Chapter 3. Physical Environment

3.1 Climate

3.1.1 General Climate

The climate of Rose Atoll can be generalized as tropical, with moderate breezes and moderate rainfall. Because Rose Atoll is a small atoll with two tiny islands only a few feet above sea level, the climate there is similar to the open ocean. The ocean temperature in American Samoa averages near 82˚F and may vary by 2-3 degrees seasonally. The constant ocean temperature has a strong moderating effect on the climate.

Because there is not a climate monitoring station at Rose Atoll, data must be generalized from Tutuila Island 180 miles away. Since both islands are at 14 degrees south latitude, temperature data are comparable between the islands.

While the climate of American Samoa is warm and wet year-round, there is some seasonal variability. The wetter, warmer season lasts from October-May and the cooler, drier season is from June-September. In the warm season air temperature averages 83˚F, and rainfall averages about 13 inches a month at the airport in Tutuila. In the cool season, air temperature averages around 81˚F, and rainfall averages about 6 inches a month. Due to a lack of any real topography, Rose Atoll receives substantially less rain than Tutuila, but the precipitation is enough to support the littoral forest (Wegmann and Holzwarth 2006).

Aside from being the drier and cooler season, June-September is also the trade wind season with winds blowing out of the southeast. Hurricanes are more common between November-April when the ocean is slightly warmer (Craig 2009). There have been six hurricanes in Samoa between 1980-2011, some of which have caused forest and reef damage at Rose Atoll.

3.1.2 Climate Change

Climate change can be defined as a change in the state of the climate characterized by changes in the mean and/or the variability of its properties, persisting for an extended period, typically decades or longer (IPCC 2007). Climate variables that may change include temperature, water vapor, sea level, precipitation, etc. Such changes are part of the natural system, but can also be affected by human activities, particularly in the form of emissions of greenhouse gases such as carbon dioxide (CO_2). The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body organized by the World Meteorological Organization and the United Nations Environment Programme to assess the causes, impacts, and response strategies to changes in climatic conditions. According to the Fourth Assessment Report by the IPCC, global temperatures on the Earth's surface have increased by 1.33°F over the last 100 years. This warming trend has accelerated within the last 50 years, increasing by 0.23°F each decade. Global ocean temperatures to a depth of almost 2,300 feet have also increased, rising by 0.18°F between 1961 and 2003 (IPCC 2007).

Global climate models offer a variety of projections based on different emission scenarios. The U.S. Global Change Research Program suggests that a continuing increase in greenhouse gas emissions (CO_2, methane, and nitrous oxides of primary concern) could double atmospheric concentrations of CO_2 by 2060 and subsequently increase temperatures by as much as 2-6.5°F over the next century.

Sea level rise (SLR) is expected to accelerate by 2-5 times the current rate due to both ocean thermal expansion and the melting of glaciers and polar ice caps. Recent modeling projects sea level rising by 0.59-1.93 feet by the end of the 21st century. These changes may lead to more severe weather, shifts in ocean circulation (currents, upwelling), as well as adverse impacts to economies and human health. The extent and ultimate impact these changes will have on Earth's environment remains under considerable debate (OPIC 2000, Buddemeier et al. 2004, IPCC 2007).

3.1.2.1 Climate Change at Rose Atoll

Small island groups are particularly vulnerable to climate change. The following characteristics contribute to this vulnerability: small emergent land area compared to the large expanses of surrounding ocean; limited natural resources; high susceptibility to natural disasters; and inadequate funds to mitigate impacts (IPCC 2001). Thus, Rose Atoll is considered to have a limited capacity to adapt to future climate changes. Other stressors brought on by increased CO_2 will be increasing at the same time, and some of them may work synergistically (Anlauf et al. 2010, Hoeke et al. 2011). Sea-level rise, higher ocean temperatures, ocean acidification and a likely increase in hurricane strength will all affect the reef and organisms of Rose Atoll and some factors will intensify others.

3.1.2.2 Sea Level Rise

According to the IPCC, the oceans are now absorbing more than 80 percent of the heat added to the Earth's climate system. Since 1961, this absorption has caused average global ocean temperatures to increase and seawater to expand. Thermal expansion of the sea is the primary cause of global sea level changes. Melting ice-sheets, ice caps, and alpine glaciers also influence ocean levels. Worldwide, sea level changes have occurred historically on a small scale; however, scientific evidence suggests that the current, accelerated rate of global change began between the mid-1800s and 1900s. Similarly, sea levels in the Pacific have regularly changed over the centuries due to variations in solar radiation. Since 1800, sea levels in the Pacific region have been rising. During the last century, these levels have risen about 6 inches and this is likely to rapidly increase in the next century (Noye and Grzechnik 2001, GAO 2007).

