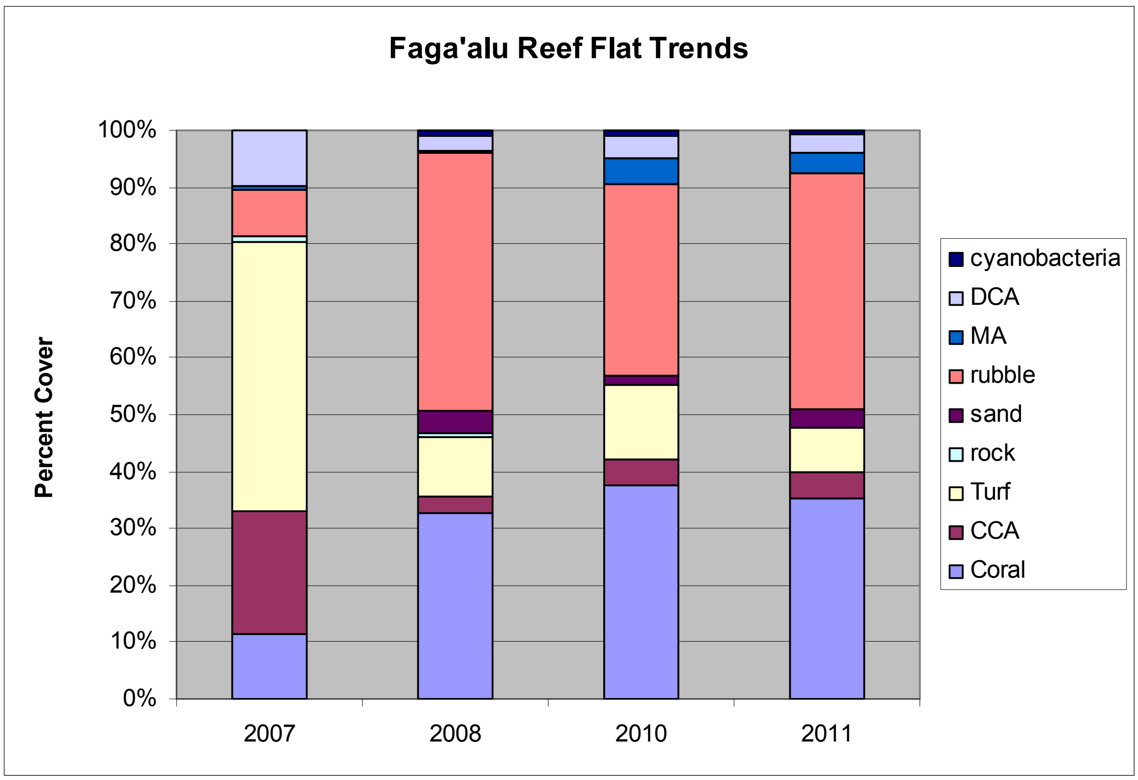
Trends in benthic cover at Gataivai are shown in Figure 79. There was a slight decrease in coral cover from 2007 to 2010, but it appears to have stabilized now. The cover of the colonial ascidian (sea squirt) *Diplosoma simili* in the area seems to have undergone great fluctuations. It has been reported to under major changes elsewhere, at one point it covered a large amount of the reef on Swains, as reported in Vargas-Angel et al. (2009). Turf also increased and decreased in the opposite pattern to the ascidian, suggesting that the ascidian covered up and uncovered turf, not coral. Coralline algae cover appears to have increased over time. The causes of all these changes are not clear.

Figure 79.



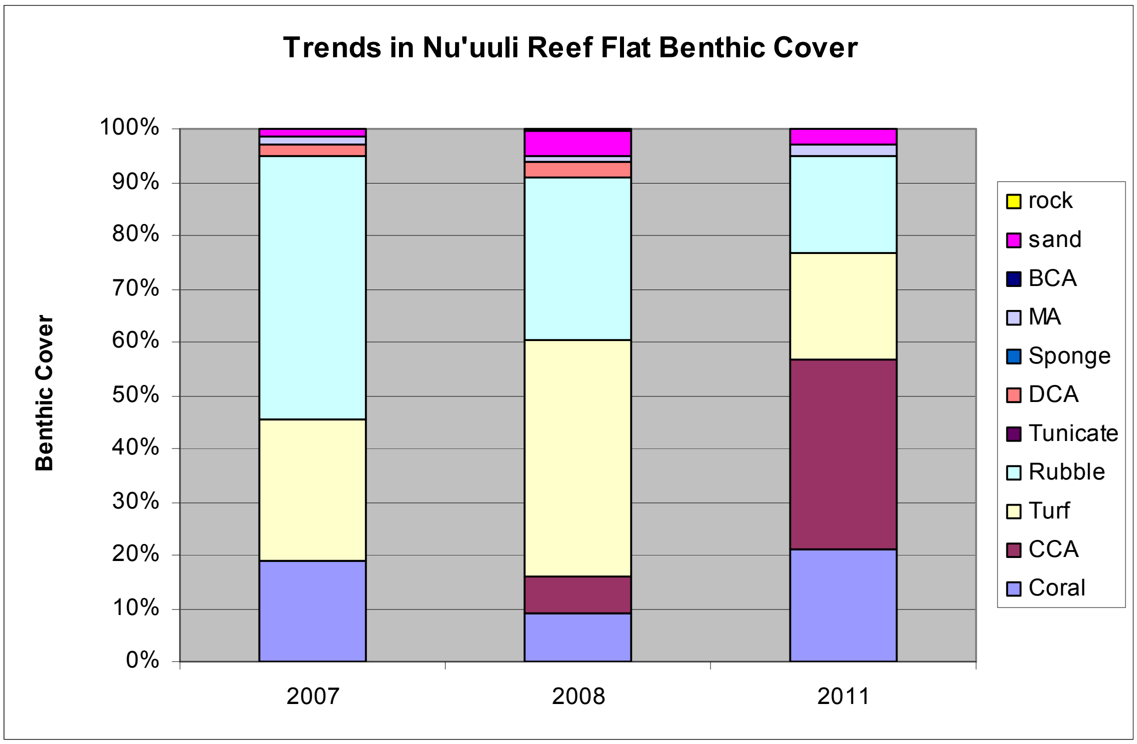
Trends in benthic cover on the reef flat at Faga'alu is shown in Figure 80. Coral cover recorded increased greatly from 2007 to 2008, but has been steady since then. Most likely, there was a change in the exact location of the transect tapes from 2007 to 2008. The area appears to be pretty steady, but some of the coral is thickets of *Acropora aspera*. That species grows only on reef flats and grows higher than other corals. During low tides it can then get exposed for too long and killed. That doesn't seem to have happened to the *A. aspera* in these transects, perhaps because they are not as high as others. There is also an area farther back in the reef flat which is a thicket of *Acropora muricata*, and it has indeed had its upper branches killed by low tide.

Figure 80.



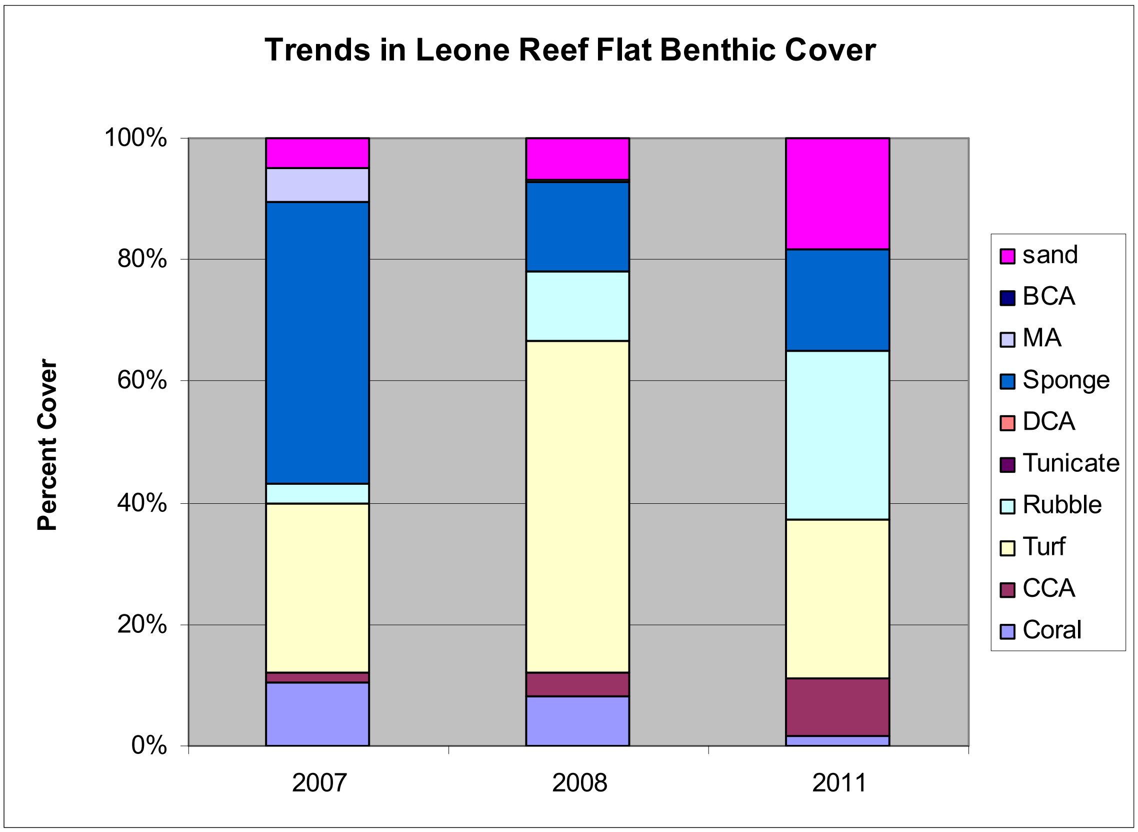
Trends in benthic cover on the reef flat at Coconut Point, Nuu'uli, are presented in Figure 81. It appears that there is no overall trend in coral cover, and the lower coral cover in 2008 may be due to a slight change in transect tape location. Crustose coralline algae increased greatly and turf decreased. It seems likely that these changes are due to changed transect tape locations. The location is far from the shore and does not have reliable markers for location, such as a rock that projected from the water that was seen in the early years but not later.

Figure 81.



Trends in benthic cover on the reef flat at Leone are shown in Figure 82. Coral decreased and sand increased, and other categories varied large amounts. The reef flat is large and has little to mark specific spots, and it seems likely that the tapes were in slightly different locations, which produced the changes in cover recorded. The one change that appears to be very real is the reduction in sponge cover. A grey sponge had very large cover the first year, then decreased the second year, and remained steady. The cause of the reduction is unknown.

Figure 82.



Trends in benthic cover on the inner reef flat in Alofau was also recorded in 2011, and the results shown in Figure 83. Alofau has had rubble on the inner reef flat since the author first saw it in 2004. That suggests that at some previous point there was live branching coral on the inner reef flat, but it is not clear why it died. Coral cover has not increased. The tsunami in 2009 moved the rubble around, leaving less turf visible on the rubble.

Figure 83.

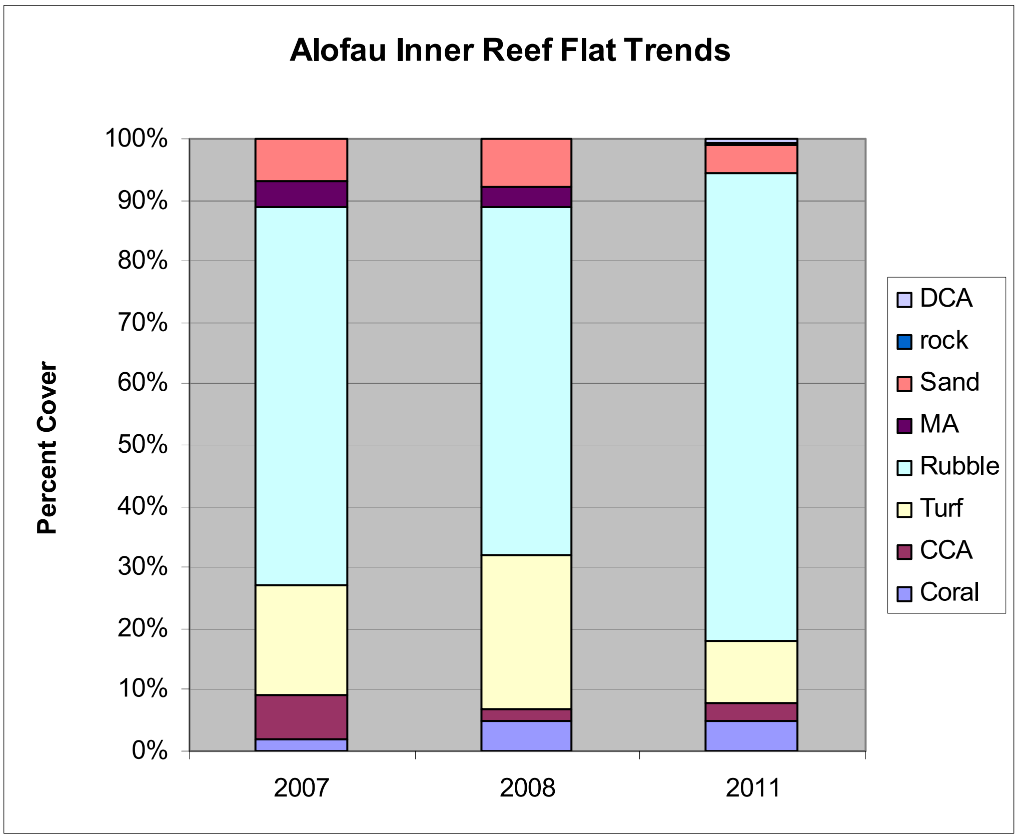


Table 11 gives a summary of trends at the individual sites, and shows that three sites showed increases, three showed decreases, and four were steady. This shows that the number of sites showing increases is the same as the number showing decreases, so the increasing trend is not as strong as on the reef slopes.

Table 11.

	decrease	steady	increase
Fagamalo			X
Fagasa			X
Vatia	X		
Aoa			X
Alofau		X	
Amaua	X		
Gataivai		X	
Faga'alu		X	
Nuu'uli		X	
Leone	X		
total	3	4	3

Corals in Reef Flat Transects

Coral Lifeforms

Coral lifeforms on reef flats is shown in Figure 84. Encrusting was the most common lifeform, followed by *Acropora* branching, foliose, branching, and *Acropora* table.

Figure 84.

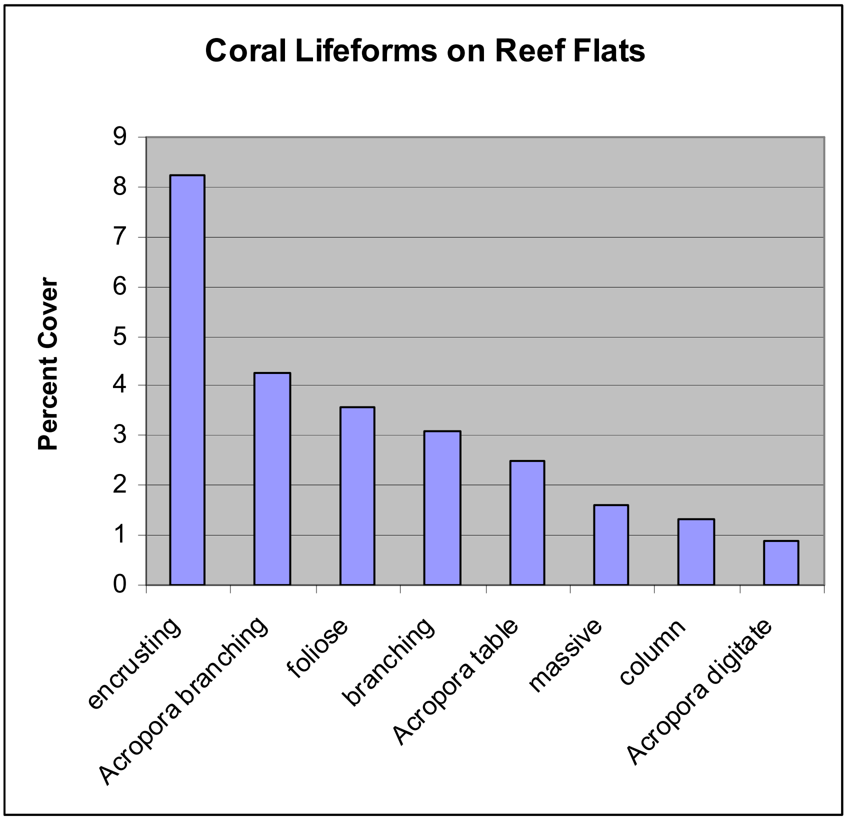
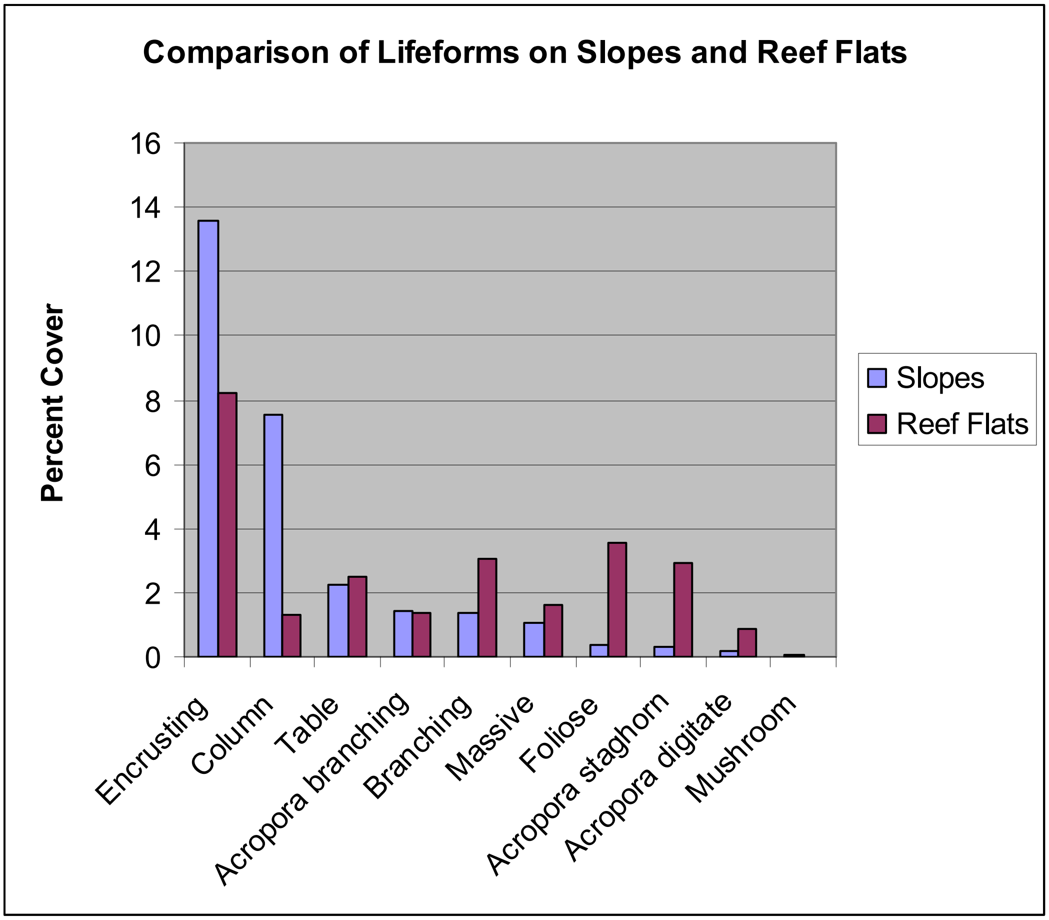


Figure 85 compares the amount of each coral lifeform on the reef flat with the amount on the reef slopes. There was more encrusting on slopes than reef flats, much more column on slopes than reef flats, and more foliose, branching, and *Acropora* staghorn on reef flats than on slopes. The coral communities are quite different on reef flats and slopes.