Due to localized geographic and oceanographic variations, it is not possible to discuss impacts of SLR on a global scale. Near Pacific Island ecosystems, SLR is influenced by the rate and extent of global SLR, as well as changes in episodic events, such as the El Niño Southern Oscillation (ENSO, which results in light trade winds in the western Pacific and drier conditions) and the varying strength of trade winds over multi-year timespans. Furthermore, it is important to note that shoreline sea levels are historically and currently influenced by isostatic tectonic changes as the islands move with the Pacific Plate, which are not due to global changes in sea level. Thus, sea level change in the Pacific is highly variable due to geologic uplift (Michener et al. 1997, Carter et al. 2001).

Despite this variability, SLR will have an impact on Rose Atoll, specifically to the reef height that currently protects the islands and lagoon habitats. The rate of growth of corals and CCA (i.e., calcification) must meet or exceed the rate of erosion and any SLR to maintain current conditions. Biological accretion of the reef will also be affected by increased temperatures, changes in seawater chemistry, and increases in destructive weather events. For Samoa, monthly averages of the historical tide gauge, satellite (since 1993) and gridded sea-level (since 1950) data agree well after 1993 and indicate interannual variability in sea levels of about 7.9 inches (estimated 5–95 percent range) after removal of the seasonal cycle. The sea-level rise near Samoa measured by satellite altimeters since 1993 is about 0.16 inches per year, slightly larger than the global average of 0.13 ± 0.016 inches per year. This rise is partly linked to a pattern related to climate variability from year to year and decade to decade (PCCSP 2011). Increased water depths on reef flats may allow for faster upward growth of the reef flat (Brown et al. 2011) but other factors such as ocean acidification may be slowing reef growth at the same time. It is not yet clear whether reefs will continue to produce enough sand to add to both islands to maintain them above sea level.

3.1.2.3 Ocean Temperatures

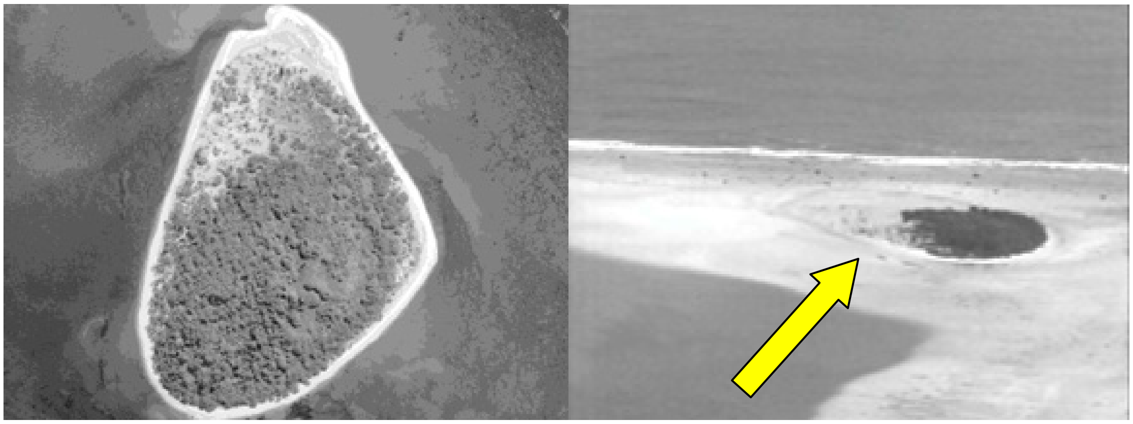
Many corals are living near the limit of their thermal tolerance, and increasing sea-surface temperatures are leading to more frequent cases of coral bleaching. Coral bleaching is a condition where corals expel the tiny zooxanthellae (microscopic plants) that live inside the coral tissues and provide food for the coral through photosynthesis. The zooxantellae give coral their colors. When corals expel their zooxanthellae in high temperature conditions, the coral appears bleached white because we see through the translucent live coral tissue to the skeleton. If temperatures rise just slightly above the bleaching threshold, corals can recover, but higher temperatures typically cause coral mortality. The longer the corals are exposed to higher temperatures, the less likely they are to recover. With warming oceans, corals will suffer more frequent, more severe, and longer duration bleaching events. More frequent and severe coral die offs are expected to cause coral populations to decline because they will have less time to recover between these stress events and while under this stress, their reproductive capacity is diminished (Hoeke et al. 2011, Buddemeier et al. 2004, Hoegh-Guldberg et al. 2007).

Different corals have different tolerances to sea-surface temperature (Fabricius et al. 2011), so bleaching will likely lead to changes in the coral communities. American Samoa is already experiencing this with mass bleaching events in 1994, 2002, and 2003 (Craig 2009) and annual summer bleaching in back reef pools of Tutuila (Fenner and Heron 2009). By mid-century, coral reefs are predicted to be shifting rapidly from coral-dominated to algae-dominated (Hoeke et al. 2011, Buddemeier et al. 2004, Hoegh-Guldberg et al. 2007).

3.1.2.4 Storm Frequency/Intensity

Most climate projections suggest that more intense wind speeds and precipitation amounts will accompany tropical hurricanes and increased tropical sea surface temperatures in the next 50 years. The intensity of tropical hurricanes is likely to increase by 10-20 percent in the Pacific region when atmospheric levels of CO_2 reach double preindustrial levels (McCarthy et al. 2001). One model projects a doubling of the frequency of 4 inches per day rainfall events and a 15-18 percent increase in rainfall intensity over large areas of the Pacific. While powerful storms can move through deep ocean without leaving much evidence, these hurricanes have the ability to cause great damage to terrestrial species on islands – as seen in 2005 when Hurricane Olaf, a Category 5 storm, hit Rose Atoll and washed over much of Rose and all of Sand Islands causing loss of forest cover and mortality of seabird eggs and chicks. Storms toss chunks of the fore-reef up onto the reef platform, leaving Rose’s characteristic boulder-strewn reef flat.

Shallow reef organisms are also affected by being buried by redistributed sediment. Coral reefs are also impacted by hurricanes when wave height and energy break apart coral reefs. During the past 30 years hurricanes have impacted American Samoa at intervals of 1-13 years: 1981 (Esau), 1987 (Tusi), 1990 (Ofa), 1991 (Val), 2004 (Heta) and 2005 (Olaf).



Rose Island before Olaf and Rose Island after Olaf, where ocean inundation is clearly visible. USFWS.

18-foot storm surge effects on Rose Island. Holly Freifeld, USFWS.

3.1.2.5 Ocean Acidification

In addition to SLR and warmer ocean temperatures, as CO_2 levels rise, corals and coralline algae will live in an ocean that is more acidic and contains less carbonate. Corals and crustose coralline algae need a minimum concentration of carbonate (CO_3) in sea water to build their calcium carbonate skeletons. As CO_2 increases in the ocean it triggers a series of reactions that remove CO_3 from the water. Thus, the same process that makes the ocean more acidic, reduces the concentration of CO_3. Reef building requires a minimum carbonate concentration of 200 micromoles per kilogram, and concentrations are presently at 210 micromoles per kilogram and dropping (Hoegh-Guldberg et al. 2007). Once atmospheric CO_2 reaches 550 parts per million, scientists predict calcification of corals will stop in the Samoa area (Jokiel et al. 2008, Guinotte et al. 2003). Early research shows that CCA are even more susceptible to reductions in carbonate than corals (Kuffner et al. 2008). Coralline algae form the rose-colored reef crest that protects the reef flat and islands from erosion. Once acidification slows or stops that growth, the reef flats and islands will be at risk. While research still needs to be done, the long-term outlook for Rose Atoll and other coral reefs is one of slowed growth due to decreased calcification and increased erosion.

3.1.2.6 Additional Ecological Responses to Climate Change

Evidence suggests that recent climatic changes have affected a broad range of individual species and populations in both the marine and terrestrial environment. Organisms have responded by changes in phenology (timing of seasonal activities) and physiology; range and distribution; community composition and interaction; and ecosystem structure and dynamics. For example, paleoecological studies have shown that the distribution of vegetation is highly influenced by climate. The reproductive physiology and population dynamics of amphibians and reptiles are highly influenced by environmental conditions such as temperature and humidity (i.e., sea turtle sex is determined by the temperature of the nest environment; thus, higher temperatures could result in a higher female to male ratio). In addition, increases in atmospheric temperatures during seabird nesting seasons will also have an effect on seabirds (Duffy 1993, Walther et al. 2002, Baker et al. 2006) by increasing thermoregulatory stress in young chicks.