Figure 85.



Coral Genera

The cover of coral genera on reef flats is shown in Figure 86. *Acropora* is the genus with the most cover on reef flats, followed by *Montipora*, *Porites*, *Pavona*, and *Pocillopora*.

Figure 86.

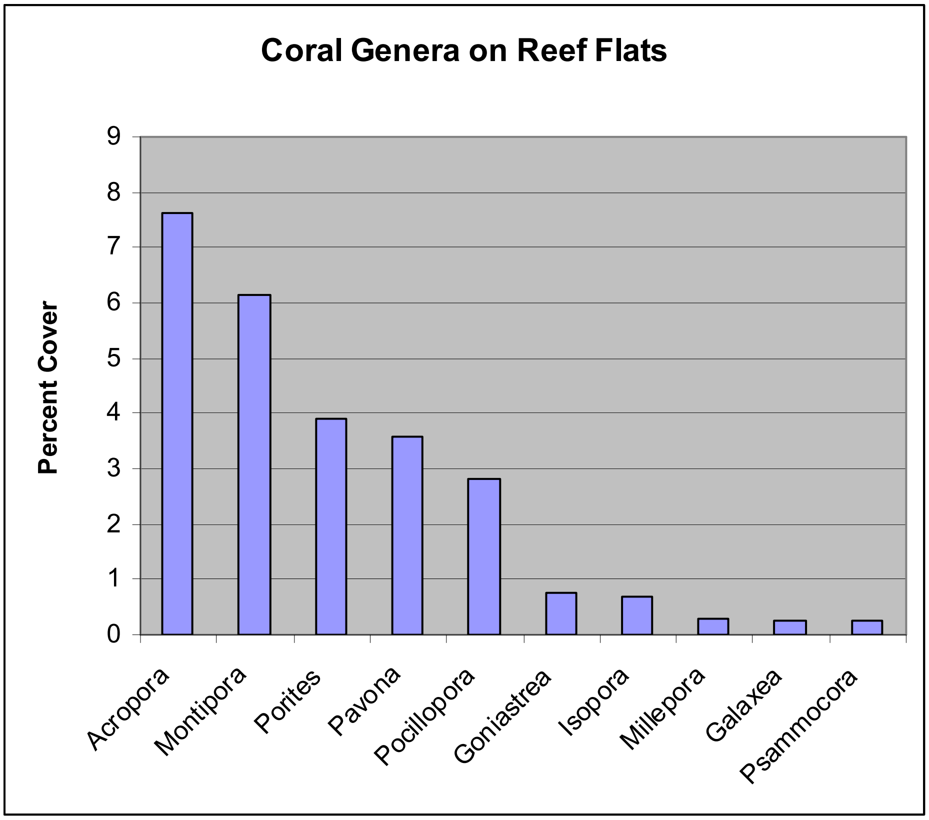


Figure 87 shows a comparison of the cover of coral genera on slopes and reef flats. *Porites* is has much more cover on the slopes than on the reef flats, and *Montipora* also has more cover on slopes than reef flats. However, *Acropora* and *Pocillopora* have more cover on reef flats than on slopes. This is consistent with the finding that coral lifeforms are different on reef flats and slopes.

Figure 87.

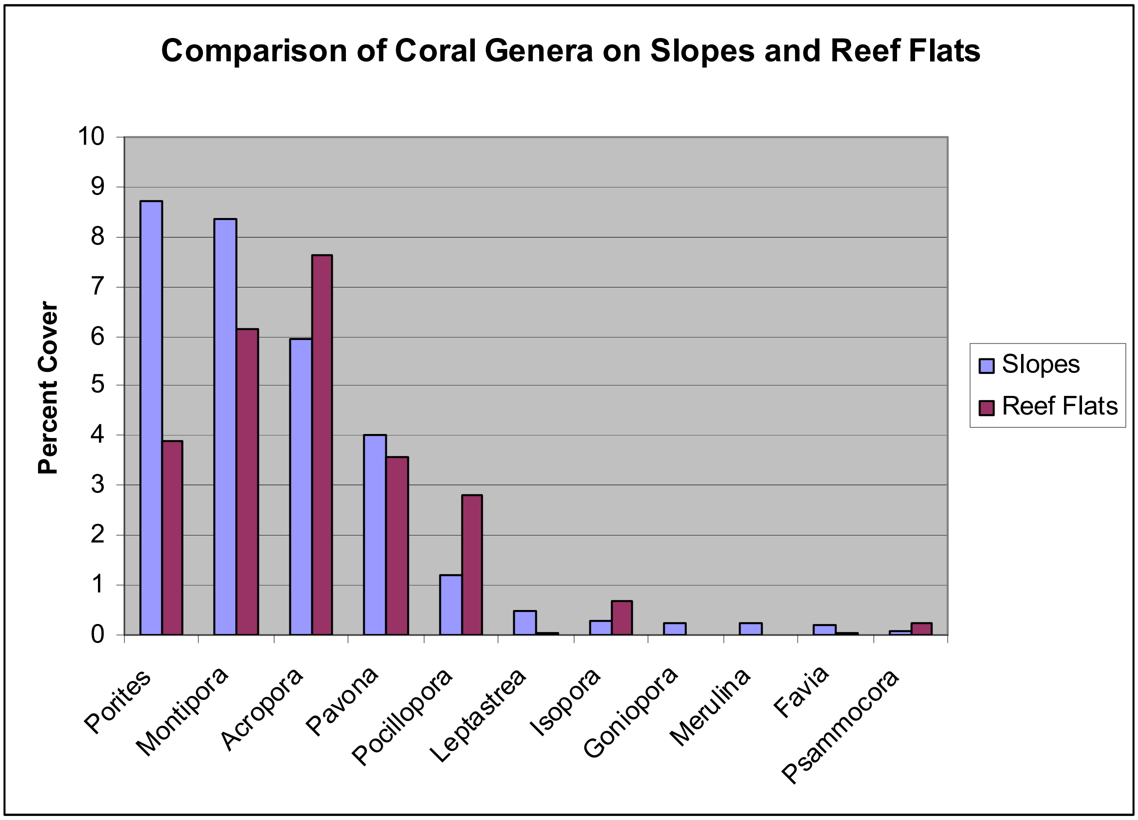


Figure 88 shows the trends in the mean number of coral genera in transects on reef flats. The number increased during the study period.

Figure 88.

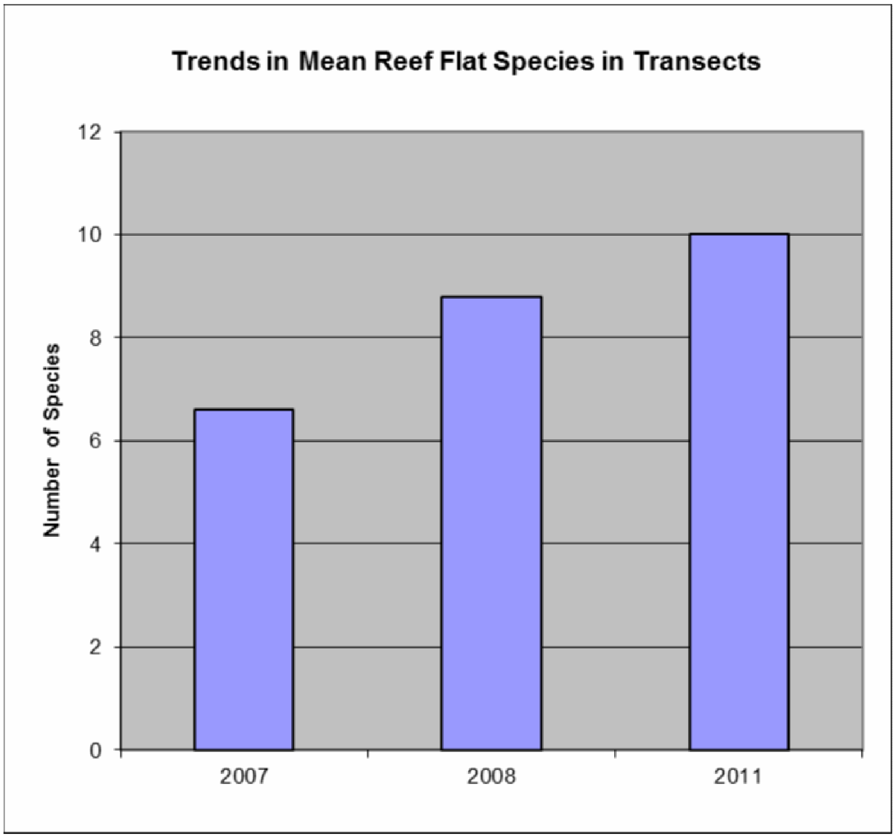
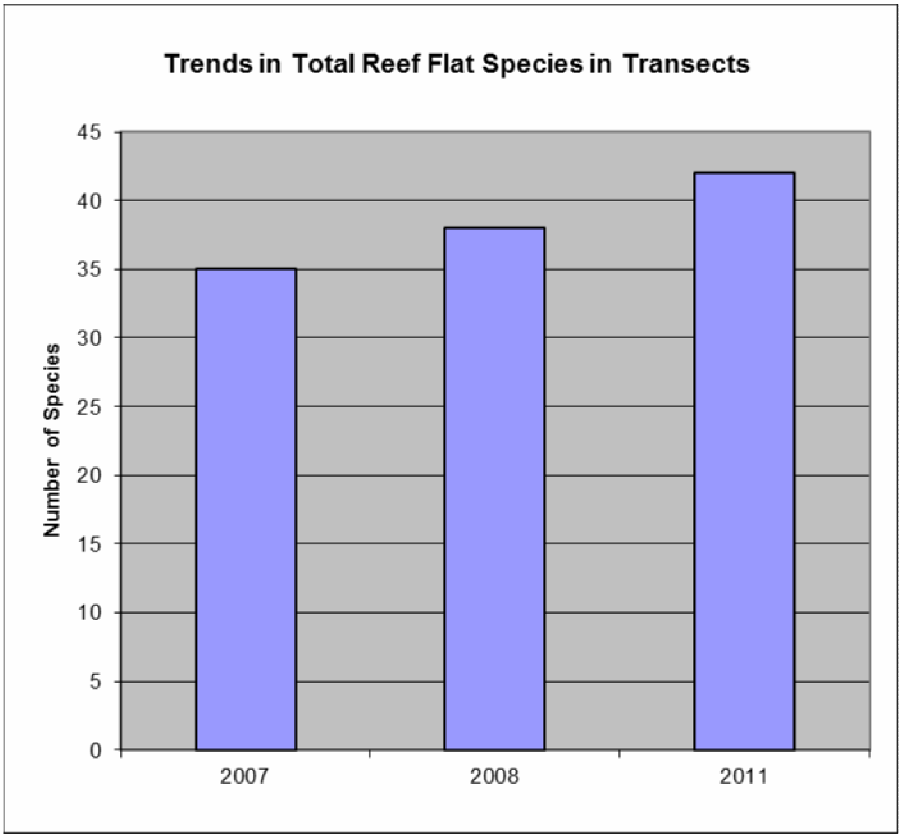


Figure 89 shows trends in the total number of coral genera in all transects combined. The total number of genera increased over the study period.

Figure 89.



Coral Species

The cover of coral species on reef flats is shown in Figure 90. *Montipora grisea* covers the most area on reef flats, followed by *Pavona frondifera*, *Acropora aspera*, and *Acropora hyacinthus*.

Figure 90.

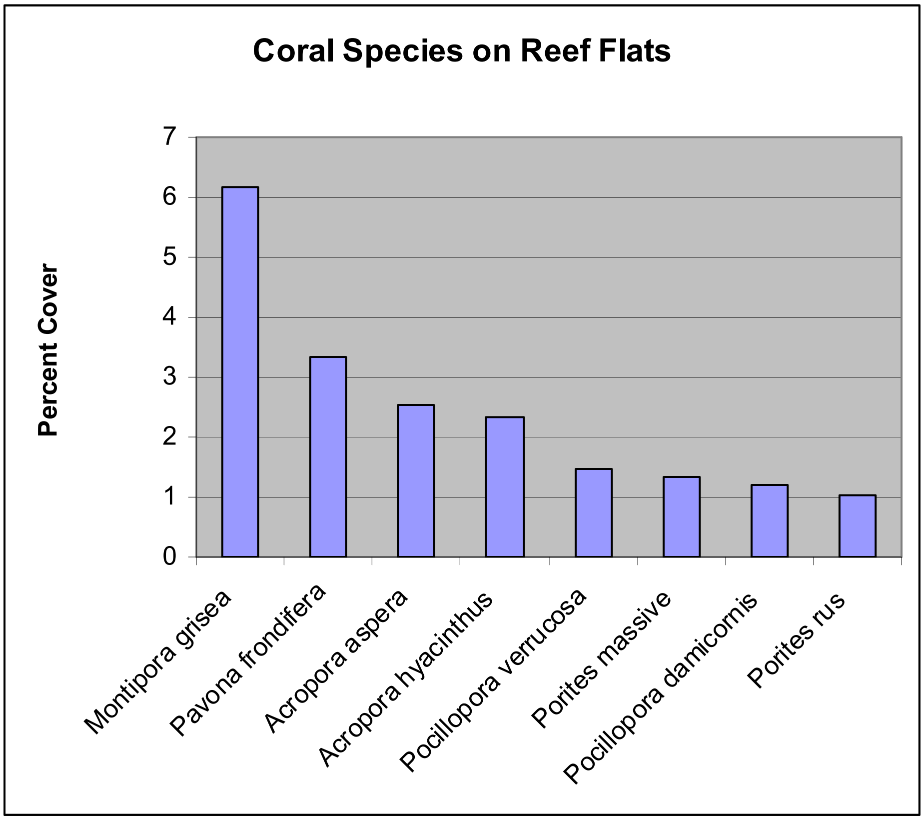
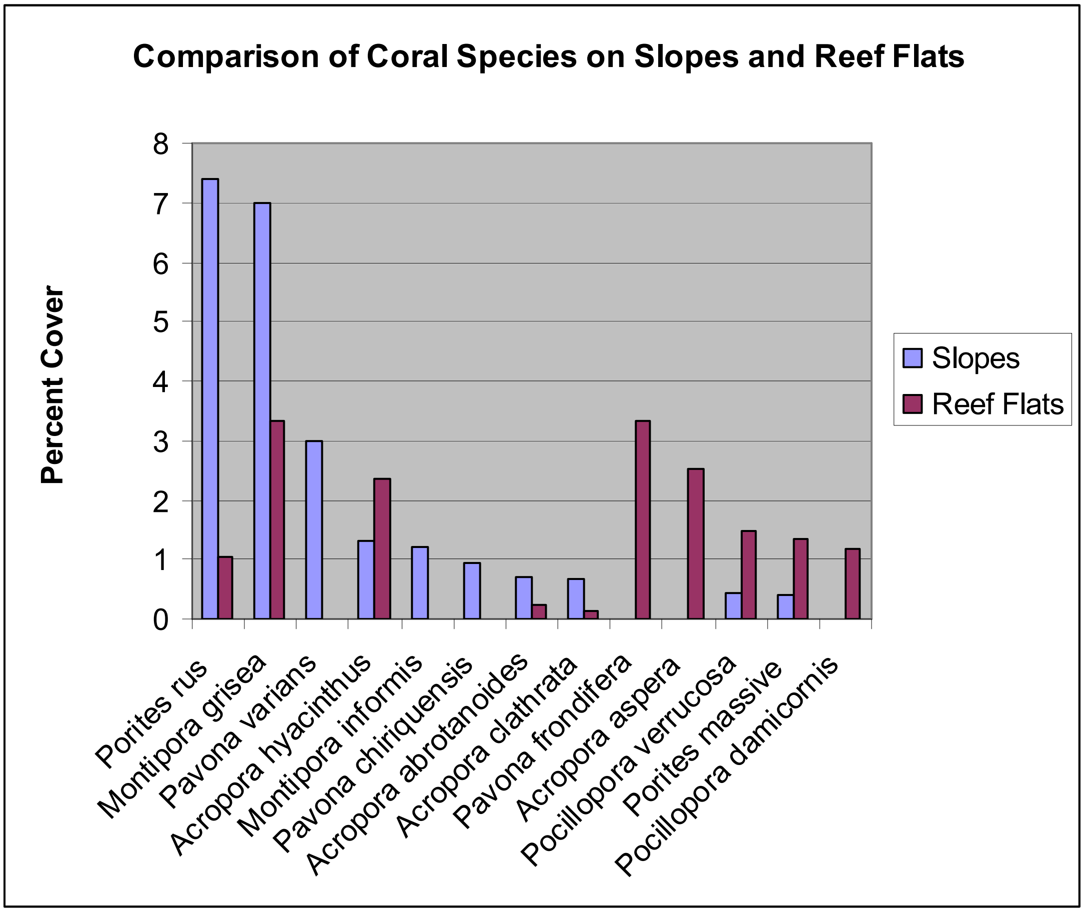


Figure 91 presents a comparison of coral species on slopes and reef flats. *Porites rus*, *Montipora grisea*, *Pavona varians*, *Montipora informis* and *Pavona chriquensis* were all more abundant on the slopes than on the reef flats. *Pavona frondifera*, *Acropora aspera*, *Acropora hyacinthus*, *Pocillopora verrucosa*, *Porites* massive and *Pocillopora damicornis* were all more abundant on the reef flats than on the slopes.

Figure 91.



The data from transects can be used to provide information on where coral species live. A ratio was taken of the coral cover for each species, flat/(flat + slope), the proportion of all the coral cover that is on the flat. For quite a few species, the species was recorded only on the flat or on the slope, not on both. Those species are listed below in Table 12.

Table 12. Coral species found only on the reef flat or slope.

Reef Flat Only	Slope Only
A. cophodactyla	*A. cerealis*
A. corymbose	*A. cytherea*
A. digitifera	*A. globiceps*
A. muricata	*A. monticulosa*
A. nana	*A. paniculata*
A. pulchra	*A. vaughani*
A. robusta	*A. cuculata*
A. surculosa	*Asteopora myrio*
digitate Acropora	*Diplo. heliopora*
Favites abdita	*Echino hirsutiss*
Millepora exesa	*Echino lamellosa*
Pavona decussata	*Favia stelligera*
Pavona frondifera	*Fungia concinna*
Pocillop damicornis	*Fungia klunzingeri*
Porites annae	*Galaxea astreata*
Porites encrusting	*Goniastrea*
Porites randalli	*Gonia pectinata*
Psammoc contigua	*Goniop fruiticosa*
	Isopora palifera
19 sp	*Lept transversa*
	Merulina ampliata
	Monta annuligera
	Mont informis
	Mont turgescens
	Pachy rugosa
	Pavona chiriquen
	Pavona explanulata
	Pavona varians
	Porites arnaudi
	Porites lutea
	Porites monticulosa
	Psam nierstraszi
	33 sp

Other coral species are found on both the reef flat or slope, but have more cover on one of the two zones. Table 13 lists coral species with the two preferences.

Table 13. Coral species that prefer either reef flat or slope, but are found in both.

prefer flat >0.5	prefer slope <0.5
Acropora aspera	*A. abrotanoides*
A. hyacinthus	*A. austera*
Cyphastrea	*A. clathrata*
Favites	*A. cophodactyla*
Galaxea fascicularis	*A. intermedia*
Goniastrea minuta	*A. pagoensis*
Hydnophora microconos	*Favia matthai*
Isopora crateriformis	*Leptastrea purpurea*
Leptoria phygia	*Montastrea curta*
Millepora playphylla	*Montipora grisea*
Pocillopora verrucosa	*Pocillopora eydouxi*
Porites cylindrica	*Pocillopora meandrina*
Porites massive	*Porites rus*

Figure 92 shows the trends in the mean number of coral species in transects on the reef flats. The number increased over the study period.

Figure 92.

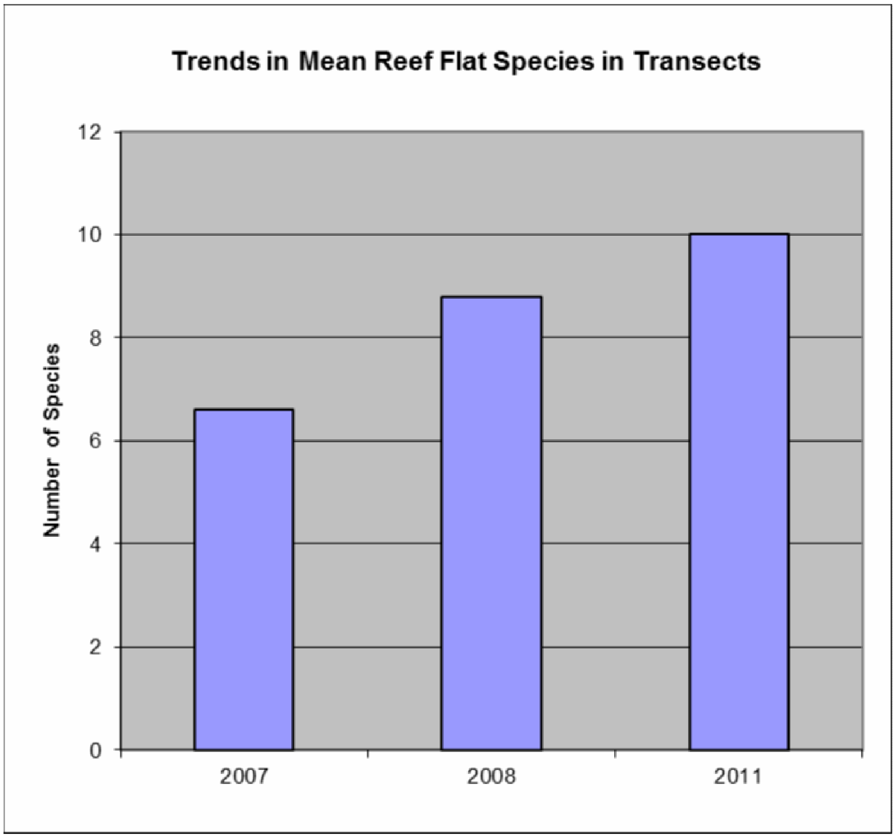
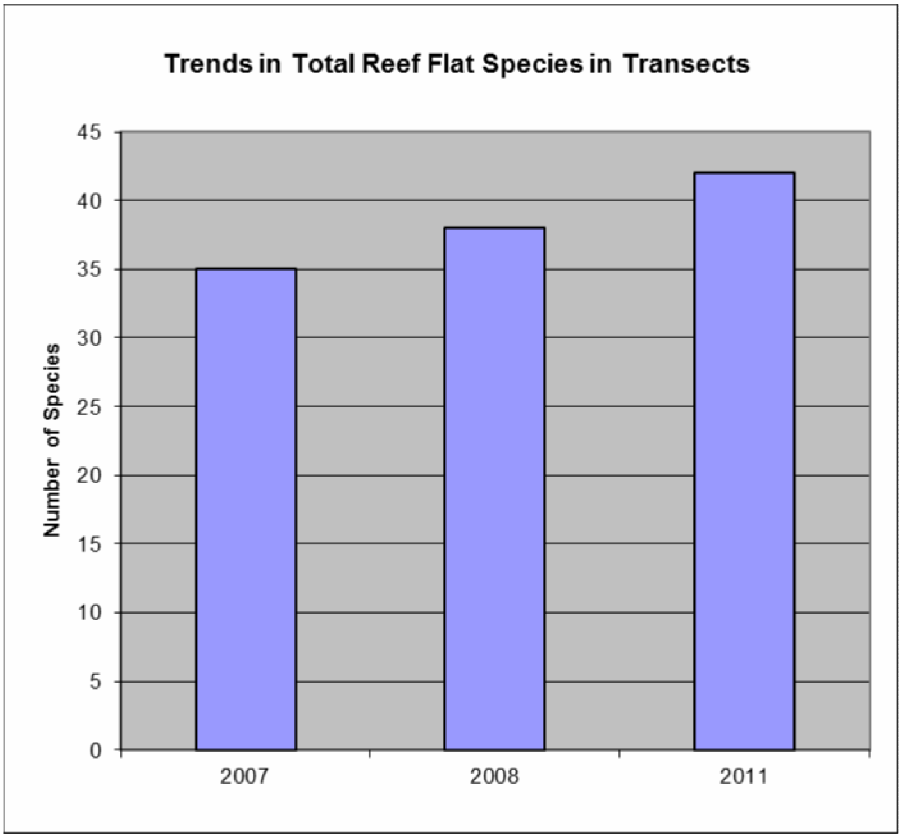


Figure 93 presents trends in the total number of coral species in reef flat transects. The number increased over the study period.

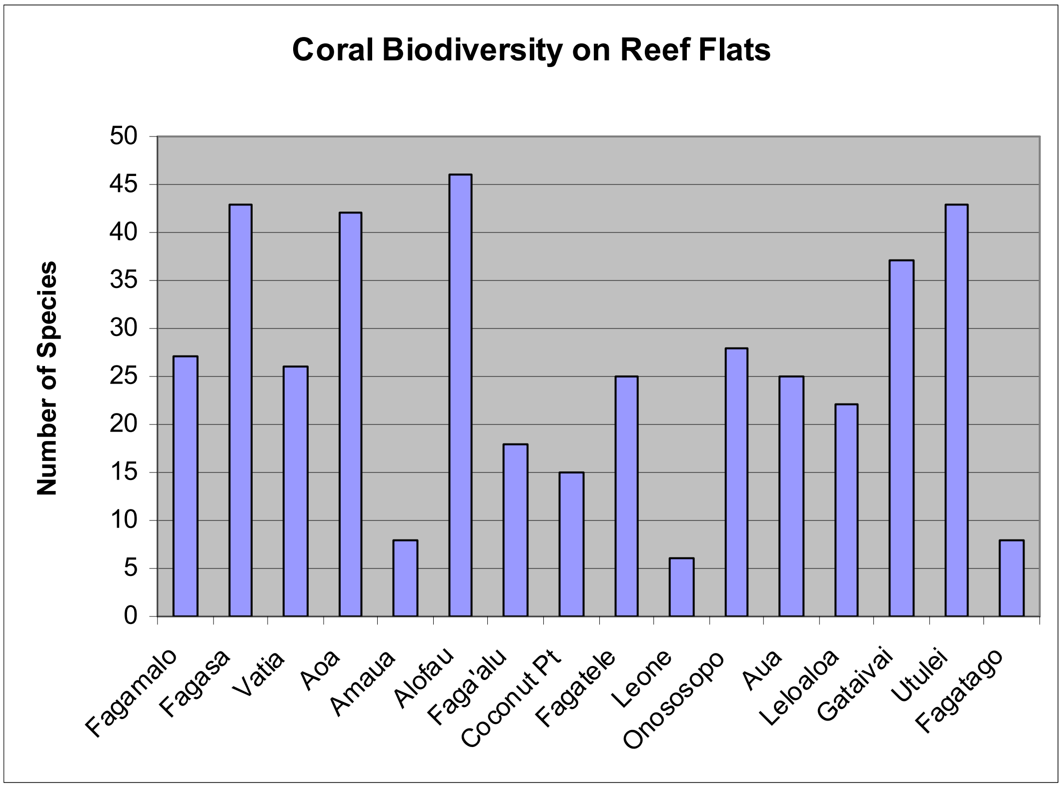
Figure 93.



Coral Biodiversity on Reef Flats

Coral biodiversity on reef flats was assessed in one hour snorkels much like on the reef slopes. Several additional sites were surveyed in the harbor. The results for each site are shown in Figure 94. Sites on the left are outside the harbor, and the six sites on the right are inside the harbor. As on reef slopes, variation between sites is large.

Figure 94.



There were many coral species that were found in biodiversity surveys only on the slope or only on reef flats. Table14 presents the species that were found in the biodiversity surveys only on the reef flats or only on the slopes. Ten species were found only on the reef flats, but 78 species were found only on the reef slopes. The list for the slope has larger numbers of species than the 33 species listed in Table 10, because biodiversity dives cover a much larger area than just 400 points at 8.5 m depth, and so many more species are found.

Table 14.

Reef Flat Only	Slope Only
Acropora aspera	*Acanthastrea brevis*
Acropora muricata	*Acanthastrea echinata*
Acropora gemmifera	*Acropora aculeus*
Acropora pulchra	*Acropora granulosa*
Cyphastrea sp. 1	*Acropora insignis*
Favites halicora	*Acropora microclados*
Millepora exesa	*Acropora paniculata*
Montipora capitata	*Acropora speciosa*
Porites stephansoni	*Acropora verweyi*
Psammocora contigua	*Alveopora*
	Astreopora eliptica
10 species	*Astreopora gracilis*
	Astreopora randalli
	Caulastrea echinulata
	Ctenactis crassa
	Diploastrea heliopora
	Echinophyllia aspera
	Echinopora gemmacea
	Echinopora lamellosa
	Euphyllia glabrescens
	Favia stelligera
	Favites paraflexuosa
	Favites pentagona
	Fungia concinna
	Fungia granulosa
	Fungia paumotensis
	Fungia scruposa
	Fungia scutaria
	Gardineroseris planulata
	Goniastrea edwardsi
	Goniastrea pectinata
	Goniopora fruiticosa
	Halomitra pileus
	Herpolitha limax
	Hydnophora exesa
	Hydnophora rigida
	Leptastrea bewickensis
	Leptastrea pruinosa
	Leptoseris mycetoseroides

Leptoseris scabra
Merulina ampiata
Millepora dichotoma
Montipora aequituberculata
Montipora foveolata
Montipora informis
Montipora tuberculosa
Montipora turgescens
Mycedium elephantotus
Mycedium sp.
Oulophyllia bennettae
Oulophyllia crispa
Oxypora lacera
Pachyseris gemmae
Pachyseris rugosa
Pachyseris speciosa
Pavona duerdeni
Pavona gigantea
Pavona maldivensis
Platygyra pini
Plesiastrea versipora
Porites arnaudi
Porites horizontallata
Porites lutea
Porites monticulosa
Porites sp.
Psammocora haimeana
Psammocora nierstraszi
Sandalolitha dentata
Scapophyllia cylindrica
Stylaster sp.
Stylocoeniella armata
Stylocoeniella guntheri
Stylophora pistillata
Symphyllia agaricia
Symphyllia radians
Symphyllia recta
Turbinaria mesenterina
Turbinaria stellulata

78 species

Almost all these species were found only where experience indicates they are found. One exception was *Millepora dichotoma*, which is most common in backreef pools by far.

There were also species which showed a preference for either the reef flat or the slopes. A ratio of the mean abundance scores was calculated for each species, flat/(flat + slope), and ratios over 0.7 were considered a preference for the reef flat, and ratios under 0.3 were considered a preference for reef slope. These numbers were used instead of 0.5, because the scale is an ordinal scale not a cardinal scale, and calculating a mean score like they were cardinal numbers can be inaccurate. The scale is probably closer to something like a log scale, so a 5 might be twice or even 10 times as abundant as a 4. So a cautious approach was taken to require a stronger signal before ascribing preference. The weaknesses of this procedure should also lead to caution in their interpretation. However, almost all the species listed in one category or the other, fit with experience, so it appears to work surprisingly well. Table 15 gives species that prefer the reef flat or the reef slopes. Ten species prefer reef flats and 27 species prefer slopes. Both the number of species that were found on only one and not the other, and the number of species that prefer slopes and reef flats, indicate that the slopes have higher species diversity than the reef flats, which is also the conclusion from the quantitative measure of the number of species on flats and slopes.

Table 15.

prefer flat	prefer slope
Acropora palmerae	*Acropora abrotanoides*
Acropora robusta	*Acropora austera*
Favites abdita	*Acropora cerealis*
Pavona decussata	*Acropora clathrata*
Pavona frondifera	*Acropora globiceps*
Pocillopora damicornis	*Acropora latistella*
Pocillopora setichelli	*Acropora monticulosa*
Porites annae	*Acropora nasuta*
Porites cylindrica	*Acropora pagoensis*
Porites massive	*Acropora surculosa*
	Astreopora cucullata
10 species	*Coscinarea collumna*
	Cyphastrea sp.
	Echinopora hirsutissima
	Fungia fungites
	Galaxea astreata
	Hydnophora microconos
	Leptastrea cf. purpurea
	Leptastrea transversa
	Lobophyllia hemprichii
	Millepora tuberosa
	Montastrea annuligera
	Montastrea curta
	Pavona chiriquensis
	Pavona varians
	Pocillopora eydouxi
	Psammocora digitata
	27 species

Coral biodiversity was also recorded in several backreef pools. No species were found only in pools, but eight species preferred pools over both reef flats and slopes. All of the species that were found to prefer backreef pools in the biodiversity data also are known from experience to be more abundant in backreef pools than anywhere else. Table 16 lists the eight species.

Table 16.

prefer pools
Acropora muricata
Acropora pulchra
Alveopora
Millepora dichotoma
Millepora exesa
Pocillopora damicornis
Porites cylindrica
Porites randalli

Figure 95 shows the mean number of coral species in diversity snorkels on reef flats for the harbor and outside the harbor. The mean number of coral species inside the harbor on reef flats was slightly higher than outside the harbor. This is quite different from on the reef slopes, where the mean number was lower inside the harbor. The lower number on slopes inside the harbor could be due to pollution in the harbor, but the higher number on reef flats in the harbor suggests that maybe the corals on reef flats weren't affected by pollution, at least as far as diversity is concerned.

Figure 95.

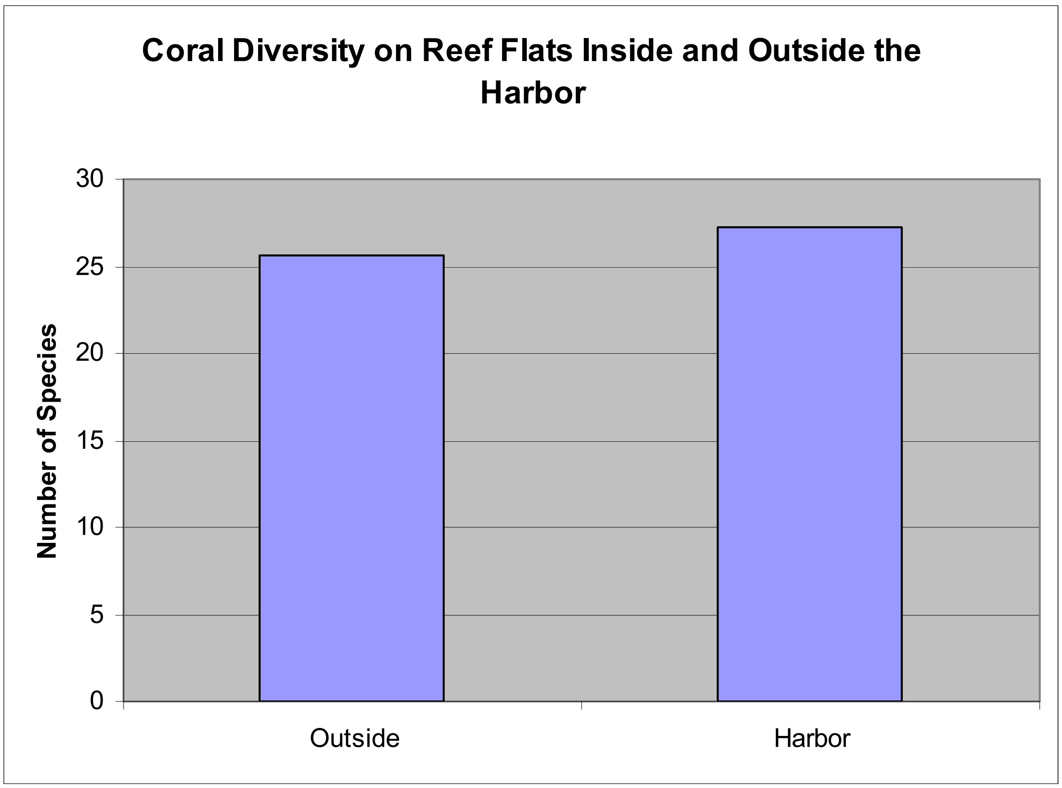


Figure 96 compares the mean number of coral species in biodiversity searches on the slopes and reef flat, inside and outside the harbor. The number of species on the slopes was higher than on reef flats, as was found in transects. On the slopes, the number of species in the harbor was less than outside the harbor, but on the reef flats there were slightly more in the harbor than outside the harbor.

Figure 96.

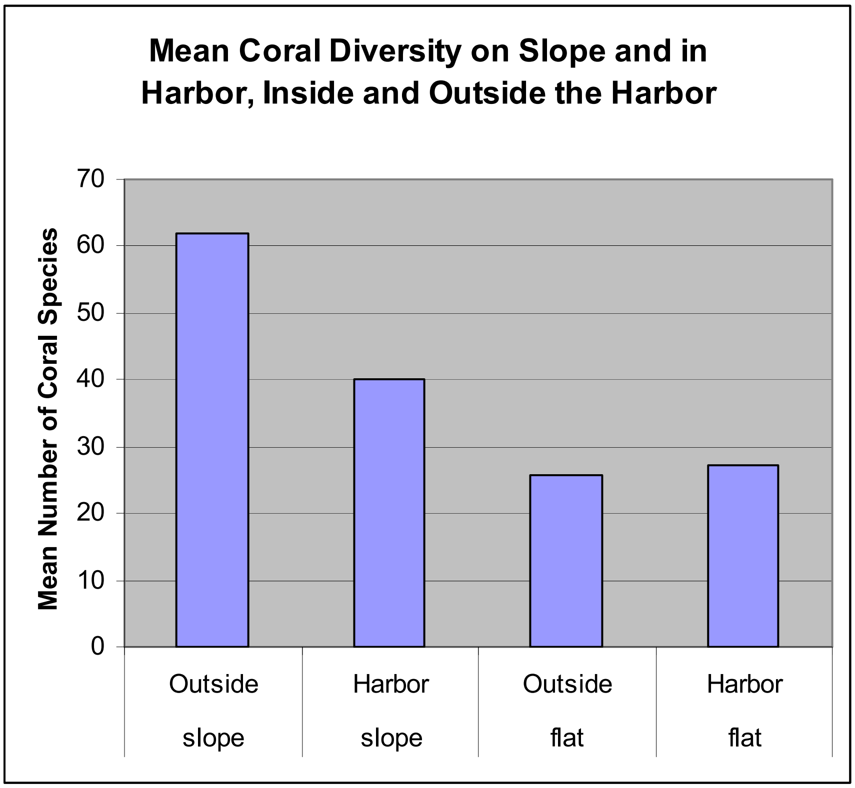


Figure 97 compares the mean number of coral species in one hour diversity searches on the reef flats on the North compared to the South sides. The North side sites had much higher diversity than the South side sites.