Warming has also caused species to shift toward the poles or higher altitudes and changes in climatic conditions can alter community composition. Increases in CO_2 levels can impact plant photosynthetic rates, reduce water stress, decrease nutrient content, and lower herbivore weights. Climate change can also increase the loss of species as has been shown by the extirpation of two populations of the Bay checkerspot butterfly (*Euphydryas editha bayensis*) in California (Bedoya et al. 2008). Some of the characteristics that make species vulnerable include small population sizes, restricted or patchy ranges (such as those organisms that live on isolated islands), occurrences at either high or low-lying areas, with limited climatic ranges, and narrow or specific habitat requirements. Although there is uncertainty regarding these trajectories, it is probable that there will be ecological consequences (Vitousek 1994, Walther et al. 2002, Ehleringer et al. 2002).

Effects of climate change to nesting green turtles on Rose Island could include loss/degradation of nesting habitat from sand erosion, and changes in incubation times, hatchling success, and sex ratios. As incubation temperature increases, incubation time goes down, the sex ratio is predicted to be highly biased toward females, and hatchling survival will be reduced (Fuentes et al. 2011).

Effects of climate change to seabirds could include loss/degradation of nesting habitat from sand erosion and changes in food source abundance or behavior. Increased salt water intrusion onto Rose Island may lead to the loss of vegetation that is less tolerant of salt water, while increased erosion would lead to the loss of terrestrial habitats.

Climate change represents a growing concern for the management of national wildlife refuges. The Service's climate change strategy, titled "Rising to the Urgent Challenge," establishes a basic framework for the agency to work within a larger conservation community to help ensure wildlife, plant, and habitat sustainability (USFWS 2010). In addition, the Service is supporting regional Landscape Conservation Cooperatives (LCC). These cooperatives are public-private partnerships that recognize conservation challenges transcend political and jurisdictional boundaries and require a more networked approach to conservation—holistic, collaborative, adaptive, and grounded in science to ensure the sustainability of America's land, water, wildlife and cultural resources. The local LCC is the Pacific Islands Climate Change Cooperative (PICCC), headquartered in Honolulu, Hawai'i, but working across the Pacific. The PICCC was established in 2010 to assist those who manage native species, island ecosystems, and key cultural resources in adapting their management to climate change for the continuing benefit of the people of the Pacific Islands. The PICCC steering committee consists of more than 25 Federal, State, private, indigenous, and nongovernmental conservation organizations and academic institutions, forming a cooperative partnership that determines the overall organizational vision, mission, and goals.

3.2 Hydrology

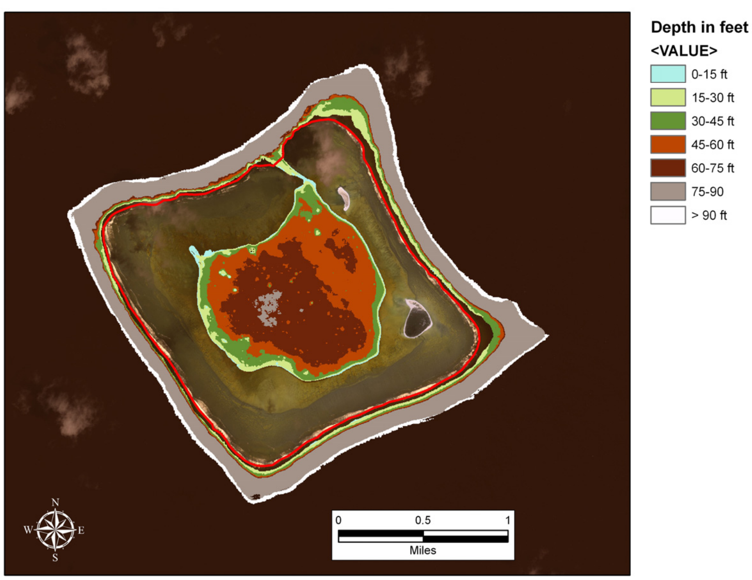
No known hydrological studies have been conducted at Rose Atoll. There are no streams, lakes, wetlands or any other surface water on Rose Atoll (Brainard et al. 2008). Rain water on Rose Island is likely taken up by plant roots and lost through transpiration. It is unlikely that any freshwater is stored in an aquifer due to the small size of the islands, the sandy soils, and the fact that there would likely be salt water intrusion if there was an aquifer.