Figure 97.

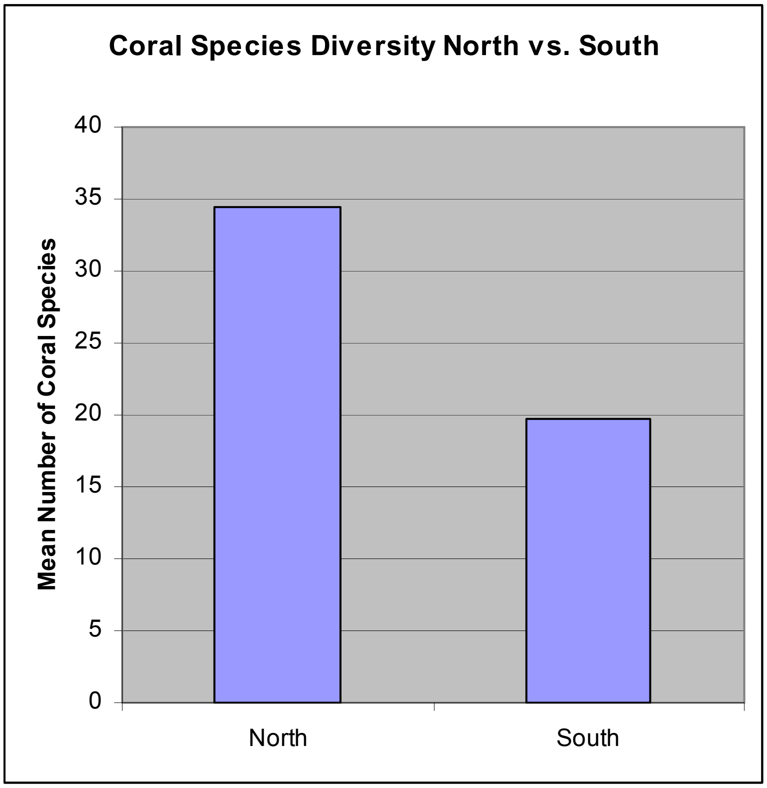
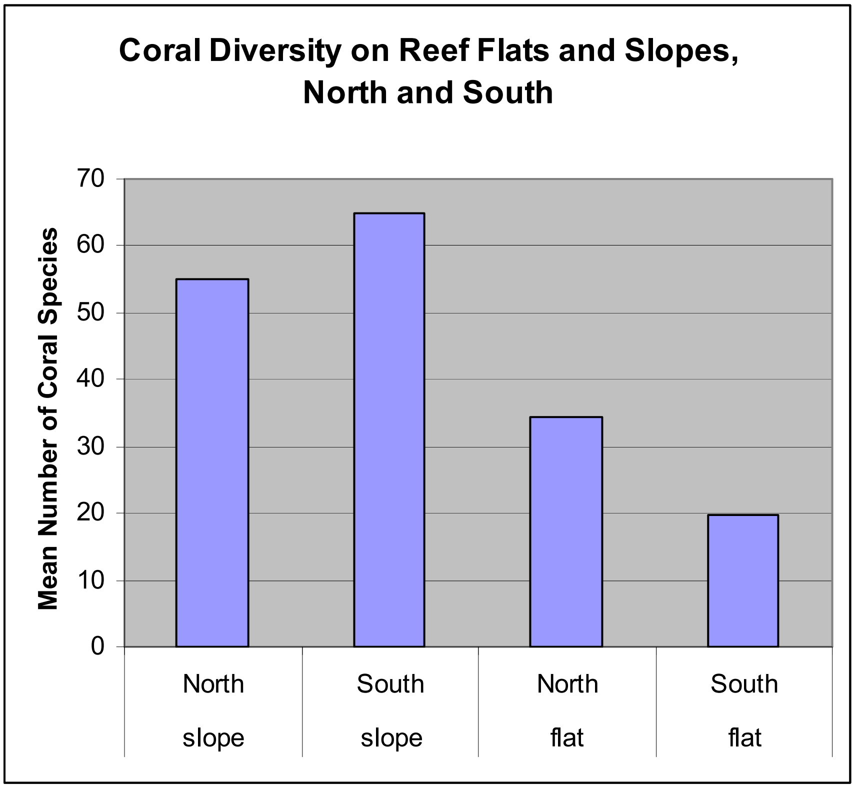


Figure 98 compares the mean number of coral species in diversity searches on reef slopes and reef flats, on the North and South sides. There were more coral species on slopes than on reef flats. Also, there were more on the south side than north in slopes, but more on the north side than south for reef flats. It is not clear what caused this pattern, though 2011 is the first year in which the south slopes had more species than north.

Figure 98.



Ofu-Olosega Reef Flats and Pools

The opportunity arose to collect coral data from reef flats and pools on Ofu and Olosega for the first time in November, 2011. Transects were run on reef flats, but corals in pools were so patchy that transects in the pools were not attempted. Two transects were taken on the reef flat near Vaoto Lodge on the south side of Ofu, one on the inner reef flat and one on the outer reef flat. One transect in each of these two zones was also taken near Pool 500 on the south side of Ofu, and between the bridge and Sili village on the north side of Olosega. Although the two islands are separate (connected by a short bridge) the reef is continuous around the two islands. The results are shown in Figure 99. Coral cover was higher at Sili/bridge on the north side of Olosega than at the Ofu sites, though there was considerable variation. Mean coral cover at the three sites was slightly higher on the inner reef flat than on the outer reef flat. Average coral cover overall was just under 20%, close to that on Tutuila when reef flats were first surveyed in 2007 (Figure 67).

Figure 99.

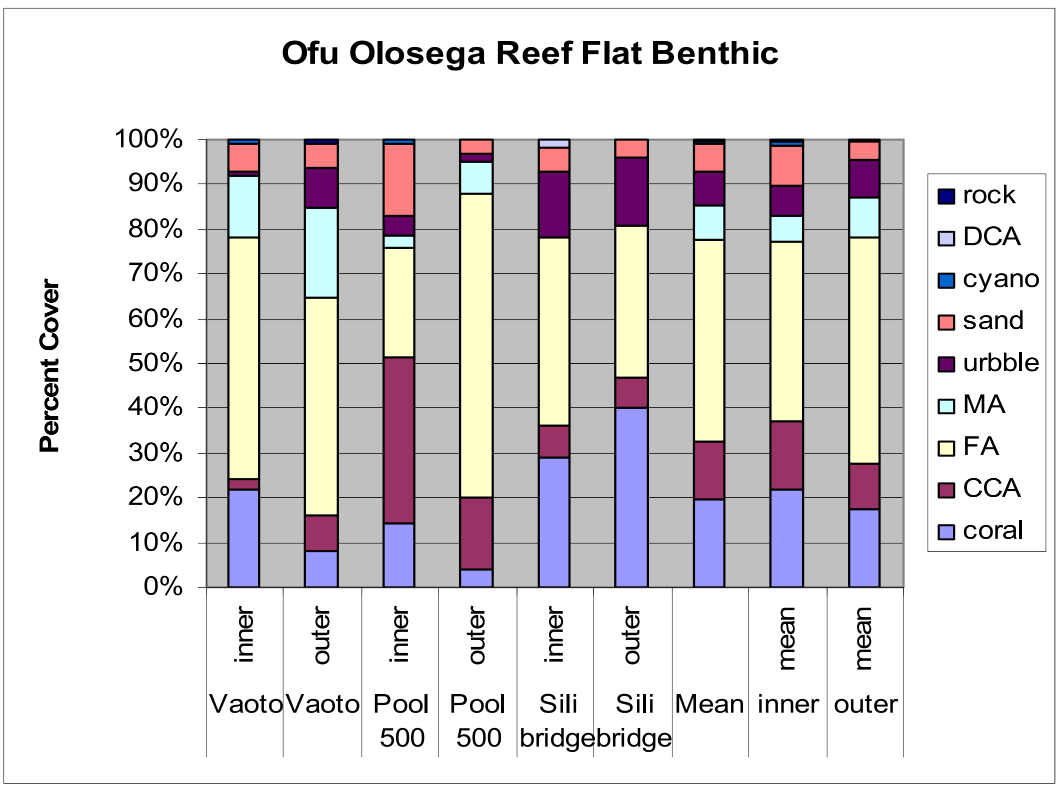


Figure 100 shows a comparison of reef flat cover on outer reef flats at Ofu-Olosega and Tutuila, from the data taken in 2011. Tutuila had higher coral cover on the outer reef flat than Ofu-Olosega and higher crustose calcareous algae cover, but lower turf algae cover. It is not clear why there should be this difference. The sample in Ofu-Olosega was much smaller and it could well be that it was not representative of reef flat there.

Figure 100.

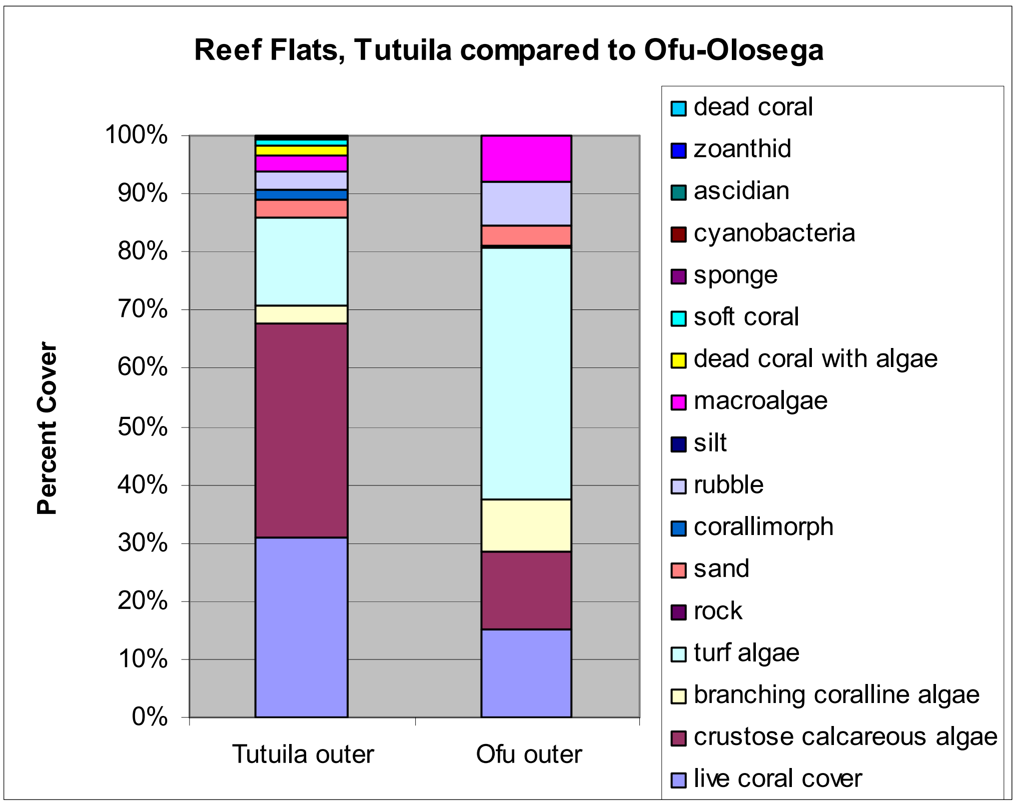
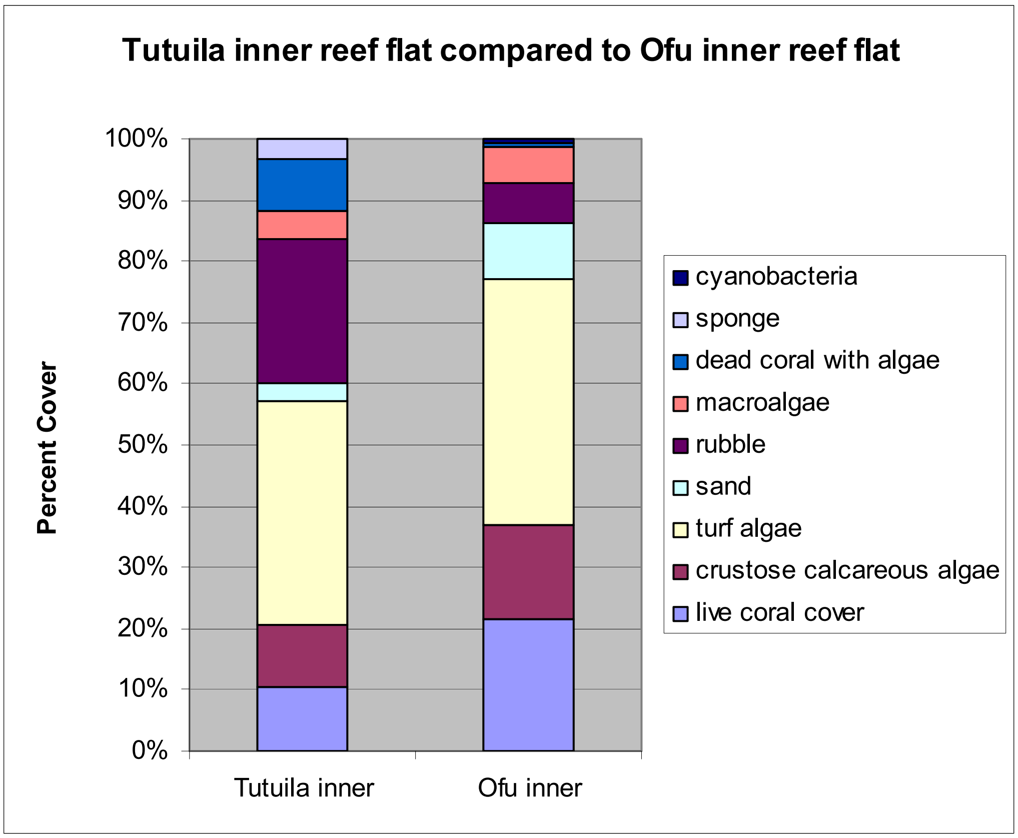


Figure 101 compares reef flat cover for the inner reef flat on Ofu-Olosega and Tutuila. The source of the data for Tutuila inner reef flat was the data from 2008, which was the last time there was more than just two sites where inner reef flat was surveyed on Tutuila. Six inner reef flat sites were surveyed on Tutuila in 2008. Coral cover was higher on Ofu-Olosega than at Tutuila, while rubble cover was higher on Tutuila. Again, it is not clear why these differences occurred.

Figure 101.



Ofu-Olosega Coral Biodiversity on Reef Flats and in Pools

Coral biodiversity was surveyed on the reef flats and in the pools of Ofu-Olosega, using the standard one-hour search technique. Data was collected from four reef flat sites and eight pools. Figure 102 shows the results for individual reef flat sites and pools.

Figure 102.

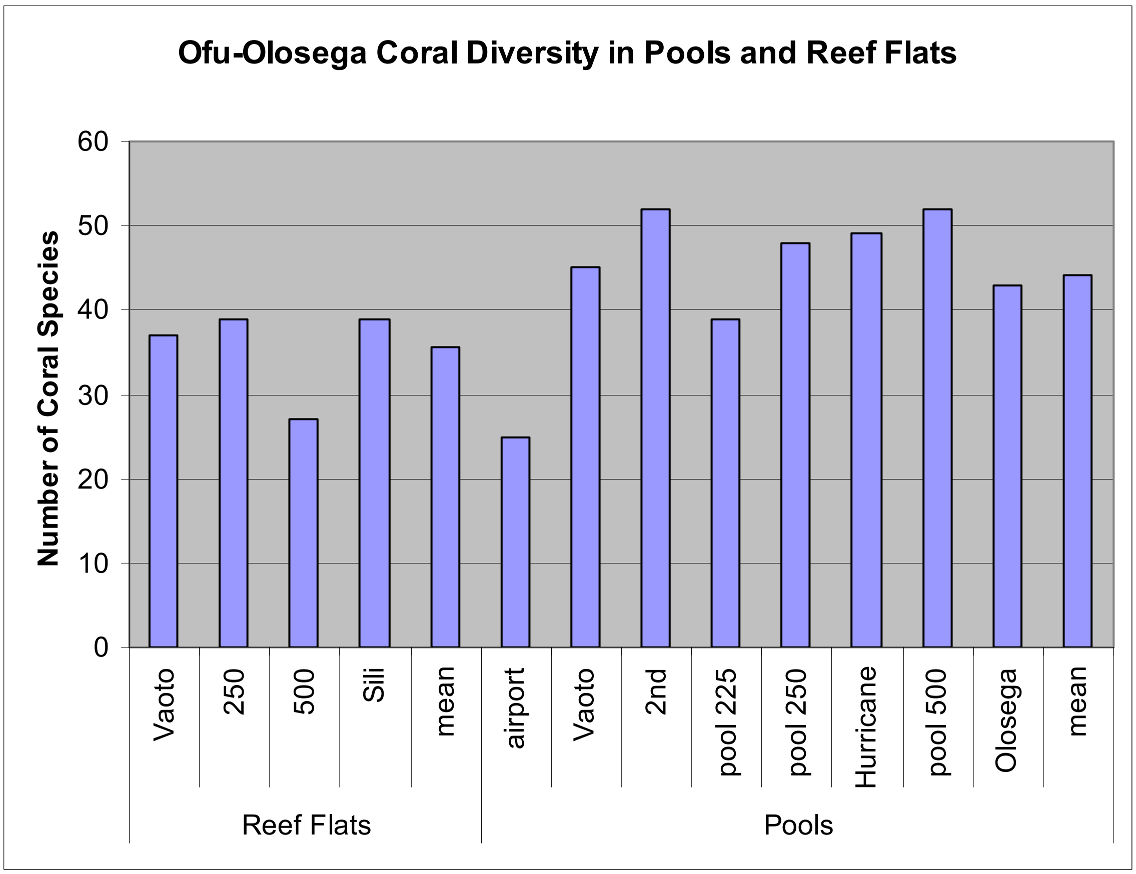


Figure 103 shows a comparison of the mean number of species found in one hour searches on reef flats and in pools on Ofu-Olosega and Tutuila. Diversity was highest in the pools on Ofu-Olosega, and lowest in the pools on Tutuila. Ofu-Olosega had higher diversity on reef flats than Tutuila, and higher diversity in pools than Tutuila. The pools in Tutuila were all excavated to provide material for villages or airport construction a few decades ago, but the pools on Ofu appear to be natural and probably have been there for at least hundreds and perhaps thousands of years. Thus, the Ofu pools are much older, and the higher diversity there could reflect a process of accumulation of species slowly over time. There appears to be no direct test of this hypothesis so far. This hypothesis would not explain why Ofu-Olosega has higher diversity on its reef flats than Tutuila (because reef flats on Ofu have no reason why they would be older than on Tutuila), but that difference is less than in the pools.

Figure 103.

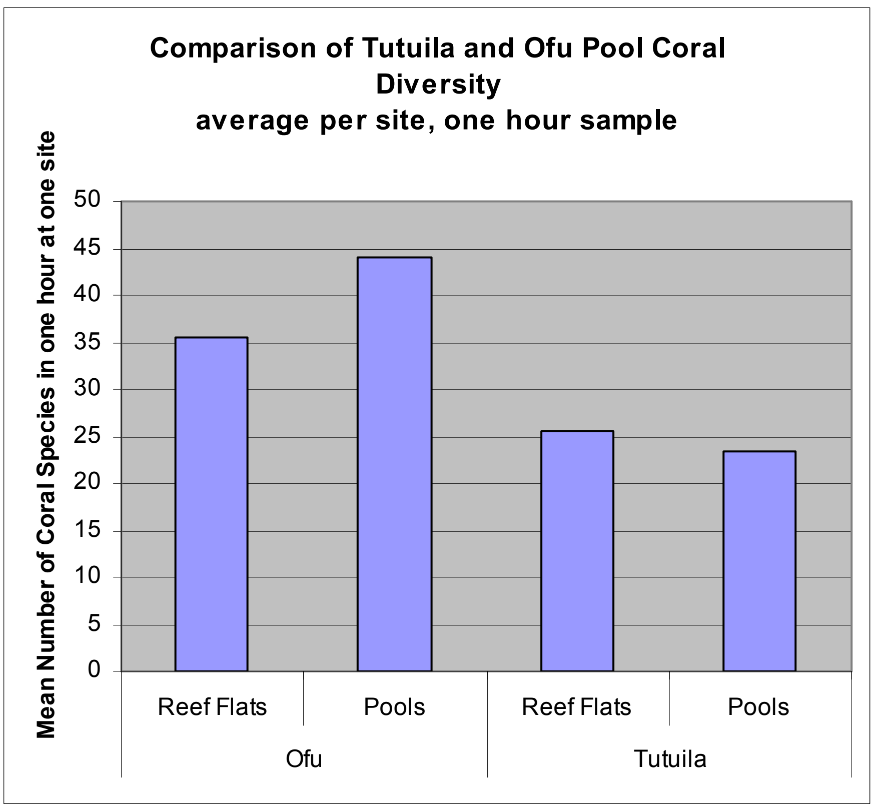


Figure 104 presents the total number of coral species found on flats and in pools in all searches, on the two islands. In this graph, the reef flats on Tutuila have the largest total number of species. However, there were one hour searches at 12 reef flat sites on Tutuila, but only four on Ofu reef flats, six in Ofu pools, and five in Tutuila pools. Additional searches at additional locations will always add to the total number of species, so Tutuila reef flats benefit from having a larger sample size than the other locations, and this comparison does not reflect differences in actual diversity.

Figure 104.

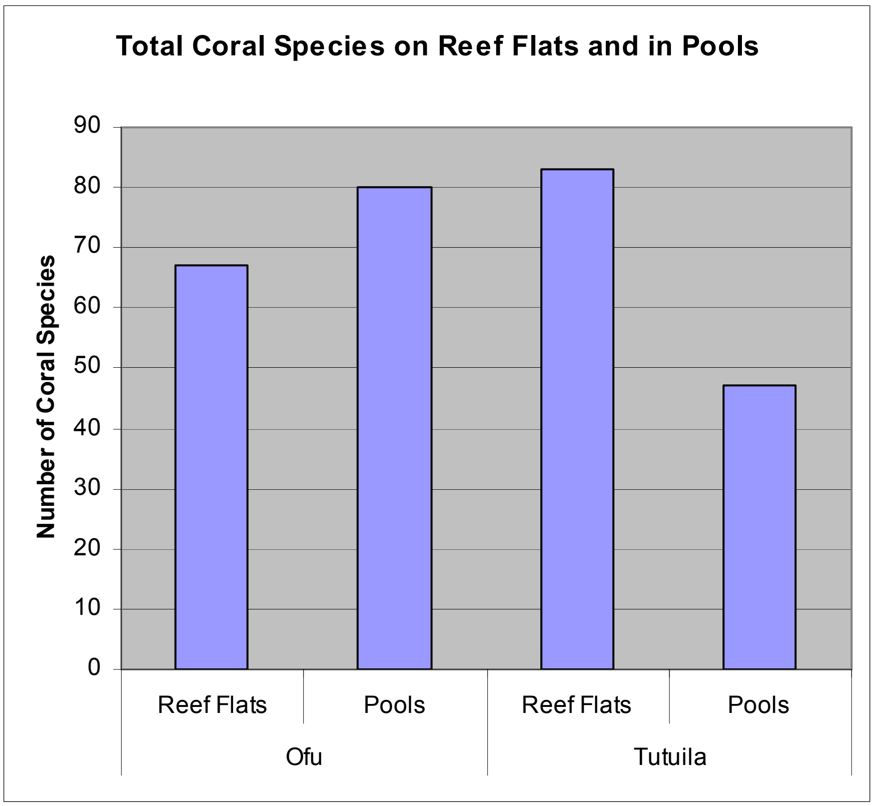
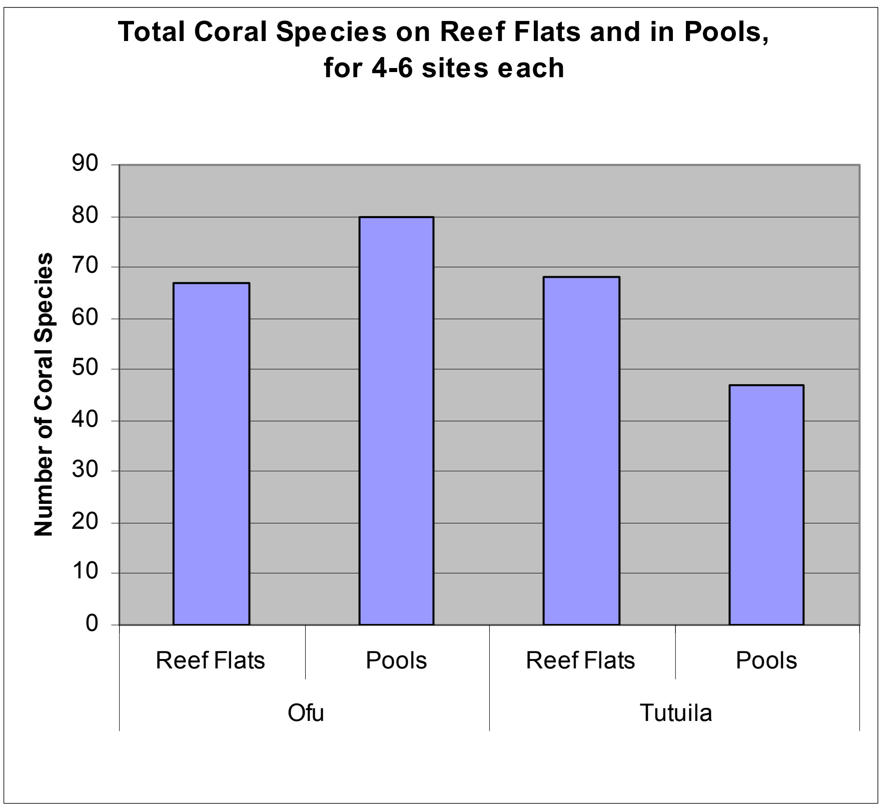


Figure 105 presents a comparison of the total number of coral species found in the different zones based on four samples on Ofu reef flats, six in Ofu pools, five on Tutuila reef flats, and five in Tutuila pools. In this comparison, Ofu and Tutuila have almost identical total numbers of coral species on reef flats, but Ofu has more coral species than Tutuila in the pools. This data is consistent with the hypothesis that Ofu pools have more species because they are older and have had more time to accumulate species. One possible problem with that hypothesis could be that hundreds or even thousands of years seem like a long time for coral species to become established, since larvae available to settle seem likely to be fairly large each year and the pools should have as many as reef slopes. Quantitative measures of diversity of coral recruits on reef slopes and in pools are not available.

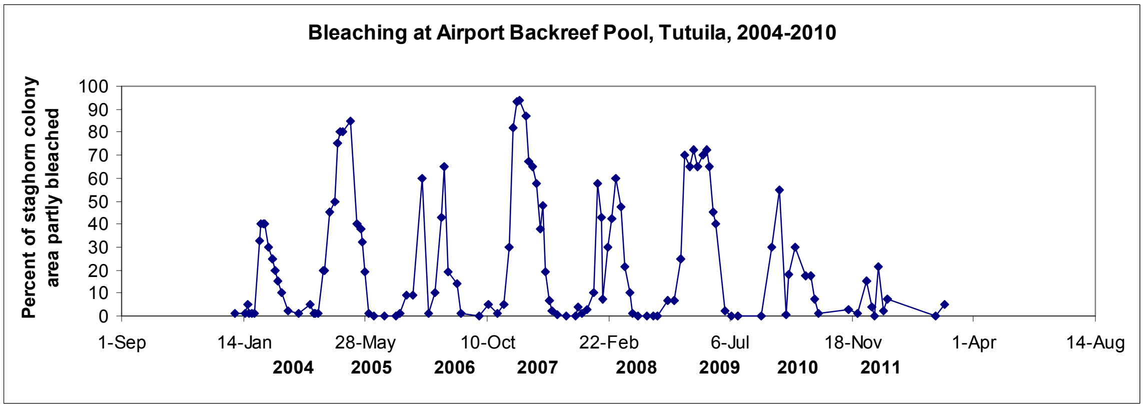
Figure 105.



Bleaching

Bleaching monitoring continued in the airport backreef pool, and the Alofau pool. The annual austral summer bleaching of the staghorns continues, with the graph for the airport through 2010 shown below in Figure 106. The bleaching for 2010 had a notch in

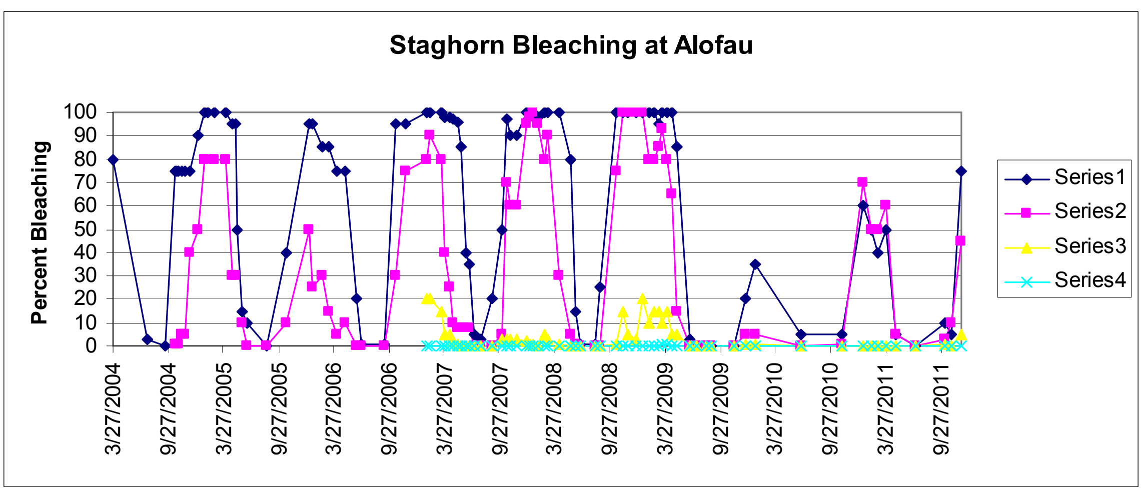
Figure 106.



it, like the notches in 2006 and 2008 due to cloudy, rainy, cool weather. Then in 2011, bleaching was much less than in previous years. It is not clear why that was the case.

Figure 107 shows the bleaching record at Alofau. The unbleached period in late 2009 was the longest recorded so far, and bleaching in 2010 was the least intense of all the years it has been recorded. A gap in monitoring in 2010 may help explain the low level of bleaching recorded, since it was not recorded at a time when it may have been highest. This was due to the lack of vehicles, since the tsunami had destroyed most of the departmental vehicles and they had not been replaced yet. In 2011, bleaching increased closer to levels in previous years.

Figure 107.



Disease

A disease outbreak was observed in Vatia Bay on 2/19/11 following Hurricane Wilma on 1/24/11. Observations were made along the south side of the bay. The disease observed was areas of white skeleton between live tissue and skeleton which showed progressively darker turf algae with distance from the live tissue. *Acropora abrotanoides, Acropora monticulosa, Pocillopora verrucosa* and *Pocillopora edouxi* were the most commonly affected, and *A. monticulosa* appeared to be the most severely affected. Almost all *A. monticulosa* colonies appeared to be affected and a few were completely dead. Subsequent observations showed that the width of the white area decreased in time, as well as the proportion of colonies that had white areas indicating active disease. The width of the white area is probably an indicator of the speed with which the disease is killing the colony. Observations of other areas following the first observations indicated that the disease was also present on the north side of the bay and that the reduction in disease was a little earlier on the north side than the south side. Observations of other areas indicated that there was a fair bit of white disease on *Acropora nana* near the reef crest at Alofau even though there was no hurricane damage observed at Alofau. Also, heightened levels of white disease were seen on *Pocillopora* at Alofau and some other sites. Fairly low levels of white disease on *Pocillopora* appears to be chronic all over Tutuila, with scattered diseased colonies seen at many sites and over the entire span of the author's observations since 2004. Also, the reefs all have a significant amount of old standing dead *Pocillopora* colonies that are covered with a mixture of turf and coralline algae, indicating significant amounts of mortality over the years. The observed disease on *Pocillopora* after Wilma was greater than this background level, but not all colonies had disease. *Isopora crateriformis* was observed to have a very few diseased colonies on the southwest of Tutuila where they are abundant, the first colonies of that species that the author has ever observed with disease. *Isopora* was previously considered a sub-genus of *Acropora*, but recently has been elevated to genus status. Clearly, *I. crateriformis* is closely related to *Acropora*. Interestingly, no white disease was observed on the staghorn species *Acropora nobilis* in Vatia Bay, nor any of the staghorns (*Acopora muricata*, *Acropora pulchra*, and *A. nobilis*) in any of the backreef pools. Even colonies of *A. nobilis* with damage from the hurricane did not have disease. Thus, although *Acropora* and *Pocillopora* were the only genera affected, not all *Acropora* species were affected. *Acropora hyacinthus* in Vatia had very few affected colonies. Oh the south side, the diseased colonies were all in the mid to outer part of the bay, but then the inner part of the bay had no colonies left due to the tsunami, and some like *A. monticulosa* and *A. abrotanoides* were much more common in the outer bay even before the tsunami.

No outbreak of disease was observed following the tsunami. The fact that the disease was well underway when first observed 26 days after the hurricane, plus the fact that the disease was most intense at the only location where the hurricane did significant damage, suggests but certainly does not prove that the hurricane caused the disease outbreak. Disease outbreaks have been reported following bleaching events (Bruno et al 2007; Wilkinson and Souter, 2008), however this report appears to be the first report of a disease outbreak following a hurricane. Higher temperatures are reported to increase disease such as black band (Boyett et al 2007; Bruno et al 2007), which suggests a mechanism for disease outbreaks to follow bleaching events, since bleaching is caused by high temperatures. However, it is not at all clear how a hurricane might cause a disease outbreak, nor why this relatively mild hurricane would produce disease while disease outbreaks have not been reported following far stronger hurricanes. Speculative possible mechanisms might include stress on the corals that could make them vulnerable to diseases they could resist otherwise, and the possibility that the heavy surge could disperse diseases. But if a hurricane could produce a disease outbreak, why couldn't a tsunami? They both produce violent water motion and damage to corals. The possibility remains that the timing and location of the disease outbreak followed the time and location of the hurricane by chance.

During the work on Ofu-Olosega in November, 2011, disease was noticed on colonies of *Porites rus* in the Vaoto Lodge pool. The disease produced white areas that graded from white to yellow to normal colony color. Parts of the colonies were dead. There were many large, essentially massive colonies with very lumpy surfaces. The white was not on the upper surfaces of lumps any more than on lower surfaces, and nearby surfaces at the same orientation were not the same shade of color, indicating it was likely disease instead of bleaching. Further, the portions of the colonies that were dead were not restricted to upper surfaces. Also, no other corals nearby or in any of the pools were bleached, and *Porites* is much more resistant to bleaching than *Acropora* and *Millepora*, which were not bleached. Colonies of *Porites rus* in the Vaoto Lodge pool were visually surveyed for percentage of each colony's surface that was diseased, percentage of each colony's surface that was dead, and the diameter of each colony was measured.

Figure 108 shows the distribution of colony sizes of *Porites rus* in the Vaoto Pool. The modal size was 50 cm and the mean size was 69 cm. If colonies grew 1 cm a year, such a colony would be 25-35 years old (since the diameter, not the height, was measured, and thus there were two growing surfaces. The largest colony is 300 cm, and if it grew 1 cm a year, would be 150 years old.

Figure 108.

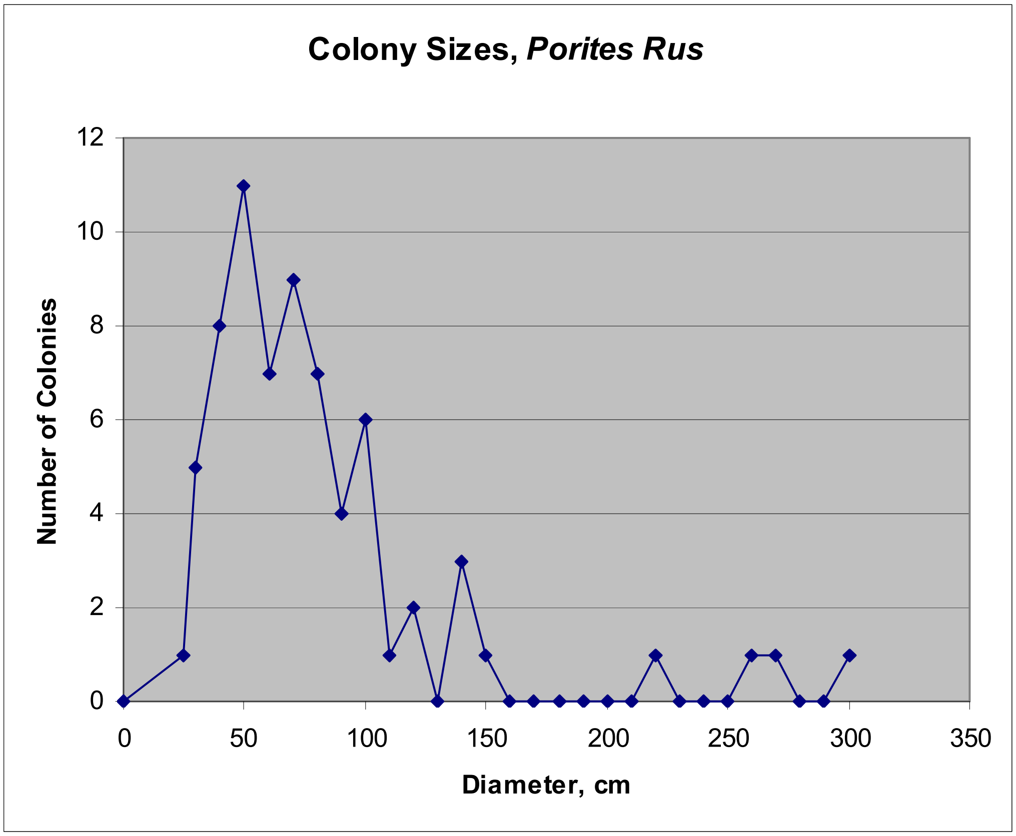


Figure 109 shows the percentage of colony surface on each colony that was diseased at that time. The modal percentage of colony surface that was infected was 30%, but the mean was 11.8%. So only a small proportion of the colony surface was currently diseased. That is probably pretty typical for coral diseases.

Figure. 109

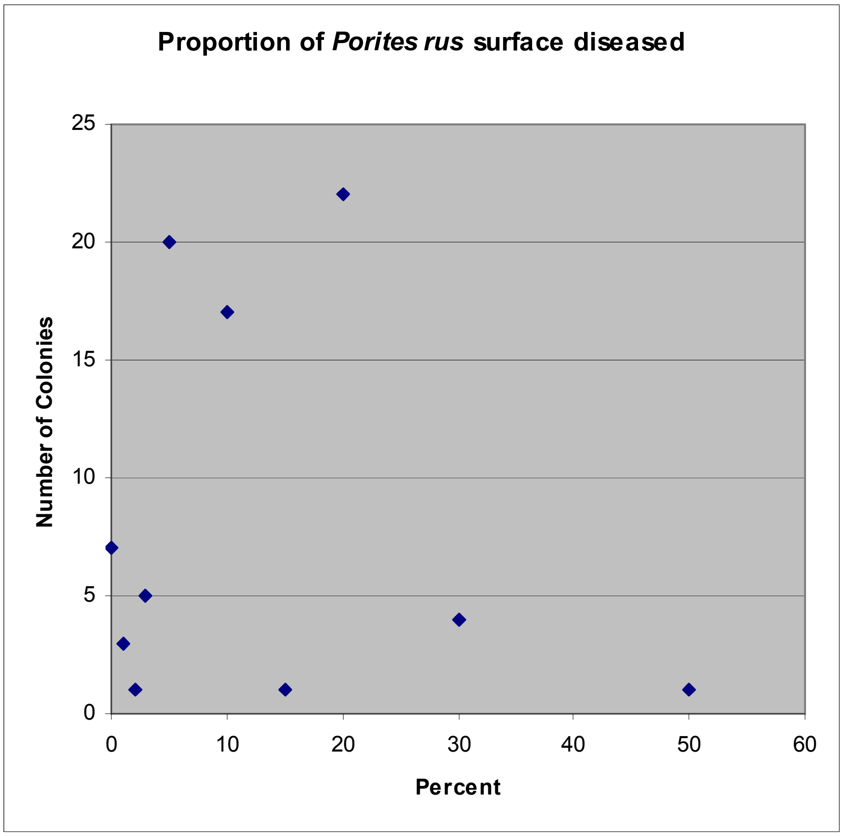
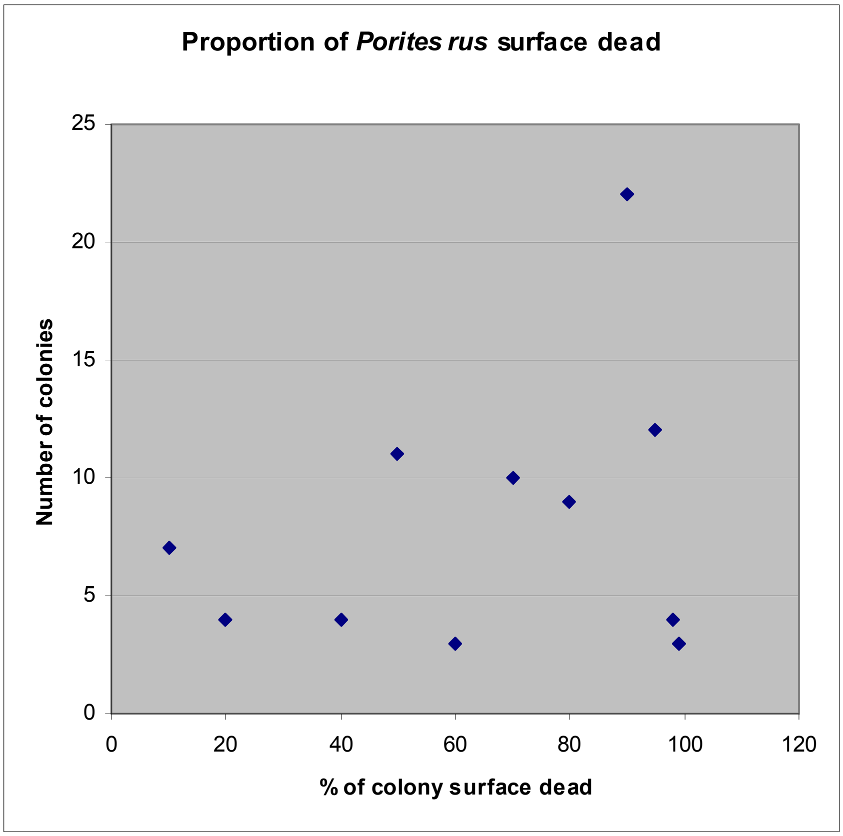


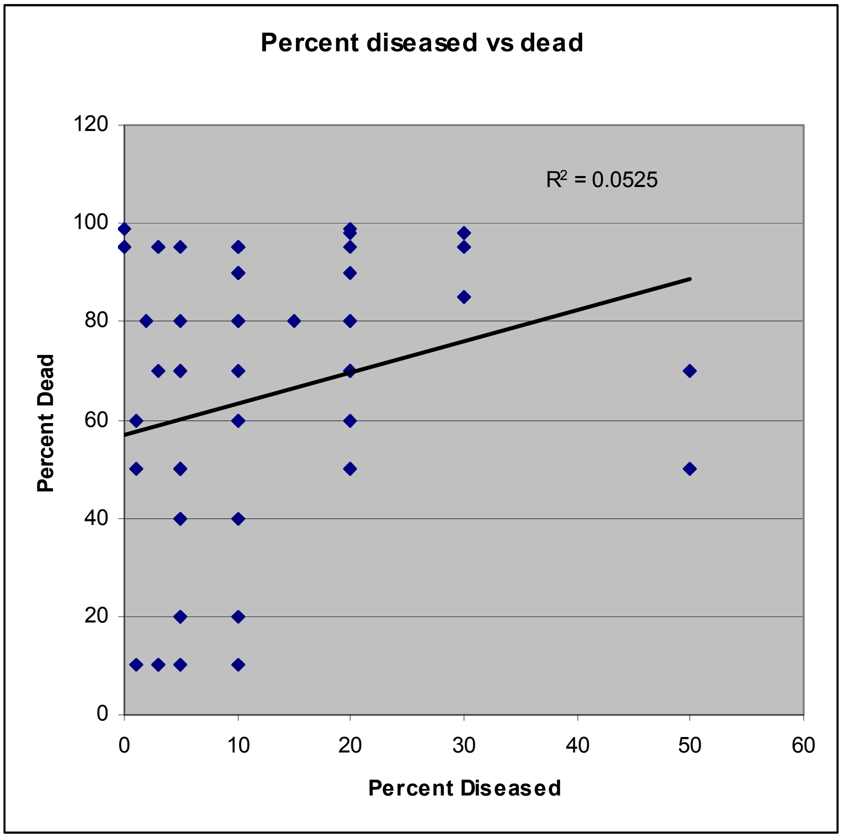
Figure 110 shows the proportion of each colony that was dead. The modal percentage dead was 90%, indicating that this disease was well advanced and very detrimental to these corals. The mean percentage of each colony that was dead was 53.7%. No disease on these corals was noticed in previous years.

Figure 110.



There was only a very weak relationship between the percentage of the colony surface that was diseased with the percentage of the colony surface that was dead, as shown in Figure 111. The correlation was r = .2291, which was significant ($p < .05$).

Figure 111.



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Appendix 1. Reef Health

The following document was provided as a summary of the condition of the benthic communities of the coral reefs, as habitat, to the Fisheries Council for incorporation into their Coral Reef Plan Team report. It was based on the report for the previous year.

The State of Coral Reef Habitat in American Samoa, 2012. Douglas Fenner, Ph.D.

Coral reef scientists have not reached an agreement on the definition of coral reef health, but they often mention the provision of ecosystem services, and comparisons with ecosystems that have not been impacted by humans. The benthic substrate and coral communities provide habitat for fish, and are essential fish habitat that is necessary for healthy fish populations and sustainable fish catches. Monitoring habitat is part of Ecosystem-based Management.

The coral reef slopes of Tutuila, American Samoa, have about 30% live coral cover in transects, in five different monitoring programs (Fenner et al. 2008). That is slightly higher than for the Pacific as a whole and the South Pacific in particular (Bruno and Selig, 2007) and for 17 countries in the Pacific (SPC, 2005). Coral cover in towboard surveys is nearly as high as the US PRIAS (which are near-pristine) and higher than in the Hawaiian and Marianas archipelagos (Vroom, 2010) (though lower than in transects in American Samoa because transect locations are usually chosen to be better than random sites). Coral cover is not as high as in the Pacific in the past (Bruno and Selig, 2007), nor as high as two estimates of American Samoan coral cover in the past (Wass, 1982; Maragos; although the accuracy of estimates is questionable mainly because sites were not chosen randomly; no quantitative data exists from before the COTS outbreak). Coral cover has increased slightly over the 7 years of the Territorial Monitoring Program, and CRED has recorded increases of average coral cover around Tutuila as well (PIFSC, 2011) as has the Key Reef Species program. Average coral cover in the Pacific has been decreasing (Côté et al. 2006; Bruno and Selig, 2007), so the increase in coral here is better than the Pacific averages for change. There is only a small amount of dead coral, only about 5% cover, much less than in the average for 17 Pacific countries (SPC, 2005). Coral cover on reef flats (about 8-21%) is not as high as on slopes. Coralline algae cover is high (Vroom, 2010) and macroalgae is low and similar to that on near-pristine reefs (Vroom, 2010). Coralline algae is considered good since it requires the same conditions as coral and attracts coral larvae, and macroalgae cover is considered bad because they compete with corals and can take over in phase shifts after a disturbance kills lots of coral. The predominant cover on the reefs is encrusting, both encrusting coralline algae and encrusting corals. This may provide less hiding cover for fish than would branching coral, though the reef matrix provides many hiding holes most places

The tsunami of Sept. 29, 2009, did significant damage to reef areas in Vatia Bay, Fagatele Bay, and Leone Bay, and lesser damage elsewhere. Heavily damaged areas were rare, moderately damaged areas more common, and lightly damaged or undamaged areas the most common. Within about 6 months, all the rubble moved in Fagatele Bay was completely covered with coralline algae, while none is at Vatia. Hurricane Wilma did additional damage in Vatia on Feb. 24, 2011, but little elsewhere.

Sedimentation rates near the mouths of streams are much higher than inside bays, which are in turn higher than outside bays. The water on outer reef slopes away from streams is relatively clear, with low nutrient levels. There is damage to small areas near stream mouths, and both Vatia Bay and the reef flat next to Coconut Point have had dense blooms of brown macroalgae. Those are no longer present in Vatia, but persist at Coconut Point. The reef slopes have more calcareous algae than non-calcareous, the calcareous is mostly coralline algae, but also the green macroalga *Halimeda*. They contribute to building the reef, and are not known to bloom during phase shifts, unlike brown algae. The reefs have remarkably little brown macroalgae. Reefs in the harbor are in very poor condition.

There are only a few introduced marine species, none of which are invasive. There are very few bioeroders or filter feeders, and calcium accumulation on the reef appears to be very good. Disease incidence is low. Macroinvertebrates, including herbivorous urchins, are in general uncommon to rare, for unknown reasons, but very likely this is natural. Some may be hidden from sight. Macroinvertebrates are food for some types of fish. Hawaii and the Marianas also lack abundant large non-cryptic invertebrates. There have been no bleaching events in the last 7 years, but 3 events before that. Peter Houk reports a negative correlation of human population with coral diversity, but TMP has been unable to replicate that using slightly different variables and different sites.

The largest single disturbance on the territory's coral reefs was the crown-of-thorns starfish outbreak around 1978. About 90% of all corals were eaten. Observers report that they remember that table corals and staghorns were common, but areas dominated by other corals were not unusual. Most of our reefs are now dominated by encrusting corals and only a few patches have high densities of tables and staghorns, except perhaps the banks where tables are common. Thus the reefs may still be recovering from that event. One reef patch at the mouth of Vatia Bay has shown remarkably rapid recovery, but other areas have recovered slowly. The cause is not known, but does not seem to correlate with human populations.

Benthic reef communities are by no means pristine, but relatively healthy and far healthier than places like the Caribbean. Habitat quality outside the harbor provides little support for suggesting that the lower fish biomass or low large fish abundances we have are due to poor habitat quality.

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Appendix 2

The Effects of Hurricane Wilma

Hurricane Wilma was a category 1 hurricane when the center (there was no eye) went directly over Tutuila on Jan 24, 2011.

To summarize, the effects of Wilma were greatest at Vatia Bay, and minor to non-existent elsewhere. The effects at Vatia were greatest near the mouth of the bay and least at the head of the bay. This was exactly the opposite pattern to that of the 2009 tsunami, which was most damaging near the head of the bay and least near the mouth of the bay. Wilma's damage extended beyond the mouth of the bay out along Pola Island. All of Vatia Bay and Pola Island reefs are now heavily damaged. Wilma was followed by white disease on *Acropora* and *Pocillopora*, that on *Acropora* may be the same as that called "white syndrome." There was heightened levels of white disease elsewhere as well, though not as great as in Vatia. Heavily impacted species at Vatia included *A. monticulosa* and *A. abrotanoides*. Nearly all colonies of *A. monticulosa* had it. After a few months the disease slowed and stopped, leaving many colonies partly dead and partly alive.

The following are emails that described the damage seen after the hurricane.

2/20/11

I was up at Vatia with Alice yesterday showing a visitor the tsunami
> damage. First, the shoreline had a lot of erosion from Wilma. Then out
> over the reef we could see a lot more rubble than there was just after the
> tsunami. Then I started spotting diseased corals. All I saw was on
> *Acropora* and *Pocillopora*. A digitate *Acropora* species that has
> pyramid-shaped branchlets, *A. monticulosa*, virtually every colony had it,
> and some were completely dead. A colony typically has some live tissue in
> the middle, surrounded by a white area, and then a green area which has
> algae growing on the dead area. There were also table corals with white
> syndrome which may be what this is. Plus some *Pocillopora* have totally
> white branches and may have some dead branches. I saw a small amount of
> similar disease a couple weeks ago at Alofau. So it is possible that it is
> on both sides of the island and thus may be very widespread, though we
> won't know until we have checked much more widely. We were only on the
> west side of Vatia Bay. The damage and disease continued out as far as we
> went though we didn't get to the mouth of the bay. Most of the rubble is
> covered with a dark green dense algal turf and I am guessing that was
> produced by the tsunami, but there are also shallow areas with very white
> clean rubble, mostly small stick rubble, and I am guessing that was put
> there by Wilma. Very sharp boundary between the green and white rubble
> areas.

> Anyhow, it looks like the north shore may have some Wilma damage.
> Please keep an eye open for hurricane damage and for disease- any kind of
> white band is the most obvious thing. Please let me know if you see it.
> I've alerted Greta Aeby and Thierry Work, and am scheduled to go back on
> Monday with Steve Palumbi and his group, and will be taking photos, data,
> and hopefully some small samples.
> Cheers, Doug

Thanks for reminding me. I saw quite a bit of damage from Wilma at Amalao - their beach is gone, and rubble was thrown about 10m inland. There is a new layer of yellow-green turf algae that I hadn't noticed before. I didn't see too much damage to coral, but then again Amalao doesn't have much coral real close to shore. I'll keep an eye out for disease.

Cheers,
Kelley

2/22/11
>
> NPS did scooter surveys of Pola Island and Vaita Bay last week and saw
> similar damage and disease. We covered the entire area from the Pola
> Channel, around the tip, into Vatia, across the bay at 60 ft. depth, and to
> the start of Amalau Bay. Tabletop corals were flipped over on the Vatia
> side of Pola Island, and along the outer reef at Vatia. White syndrome was
> also very prominant. We flipped a few of the tabletops over and there was
> still living tissue underneath, suggesting a recent event (Wilma) caused
> the damage.
>
> Tim

2/22/11
I saw only one colony of *Acropora* with a growth anomaly yesterday as I swam along. I was photographing and counting colonies with what appeared to be white syndrome, so I wasn't looking for colonies with GA's. Your guess is as good as mine. There are certainly *Acropora* of a variety of species left. Those with white syndrome won't be alive long, white band is on the order of an inch wide, some only have a few inches left alive, others more. But a lot of Acropora are gone, most just not there anymore. I did a count of some *A. monticulosa* colonies as I swam yesterday, but the area was not defined. I counted all I found, 45 colonies. 4 had no signs of disease, 36 had white syndrome, and 5 were dead. About a half dozen I was not sure if they had white syndrome or not. Doug

2/23/11
I checked the far side of Vatia Bay today, as well as the two bays on the way there, Afono and Amalau. The far side has a little less mechanical damage than the near side. There are many places where it looks like the surface of the reef got stripped away, and

underlying rubble is exposed. The rubble has heavy filamentous algae, but it is less vividly green than on the near side. The rubble in each patch looked like it was *Acropora nobilis*, I had no doubt that was what it was from. There was no new white rubble. So I deduce that the mechanical damage was from the tsunami, not the hurricane. The disease was just as bad as on the other side. Lots of *A. monticulosa* had it, maybe slightly smaller portion than the other side, but the *A. abrotanoides* has it bad. On the other side, most *A. abrotanoides* have dead sections with the dense green turf on them, and live sections, and if any white between not much. But on the far side, the white sections are obvious and all over the colonies. I was not too sure what had killed portions of the *A. abrotanoides* on the near side, but now I am sure it was the disease, and it looks like the disease over there is going slower or has arrested, at least in that species. Mechanical damage was obvious on colonies of various species on the far side, like branches broken off, but often the stump is completely alive (on *A. digitata* which has thinner branches so less skeleton to cover with tissue on a stump) or has a ring of live and the center has algae.

The two other bays showed some signs of mechanical damage, broken off branches and damaged edges of tables. Rubble may have been moved, just one patch of green turf at Afono. One bay I saw no disease at all, the other I saw a tiny bit on one A. monticulosa and one Pocillopora. So night and day different. So along with seeing no disease at Fagasa and Aoa yesterday, it is looking like Vatia may be ground zero for this outbreak

We're out diving collecting data tomorrow, likely on the south side. When I have another snorkel day I'll check Fagatele and Leone, both of which I can get to the slope without getting killed. But at this point it's looking good for not being a huge island-wide thing. Doug

2/24/11

Ben and I spent the day on the boat in Fagatele today, and I swam around on snorkel looking as well. I'm happy to say that it is just fine. Not the slightest hint of damage from the hurricane, not even broken branches. Two tiny bits of white disease on *Acropora*, out of the many hundreds of colonies I saw. About 2 dozen colonies of *Pocillopora* with white disease, but that was a small proportion of all the *Pocillopora* colonies I saw. That might be a bit above background, and worth keeping an eye on. All the rubble moved by the tsunami was covered with coralline algae 6 mo or so ago, compared to Vatia where none is. Fagatele looks clean, and there are tons and tons of live healthy coral. A wild wild guess is that maybe 5% of the reef in the bay was covered with rubble that was moved in the tsunami. It is much less than I initially thought, you have to search to find it.

> So this is looking good, the disease outbreak is certainly not island-wide, and hurricane damage seems to be restricted to the north side and major damage from it so far is only in Vatia.

> I think this is when monitoring really starts to pay off. Knowing which places are healthy, which are impacted, how they are impacted, what events impacted them, how much of it there is. It is so important to understanding the health of our reefs, the threats, and why the reefs are what they are- 10 years from now, the cause of rubble beds in Vatia will be known. For management, it is like driving with the windshield blacked out, and then suddenly having the windshield cleared.

2/25/11
Ben and I dove Leone and Amenave today. Leone had big long swells and very very murky water. No hurricane damage visible. There was lots of disease in *Pocillopora,* I counted 6 diseased out of 14 colonies I saw, Ben had a much bigger sample and kept a count, had a similar percentage. He said that one area had many more than elsewhere, he felt they were clustered. Very very few *Acropora* with any disease, surely background levels. Amenave was similar, no hurricane or tsunami damage, lots of healthy corals and clear water. There was quite a few diseased Pocillopora, might have had somewhat fewer percent disease on *Pocillopora* than Leone, but we didn't count. Above about 30 feet deep, the substrate is covered with encrusting *Acropora* (now actually that species is in *Isopora*, as *I. crateriformis*) with plate edges. Same thing happens at Leone, bit shallower, also Maloy said similar in Sili, so I think it is all along that SW coast. Anyhow, a small percentage of them, probably well less than 1%, had this disease. I don't think I've ever seen a colony of this species with any kind of disease. This was white disease just like tables get, live tissue, then white, then gradations of increasing green. White is maybe 1-2 inches wide, maybe more, so moving pretty rapidly. Like I say I've never seen that at all, so while they aren't common, they are way above background. I was able to get a couple shots with up to 3 diseased colonies in the single photo, right next to each other. All other *Acropora* had no signs of disease. For all my observing, I'm very hard pressed to remember a single colony of any genus other than *Pocillopora*, *Acropora*, and *Isopora*, though there may well be, they must be pretty rare or look different or something.
> So *Pocillopora* disease is looking pretty widespread, *Acropora* disease is many orders of magnitude more abundant in Vatia than anywhere else, but *Isopora* has a small amount of disease in Amenave.

3/4/11
> Greta,
> I got out to Alofau to check bleaching yesterday, and also check the coral disease. The diseased *Pocillopora* looked just like they did the previous time. I had to search a bit to find the area where the *Acropora nana* had disease. I could find no active disease, but I found the dead colonies. It is a relatively small area, surrounded by live colonies. So it appears that the disease in that species, there, has arrested.
> I'm beginning to see a pattern of disease outbreaks that then arrest. One was those *Goniastrea* in the Ofu pool that looked like they were going to be dead in a couple weeks, came back many months later and there was a dead green area and live tissue, the disease stopped about where we saw it. Another was the disease on *Porites cylindrica* that was on the patch reef Cindy Hunter took Zac and I to looking for *Montipora dilatata*. It must have arrested or not gotten to another patch reef or all of Kaneohe Bay would be dead. Now I realize that on the east side of Vatia bay the *Acropora abrotanoides* are partly long dead and partly alive, with very little white in between. I didn't know what killed part of them. On the west side the disease is active with white areas next to the live, followed by increasing gradients of green, so it was still active there last time I was up there. So looks like it has arrested in that species on the east, still active on the west, if I monitor it I may

be able to catch it arresting on the west. I better get up there and get samples before it stops. Not sure it will stop on the *A. monticulosa*, it may keep going until they are all dead. Not sure it will arrest on the *Pocillopora* either. So I need to monitor it.
> Today we dove at Amaua to get data. Very little disease. I did find a couple *Stylophora pistillata* that had disease- white branch with a sharp break between white and normal life tissue, looks much like diseased *Pocillopora*, except there were no branches dead long enough to have algae growing on them. Also only a couple branches white, so looks new.

4/15/11
I did a dive at Leone Thursday on the slope, starting at 30m deep and going up to a couple meters depth. I only saw one item of debris, it was a ladder that was built to get into a boat with (it curved at the top to hold on to the edge of the boat). I thought it might be one of ours, seems unlikely to have come from the village. But I saw no other debris. The deep reef showed no sign of damage from the tsunami where I was, but in shallow water the grooves between ridges were covered with dead rubble. All of the rubble was covered with coralline algae, 100%. This would appear to be a good sign, since some coralline algae attract coral larvae to settle, and it cements rubble pieces together, and it adds calcium to the reef as it grows, it is a reef-builder like coral. In contrast, so far there is no sign of any coralline algae growing on the tsunami rubble in Vatia. In Fagatele, I found and photographed an area in which corals were growing over coralline algae that covered rubble. That is clearly an area from an earlier event than the tsunami, but shows the next stage in recovery. Doug

Appendix 3

Descriptions of individual reef sites in Tutuila, American Samoa

Douglas Fenner, 2013

These are descriptions of some sites, mainly monitoring sites for the Territorial Monitoring Program, which are recalled from memory in the text below. The reefs of Tutuila consist of fringing reefs that have a reef flat. There are also a few places that have back reef pools in the reef flat that in most cases were dug out for material to build village land or the foundation of the airport runway, and a slope into deeper water. The slopes end in a nearly flat looking shelf, which extends about a mile from shore most places (except the Tafuna plains where the land is on top of the shelf, and the west end of the island where it extends over 3 miles). The shelf undulates and is between 30 and 100 m deep. The shelf is probably covered mostly by sand, but it also has some "banks" that grow upward from it, mostly in a ring shape that may reflect a drowned barrier reef from previous geological periods. The banks have corals on them in some areas. The shelf ends seaward of the banks, where it ends as a vertical escarpment that goes down from about 100 meters to 350 meters depth. It is bare of corals and most anything else.

Reef Slope sites:

Fagasa

Reefs reach the surface only within bays on the north shore, though there is reef buildup below the surface outside the bays along much of the coast. The slope at Fagasa has a sharp dropoff at the top where it descends from the reef flat at nearly a vertical slope. However, there are a variety of mounds on the slope, and by mid-slope on the eastern part of the reef there is a maze of mounds and gullies with good coral on it. There are a couple of fairly large avas that correspond to the two large streams coming into the bay, one at the boat ramp on the west side of the bay and another near the east side of the bay. The slope ends in sand, with some mounds on the sand. The sand is relatively shallow, perhaps 20 m deep at the deepest, and closer to 12-15 m deep nearer the center of the bay and the avas. The slope near the sand, in the areas where the sand is shallow, is near vertical and nearly devoid of corals. No currents have been noticed.

Tafeu

Tafeu is a small bay on the north side with no people because there is no flat land. It has the least human impact of any site in the TMP program. The slope is quite lumpy, with lumps and grooves. There is good coral cover. There is one very large massive Porites colony, several meters tall. There is also a fairly large area covered with corallimorph polyps, Rhodactis sp., called "Matu-malu" in Samoan. The *Rhodactis* seems to be relatively stable in area. No currents have been noticed.

Vatia

Vatia is a narrow bay on the north shore. A TMP monitoring site is on the west side. Before the tsunami, at mid-depths, the west side of Vatia had lumps of coral such as *Porites rus* or massive *Porites*, separated mostly by sand, some of which was covered by *Halimeda* algae. The upper part of the slope in the inner harbor mostly had *Porites cylindrica* and *Porites rus*, while the upper slope in the outer bay had more diverse corals. The slope ends in nearly flat sand at about 25 m depth. In the years prior to the tsunami, a brown macroalga, *Dictyota*, covered a large part of the reef slope, some even growing on coral. After the tsunami, almost all the coral on the slope in the inner part of the bay was destroyed and replaced by rubble. In the middle and outer parts of the bay there were rubble flows on the upper slope, between lumps where corals survived. Damage was much greater in the inner part of the bay than the outer. In the inner part of the bay, the rubble after the tsunami quickly became covered with green filamentous algae and has stayed that way at least to 2012, indicating a lack of resilience. This is likely due to nutrient buildup in the water of the inner bay. The tsunami removed the *Dictyota* macroalgae. At least two kinds of red macroalgae grew after the tsunami. Then Hurricane Wilma struck, and damaged the outer part of the bay much more than the inner part. On the east side of the bay, there are areas where the coral is all intact, and other areas where the living corals and a layer about 20 cm thick of rubble that it was living on were removed, with no trace of them on the reef slope. The edge between the intact reef and where corals and the rubble they were attached to were removed, is very sharp. It appears that the living corals were growing on a bed of cylindrical coral rubble, suggesting a prior coral community of *Acropora* such as *A. nobilis* staghorn. The rubble was covered with a thin layer of calcareous algae, but where the coral and upper layer was removed, the rubble just has a light layer of filamentous algae. The upper slope has crustose calcareous algae that extends down only about 3 m down the slope and ends rather abruptly there. No currents were noticed.

Masefau

The slope on the side of the bay toward Tutuila is quite degraded, lots of dead rubble with macroalgae growing on it, a little live coral on the upper slope. The center of the bay is sand, and nearer to the head of the bay it looks like there has been a lot of moving around of rubble and sand by tsunami or hurricanes.

Aunu'u

The Aunu'u site is west of the small harbor, where the surf line goes out from the land, along the northern part of the surf line as it goes away from land. The slope is fairly steep, probably a bit more than 45 degrees. There is high coral cover consisting of diverse corals. Close to land, the slope reaches flat bottom at only about 10 m deep, but this depth increases westward to at least 30 m deep. There are a few lumps out from the base of the reef at about 30 m deep. Near shore there are good size patches of coral on the nearly flat bottom at the base of the slope. Sometimes there is little or no current, at other times currents parallel to the reef surface can be fairly strong.

Amaua

The TMP site starts just east of the ava. The slope is steep in the medium depths and doesn't have much coral cover. Below the steep slope, the slope continues at about a 45 degree slope. That lower slope has high macroalgae cover which is mostly *Halimeda*, but also has some low mounds of *Lobophyllia* coral, and below that some *Mycedium* plates. To the west of the ava, there are many *Lobophyllia* colonies. The upper slope becomes lumpy and has more coral cover than the steep mid-section. The mid-section has some avas with the bottom covered with blocks about one meter diameter. No currents were noticed.

Faga'alu

The Territorial Monitoring Program site is just south of the prominence where the reef projects out into the ocean, and extends onto it. The slope is about a 45 degree angle. The mid-portion of the slope is entirely covered with cylindrical stick rubble, which is covered with and lightly cemented together with crustose calcareous algae. There are a few corals in that zone, but their cover has not increased measurably in the 9 years of the monitoring program. Below that zone, plate corals begin. The plate corals are overlapping much like shingles on a roof. The most common species is *Mycedium*. The plate corals commonly form large continuous areas with near complete live coral cover. Average coral cover including the gaps between plate coral formations is about 65%, one of the highest on slopes anywhere on the island. The upper boundary between this zone and the rubble zone undulates between about 15 m and 18 m deep. The plate corals extended down to around 25 meters deep, where the slope begins to decrease and rubble and sand that continue below as a floor, begin. The floor is probably 30 m or more deep. The tsunami of 2009 removed most of the plate corals on the lower part of this zone. The break between undamaged living plates above and the dead area below where the living plate corals were removed, is very sharp, and varies some in depth. On the upper parts of the slope, around 5 meters depth, there are more corals, primarily various species of *Acropora*. Coral cover in the shallow zone may (or may not) be increasing. The cause of the dead coral rubble in mid-depths is unknown. It is almost certainly to be from a branching *Acropora* such as *Acropora nobilis* or possibly *A. abrotanoides*. *Acropora* are among the most sensitive corals to most things that kill corals, such as hurricanes, disease, crown-of-thorns starfish, and mass bleaching. So the cause of their death is not known. But it is clear that at one time there was a lot of *Acropora* growing on this slope, and they are no longer there. No currents have been felt.

Coconut Point

The TMP site at Coconut Point begins just south of the ava, and extends south from there. In shallow water, the slope gradually gets steeper so that at mid-depths it is steep, perhaps a 70 degree slope. Then near the bottom of the slope, the angle of slope decreases as the floor is approached at around 30 m deep. The steep slope has high crustose coralline algae cover, and at times has had considerable cover of a soft, branching red alga which is actually a coralline alga. Coral cover is higher on the upper part of the slope where it is not so steep. In some areas on the lower slope there are plate corals, *Mycedium*. No currents have been felt.

Fogama'a Bay

Near the center of the bay there is a vertical rock face at the water line which extends a short way under water. Below that the slope is not steep, maybe 20 degree slope, and begins with low coral cover. Coral cover increases with depth. At about 10 m depth there is a patch of pure *Merulina* plate corals, with the plates at angles. The patch extends quite a ways horizontally on the slope, but not far vertically. Below the patch there is moderate coral cover, down to about 30 m depth where the floor is reached. No currents were noticed.

Fagatele Bay

Fagatele Bay has a large reef with an unusual shape. In the eastern half of the bay, the reef slope begins with a near vertical drop from the reef flat to about 3 m depth. From there, the slope is very gradual, so gradual it is hard to see which way it slopes. Far from shore it reaches a depth a little more than 10 m where it then descends more steeply, at around 45 degrees or more. In effect, then, there is a shelf between about 3 m and 12 m depth. The shelf has some fairly mild ridges and gullies running out toward deeper water. The inner part of the shelf now has little coral largely due to the 2009 tsunami, but the outer shelf has good coral cover. There were some large mounds of delicate plate corals (*Echinopora lamellosa*) which were completely removed by the tsunami. The upper part of the shelf has low coral cover, but there are a few large massive *Porites* on the inner part of the shelf. There is a huge colony of *Pachyseris rugosa* out at the edge of the shelf in one spot, the largest the author has seen anywhere. It is surrounded by many small daughter colonies. It has steep slopes below it. There is an increased number of mushroom corals near the bottom of the steep slope. At the bottom of the steep slope there is nearly flat sand, but at some locations more coral can be seen in the distance. In the western half of the bay, there is no reef flat, and the reef descends from near the shore at roughly a 45 degree angle or a bit less, all the way down to 30 meters. Coralline algae cover is high at all depths on the shelf and down the slope. Although the by points towards the southwest and most of the year waves come from the east, wave action in the bay is strong. Because the bay is on the outer edge of the Tafuna plains, there is no shelf beyond the bay to reduce the strength of the waves. Coralline algae does better in heavy wave motion than in calm. The 2009 tsunami produced some flows of rubble which was easily distinguishable from the intact reef. Within 6 months, the rubble which had near zero percent coralline algae cover had 100% coralline algae cover. No currents were noticed.

Leone

The reef in Leone Bay has a very gentle slope in front of the big Catholic church at around 10 m depth. Coral cover is high, and there are ridges and gullies that run toward the edge of the reef. The floor of gullies typically is coral-covered as well as the ridges. To the west, the slope becomes greater reaching around 45 degree angle. Corals are diverse. In the western area, at the bottom of the slope the slope becomes much less and corals are on lumps with flat sand between them. The flat sand is at about 30 m depth. The ridges and gullies are larger in shallower water, and at about 8 m depth plate corals (*Isopora crateriformis*) becomes more common and in about the 2-5 m range become the dominant coral with high cover. From about 4 m down to perhaps 8 m, there is an area of high coral cover of table corals (*Acropora hyacinthus*) and staghorns (*Acropora nobilis*). No currents were noticed.

To the west of Leone, the high cover of the plate corals in shallow water continues. Also, moderately strong currents were found.

Reef flat sites:

Fagamalo

In Fagamalo, the reef flat is not right at the low tide line and flat. Rather, it has a slight slope to it and has some areas higher than others. Coral cover is generally low, but there are some areas with better coral cover.

Fagasa

The reef flat at Fagasa has little or no coral cover except out near the edge of the dropoff. In the first few meters back in from the dropoff, there is good coral cover, with encrusting *Montipora* and young table corals, almost all of which are *Acropora hyacinthus*. There was a mass settlement of *A. hyacinthus* on the outer edge of the reef flat and the very top of the slope, around about 2005. Most have survived and grown, and in areas they are now growing into each other or over each other. Additional recruitment appears to continue, but it is much less than the original pulse. In one area, the tables reached a size of about 30-40 cm diameter and then were all killed. The area was back from the reef flat edge, and there are live tables near the edge. It appears that in a period of extra low tides, waves splashed the corals near the edge of the reef flat keeping them alive, while the waves did not splash the tables back from the edge and they dried out too much and died. This is probably why there is significant live coral only near the edge of the reef flat.

Vatia

The reef flat on the east west side of Vatia bay is pretty bare, with some rubble areas and a few areas with very short “microatolls” of *Porites*. These “microatolls” are very short rings of live coral that can be up to around 1 m diameter, but only about 2-4 cm tall. The best coral is near the outer edge of the reef flat, before the reef flat drops away nearly vertically to start the upper slope. Coral cover on the outer reef flat was reduced after the tsunami and Hurricane Wilma.

Aoa

The reef flat in Aoa bay is very wide. Most of it is flat sand. By the time you reach about half way out, scattered corals appear. The best coral is near the outer edge of the reef flat. Corals there are somewhat patchy, with more some places than others.

Aunu’u

The reef flat above the slope where the slope site is, receives very heavy wave action and is very dangerous to snorkel. At low tide it may be walked. There are scattered clumps of small corals.

Alofau

The inner part of the reef flat at Alofau is mostly loose rubble, with some microatolls made of massive *Porites*. The mid-section of the reef flat has areas with a fair number of *Acropora aspera* colonies, but a total low coral cover. The outer reef flat has higher coral cover and high encrusting coralline algae cover. There is a good diversity of corals, including large patches of *Acropora pagoensis*, the most I know of on a reef flat. The rubble on the inner reef flat was moved by the tsunami.

Amaua

The reef flat at Amaua has low coral cover and high rubble cover. Wave action is too rough to approach the outer edge of the reef flat.

Lauli'i

The reef flat at Lauli'i is deep enough that it has a very high cover of *Acropora muricata* staghorn corals. They grow so rapidly and are so near low tide, that they are currently being killed on top, and likely will begin forming a new higher level of reef flat in coming decades, which will end up having low coral cover.

Onososopo

The outer reef flat at Oososopo has high coral cover, composed of *Pocillopora* and *Acropora* nana. They form a lawn much like at Gataivai, and appear to be remnants of the original reef flats.

Aua

The area of the famous Aua Transect first surveyed in 1916 now has a sandy borrow pit about 20 feet deep near shore, then a rubble flat with very low coral cover, and good coral cover at the outer edge of the reef flat. In 1916 there was coral over most of the reef flat.

North Harbor

The reef flat from Aua to the canneries has little coral cover except at the outer edge where there are a fair number of corals, but not nearly as much as at Onososopo.

Gataivai

Near the sewage pipeline, the outer reef flat at Gataivai has high living coral cover of *Pocillopora* with some *Acropora nana*. It forms a lawn, and appears to be a fragment of the original reef flat that has not been disturbed. As you move toward Utulei, the quality of the outer reef flat community declines. The reef flat farther in has much lower coral cover, and near shore it is all rubble or sand. The pipeline is covered with rocks, with a depression on both sides that was dug out. In the outer portions, there are many corals on the rocks and in the depression, and a large field of *Acropora muricata* has grown since just 2005. On the south side of the outer part of the pipeline, there are now many bushes of the rare fire coral, *Millepora murrayi*, which are growing rapidly and reproducing by fragmentation. There were few if any in 2005.

Faga'alu

The reef flat at Faga'alu on the south side is a large flat, with strong currents from the surf. There are large patches of *Acropora aspera* between the rock that sticks out and the main island. There is also a large patch of *Acropora muricata* straight into the bay from the rock. Both have reached the surface and low tides kill the tips of the highest branches. Other areas are mostly rubble. The reef flat extends well into the bay but becomes a narrow strip fairly close to shore. In front of the park, the reef flat has quite a bit of *Porites cylindrica*. That area has not quite reached the low tide level. On the north side of the bay, there is shallow sand near the head of the bay. Going toward the school, live coral appears on the outer edge of the reef flat. The rest of the reef flat has dead coral on it, which probably were killed by high sediment.

Coconut Point

Coconut point has a huge reef flat, one of the largest around the island. Near the main island, the reef flat is mostly dead rubble. Along the peninsula beyond the deep pool, near the shore of the peninsula there is a current running toward the end of the point, and lumpy *Porites*. As you move farther out you quickly reach reef flat which is quite flat, and mostly rubble covered. Farther out there is coral, which in some areas is very short microatolls of massive *Porites*. In other areas there is quite a bit of *Acropora aspera*, and in some areas *Psammocora contigua*.

Airport

The reef flat at the airport is wide, and appears to be almost entirely covered with rubble, with very little coral.

Fagatele

The reef flat at Fagatele has a little coral near shore at the beach where the trail ends, and then a little out near the outer edge of the reef flat. Coral cover increases toward the west (where there is a fair bit of the plate coral Isopora crateriformis) and gets high around the head of an ava, where there is *Porites cylindrica* and *Pavona frondifera*. The surf is strong in front of the beach, and decreases towards the ava.

Leone

The reef flat in Leone bay is primarily rubble, with some live *Pavona frondifera* as you approach the rubble bar to the west. There are patches of a thin layer of dark gray sponge, particularly in the eastern part of the bay. The reef flat generally doesn't reach low tide, and covers a large area.

Backreef pool sites:

Alofau

The pool in front of the eastern part of the malai in Alofau has fairly murky water with 8 m visibility currently. Most of the pool is sand bottomed, but there are mounds, some with coral on them. The coral is all staghorn, mostly *Acropora muricata*. The coral is in clumps, most of the mounds have little on them but a few have good coral patches. So total coral cover is quite low. There is a fair amount of Porites cylindrica around the edges of the pool. In some places large colonies of *Porites cylindrica* were rolled by the tsunami.

Faga'itua

Faga'itua has a large area of high cover of staghorn *Acropora muricata* out from shore as you round the bend before driving into Faga'itua village. Much of the staghorn reaches near the low tide line, but there are some depressions in it that reach 2 m or more deep. It has been damaged by low tides, bleaching, and the tsunami, but recovers well in time. The shallow parts will likely be killed on top and start filling in a new higher reef flat surface.

Onososopo

Onososopo has a pool reached by a tiny boat ramp west of the Origin gas facility. The pool reaches about 2 m deep, and appears to be natural. To the west from the pool, there are banks of staghorn *Acropora muricata* and some other species of coral. There are many yellow bushes of the rare branching fire coral *Millepora murrayi*. The corals are abundant. The outer edge of the pool is marked by a sharp rise of about 30 cm up onto the reef flat, where surf is too rough most of the time. Around the edge of the gas facility ground there was a thicket of *Acropora aspera*, but most of that was killed by disease about 2011.

Utulei/Gataivai

The pool that goes from Gataivai to Utulei was dug out for material for village land. The inner part near the rock wall around the parking lot at the sewage plant is all sandy bottomed. From there towards Utulei the outer edge of the pool picks up *Porites cylindrica* on the hard outer edge of the pool. There is a mild current moving toward the Utulei. In front of the parks building at Utulei the shallow bottom is all sand.

Faga'alu

The pool in Faga'alu consists of a small sandy-bottomed area near the beach in front of the park on the south side, and a large area beyond the shallow reef flat area. The large area had patches and hills of the staghorn *Acropora muricata* before the tsunami. The tsunami destroyed most of the staghorn in the pool. The bay has a very large, deep, wide ava with no noticeable current. The ava may have been enlarged to the present size in order to allow boats to enter the bay, and to provide material for the village.

Coconut Point

The pool at Coconut Point was produced by removing material to add to village land. It reaches about 25 feet deep. There are several hills in the deeper area, one of which was used as a DMWR giant clam farm and has many clam shells on it, as well as fencing. There is some coral on the hills but none on the deeper sand. Toward the ocean the bottom gradually rises and there is a large area with staghorns *Acropora muricata* and *Acropora pulchra*. At the edges of the pool near the island there are areas of high coral cover of *Pavona frondifera*, and the edges toward the ocean generally have *Porites cylindrica*. The edge toward the end of coconut point has primarily *Porites rus*.

Airport

The airport pool is a long pool that parallels the runway, on the ocean side. It was dug out for material to build the base of the airport runway. Near the east end of the pool, there are large fields of staghorn *Acropora muricata* and finger coral *Porites cylindrica*. To the west much of the bottom is sand. The pool is about 25 feet deep. There is usually a current in the pool flowing to the east.

Banks:

Taema

Taema Banks parallels the south Tutuila shore, a bit less than a mile offshore. At the shallowest, it reaches about 10 m deep. In one spot at about 20 m deep, the top is very wide and covered with smooth crustose coralline algae with few corals. On the landward side, the edge of the bank is a steep slope of about 45 degrees, covered with large rubble and no corals. On the seaward edge of the bank, the slope is quite gentle and coral cover is fairly high. The slope descends to over 30 m depth, probably more like 40-50 m most places. In the area near the green buoy, the minimum depth is about 16 m, there is fairly good coral cover mostly consisting of large table corals, *Acropora clathrata*.

Appendix 4

This was written for the introduction to the Fisheries LAS, but was too long.

The State of Coral Reef Fish in American Samoa, 2011.

Douglas Fenner

American Samoa consists of several small, high, volcanic islands, 14 degrees south of the equator, near the middle of the Pacific. Two small nearly uninhabited or uninhabited more-remote atolls are present as well. Slopes are steep and densely forested on the high islands, and rainfall is high and erosion active. The islands have been inhabited for about 3000 years, with western influence growing rapidly in the last half-century or so. The population has grown exponentially from 2500 in 1900 to about 65,000 today. Population is concentrated on the largest island, Tutuila.

All the islands are surrounded with coral reefs. About half of the coast has reef flats, with reef slopes beyond the flats. Tutuila is surrounded by a large shelf about 100-300 feet deep, which has an interrupted ring of bank reefs, an apparent sunken barrier reef, about 1 mile from shore. The coral reefs have relatively high diversity, commensurate with their location near the middle of the Pacific. About 945 species of coral reef fish are known. The benthic coral reef communities are in relatively good condition, with about 30% coral cover, high coralline algae cover, low macroalgal cover, and small amounts of dead coral. There are periodic major natural disturbances from hurricanes, and more rarely, tsunamis and crown-of-thorns starfish outbreaks. The basic features of the benthic reef ecosystems are similar in coral cover, high coralline algae cover, and low macroalgae to those of the US Pacific remote island areas (PRIAS), which are near-pristine, and geographically closer than other U.S. archipelagos.

There are a variety of human impacts and threats to the reefs of American Samoa. Nutrient runoff is a problem, coming from piggeries, high phosphate laundry detergent, the soccer field, grey water, leaking sewage lines, septic systems, and other sources. Nutrients accumulate at the head of long narrow bays with little flushing like the harbor and Vatia Bay, fueling phytoplankton blooms. Relatively small areas of macroalgal blooms have appeared in recent years around the mouths of a few streams and in narrow bays. Sediment runoff in streams is obvious during and after the frequent heavy rainstorms, turning streams dark brown. Silty fresh stream water floats on the surface and is rapidly carried out avas and mixed with and diluted by the vast ocean volume. However, small areas of damage occur around some stream mouths. The harbor is quite different from the outer island coasts, with reefs in the harbor having been dredged, filled and severely damaged by nutrients, chemical pollution, and sedimentation. The harbor is a small part of the territory coast and reefs. But outside the harbor, coral populations are good, and coralline algae which is even more sensitive to sediment, nutrient-fueled algal overgrowth, and lack of herbivores, is particularly good. The habitat for reef fish is in relatively good health. A study of juvenile humphead wrasse found them only in very small areas, which are areas they prefer, but they can survive in other conditions. Habitat for juvenile reef fish is not unlimited, though the reef flat area is at least as large as that of the reef slopes, if not larger. The juvenile habitat area is large enough to support large populations of small fish species, and there is no direct evidence that it limits any of the large fish species, each of which is likely to have different juvenile preferences and requirements for habitat. Mangroves are juvenile reef fish habitat for some species, but there are only small mangrove areas here. Only a minority of reef fish species in the Indo-Pacific are reported elsewhere to use mangroves as juvenile reef habitat, and even those species can use other areas if mangroves are not available. For a few species, absence of mangroves are correlated with lower populations on reefs. Studies of fish near mangroves have failed to show that juvenile reef fish use mangroves here. Habitat certainly affects all coral reef fish, though for most species the most important feature of the reef is rugosity, i.e., hiding places, and whether the coral is alive has less effect. Death of corals is reported to decrease populations of some fish species and increase others, eventual collapse of skeletons will decrease populations of almost all fishes. Habitat, food supply, predation, larval supply, and the like completely determine populations of fish species that are so small that they are not taken by fishing. For larger fish, all those things apply, and fishing applies as well. Fishing reduces populations from the natural levels, and unlike the other factors directly kills fish, so documenting the removal of fish by fishing directly documents an effect, while documenting differences in habitats and the other factors also requires demonstrating that those factors have affected the fish populations.

The reef fish communities here differ strikingly from near-pristine reefs in several ways. They have low fish biomass, about 1/3 that of near-pristine reefs, and they have quite low populations of the largest reef fish species. On near-pristine reefs, about half of the fish biomass is in the largest reef fish species (often primarily sharks), while on Tutuila reef slopes the biomass in the largest species is negligible. Large fish are more abundant on the bank reefs which surround Tutuila at a distance of about a mile, and they are more abundant within the archipelago with more distance from the heavily populated Tutuila, but do not reach abundances or biomasses similar to that of near-pristine reefs (which are farther from people). While the biomass of large fish is greater away from human population than near it, the biomass of small fish is similar or the same near human population compared to farther away, an effect that also occurs in the two other archipelagos that have been studied this way, namely Hawaii and the Marianas. Further, the effect of reduced large fish species with unaffected small fish extends far from human population centers, 100 miles. The small fish act as a control for the effects of impacts of variables such as sedimentation, nutrients, chemical pollution, and habitat degradation, since those would affect the small fish as well as the large fish. The impact of human population on only the large fish is a fingerprint of fishing, since only fishing affects large fish differentially. The differential effect of fishing on large fish is well known and documented in fisheries around the world. Sediment and nutrient runoff extend for very short distances from the shores of small islands, and cannot possibly cause decreases of large fish at distances of 50 or 100 miles, but boats can and do easily go those distances carrying fishers. These patterns can only be explained by fishing, no other viable explanations have been found.

The reef catch not only includes many reef finfish species, but also octopus, giant clams, lobsters, small invertebrates collected by gleaning, and specific traditional fisheries for reef invertebrates such as sea cucumbers and sea urchins, especially in the more traditional Manu'a islands. There is no aquarium fishery or live food fish trade or commercial sea cucumber fishery, and no export of reef fish. Both subsistence and commercial reef fishing occurs, using methods such as spear fishing, throw nets, and hook and line. Traps are not used except for a traditional fishery for newly settled goatfish recruits. Fishing pressure on Tutuila is currently relatively low, though it still exists and can add up to significant amounts of fish taken per kilometer of reef per year. One might conclude from the relatively low current fishing pressure that reef fish stocks must be in good condition. But that does not follow, since it takes time for stocks to recover, and fishing pressure was heavy in the past. In the 1970's, fishing pressure, as measured by weight of fish caught per unit area of reef, was the heaviest then known in the entire world. Fishing pressure has declined rapidly since then, even though human populations have grown rapidly. This is a very unusual situation, and is due to the rapid rise of incomes and a subsequent cultural shift from traditional food sources including fishing, to store-bought food. Some researchers have made the mistake of concluding that the recent rapid decline of fish catches was due to a rapid reduction of fish stocks happening at the same time, since this is the normal pattern around the world, particularly with rapidly growing populations. But that assumes that fishing pressure increases with the growing population, which indeed is observed virtually everywhere except here. But in American Samoa, fishing effort has decreased rapidly with growing income in recent decades, and that has been the main driver of decreasing catches. Underwater visual surveys have shown steady reef fish populations, possibly with a slight increase, since the 1970's. That has lead to the conclusion that reef fish stocks are fine, that they are naturally low in biomass. (However, one study now shows decreasing reef fish stocks since 2002.) That conclusion neglects the fact that fishing pressure was extremely heavy in the past, and that some fish species only recover slowly from depletion. The speed of recovery of different species correlates with their size, with small fish species able to recover rapidly or even sustain heavy fishing pressure, while large fish species are unable to withstand heavy fishing pressure and are very slow to recover. FishBase lists quantitative measures of vulnerability to fishing and resilience (or the speed of recovery) for each species, and shows that large reef species can stand much less fishing pressure than small fish species, and recover much more slowly. The extreme is found in sharks, since reef sharks typically have only about 1-4 pups yearly or every two years, and so are very slow to increase in population. The low numbers of large reef fish is a ghost of fishing past, and even small catches will keep their numbers at low levels. The catch per unit effort (CPUE) can be an index of fish stocks, if it decreases that can indicate decreasing fish stocks. CPUE for reef fish has not been decreasing. On the other hand, surveys of older fishermen have found that they report that their reef fish catches are less than they once were. It appears that increasing population drove increasing fishing pressure up to about the 1970's, and that fishing did lead to the collapse of the large fish populations, but since then the shift to store food has led to decreases in fishing effort. Small fish were never depleted in the first place (as underwater surveys found) and large fish (which were depleted before underwater surveys began) have not recovered. The species that is in the very worst shape by far is the bumphead parrotfish, which is close to local extinction throughout the archipelago. All observers and recorders combined see about one fish per year. In spite of the massive coverage of the CRED surveys, with tow boarders covering over 100 km of Tutuila coast and all of the coastline of the smaller islands (several times for the smallest islands), recording all bumphead parrots of all sizes at any distance, plus all of the roughly 7000 dives the CRED team made, not a single individual was recorded by anyone in their last surveys in March, 2010. On the other hand, four different eyewitnesses, including two expert reef fish biologists, report schools of bumpheads several decades ago, the largest school being estimated at 30-50 fish. The location where that large school slept was found by the fisherman who reported it, and since they sleep at the same location every night, he was able to spear them one by one until they were gone. (This likely happened during the scuba spear fishing period.) The largest school seen in the last decade was just two fish. So the population has decreased over the decades by at least by a ratio of 30 to 2, and we know the cause, fishing. This species is critically locally endangered, due to fishing. Although sharks and humphead wrasse are at low levels compared to near-pristine remote islands, they are not in immediate danger of extinction. Most of the largest reef fish species are predators, such as sharks, and humphead wrasse which mostly eat invertebrates. The removal of predators can have major effects on ecosystems in what are called trophic cascades. Likely such effects are hidden because fishing also takes their prey. There are many species of very small fish which are not fished at all and thus are not impacted by fishing. Relatively small fish like surgeonfish and damsels are abundant, and the most abundant species, the surgeonfish *Ctenochaetus striatus*, has large recruitment events most years and huge recruitment some years, indicating that it is more than able to replace itself and is not impacted significantly by fishing. There are good stocks of herbivorous fish, even when the detritivores (like *C. striatus*) are removed from that category. The status of intermediate-sized fish is not known in detail, though is likely to be intermediate. There are some fish which are a disproportionately large portion of the fish catch compared to their proportion of the living fish populations, some of which may be in some trouble. For example, Alongo (*Acanthurus lineatus*) is less common than Pone (mostly *Ctenochaetus striatus*) yet Alongo forms a larger portion of the catch than Pone. Both of those species are probably in good condition, yet Alongo clearly has higher fishing pressure than Pone. The status of spawning aggregations has not been documented. Fish catch data comes from only a tiny proportion of the actual fish catch, so rare fish are essentially absent from the fish catch data. Fish catch data is inadequate to assess the status of fish which are in the very worst condition (near extinction due to fishing).

In conclusion, the evidence indicates that the primary cause for the low reef fish biomass and low abundances of the large reef fish is fishing, though there are effects of other factors which are primarily in the harbor where the reef habitat has been largely destroyed, and fish catches are now quite small compared to historical catches, likely due to the degradation and loss of habitat. It should be noted that the 1/3 reduction in total biomass is the amount that is the normal expected reduction of a virgin fish stock produced by fishing at MSY, it is not overfishing. However, MSY is defined for individual fish stocks, which are subsets of fish species, not for groups of fish. A 1/3 reduction of all fished species together is some kind of weighted average, and since there is variation between species some are above and some below. The overall 1/3 reduction obscures much heavier reductions in some species and lesser reductions in others. A 1/3 reduction in the total requires reductions greater than 1/3 in as much as half the species, which qualify as overfishing. Thus, a 1/3 reduction of total biomass implies that some species must be overfished. The effects of fishing appear to be the largest single human impact on the coral reef ecosystems of the territory (the COTS outbreak of 1978 which was the largest single impact of any kind was likely mostly natural. The construction of the airport runway on the reef flat appears to be the largest single construction impact on the reefs.). It is thought that whole ecosystems are more resilient than ecosystems with large parts missing. Resilience will be needed to disturbances such as the projected devastating effects of mass coral bleaching coming in a few decades. The coral reef ecosystem needs to be allowed to return as near as possible to the natural state to regain resilience to the oncoming threats. In addition, one species, the bumphead parrot, is critically endangered locally. The director of DMWR publicly announced in July, 2007, at a US Coral Reef Task Force meeting here, that he would protect the large reef fish (based on rarity), but that has not happened. Banning the take of the largest reef fish species would come at little cost to fishers, since few are being caught due to their very low abundances, and would allow much greater sustainable harvest once they had recovered. There are several community-based MPAs, and one no-take MPA, but all are small, and large fish, particularly sharks, range widely, much wider than any of the MPAs, so the MPA's are quite ineffective at protecting them, and there is no evidence so far of increased abundances of any fish in MPAs. The fishing regulations ban scuba spearfishing, destructive fishing methods and removing coral, and specifies minimum sizes for giant clams and lobsters. However, there are no bag limits, seasonal closures, size limits for fish, or other such limits. The fisher community appears to be less vocal than in places like Hawaii or Guam. Traditional controls on fishing, such as the edicts of village chiefs, are much weaker than they once were. Governor Toniola Tulafono has directed the CRAG agencies to use the best available scientific information and the precautionary principle.