3.3 Topography and Bathymetry

Both islands have elevations of less than 15 feet and are subject to wash overs by waves in larger storms. Because both islands have components of mobile sand and coral rubble, they can vary in size and shape (Mayor 1921, Satchet 1954, Setchell 1924, Shallenberger et al. 1980, Williamson 1998), but maintain their position on the reef due to central cores of rock (exposed on Rose, inferred for Sand Island). Freycient pointed out in 1826 that Rose Island was highest in the southwest and gradually sloped down toward the northeast where it merged with the sand of the shore (Rodgers et al. 1993). Rose Island has the same basic shape today. Sand Island is likely more variable in shape, but has maintained the same basic location over the years.

Below the elevation of the islands is the reef crest which maintains roughly the same elevation all the way around the atoll. The one exception is the ava, the channel that connects the lagoon with the outside ocean, which is between 6-50 feet deep. Inside the reef crest is the lagoon slope, which is mostly less than 10 feet deep. In the middle of the atoll is the lagoon with a maximum depth near 98 feet. On the outside of the reef crest the atoll plummets steeply to the bottom of the Pacific Ocean over 2 miles below the surface.

In 2006 the NOAA CRED mapped the bathymetry in and around Rose Atoll using multibeam equipment and towed-diver surveys. This was the first high resolution mapping of the area and the data are available at http://www.soest.hawaii.edu/pibhmc/pibhmc_amsamoa_rose_bathy.htm.



Depths at Rose Atoll. USFWS.

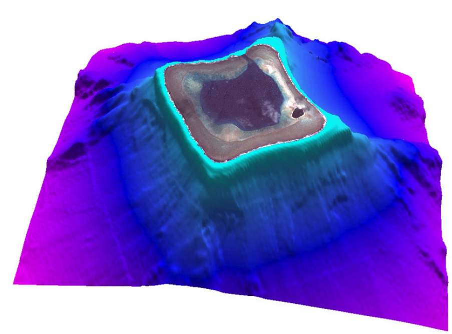
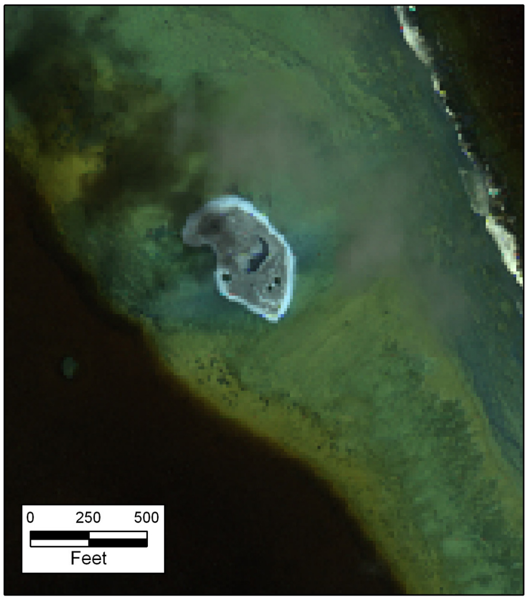
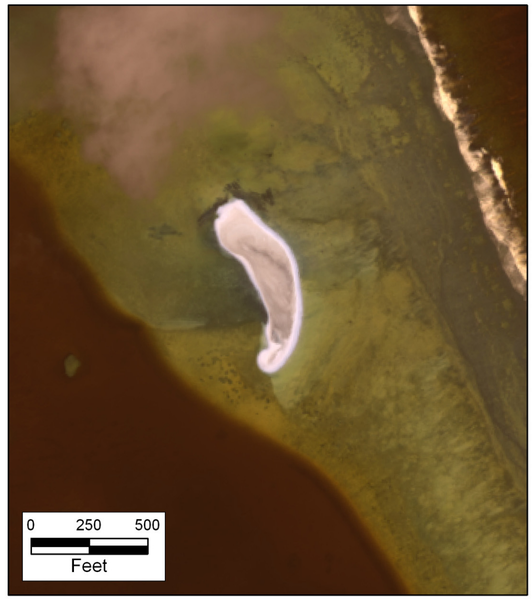


Image showing the steep sides of Rose Atoll sloping rapidly down to more than 2 miles deep. Roger Meyers, American Samoa Department of Marine and Wildlife Resources.



Sand Island 2001



Sand Island 2011

These photos illustrate how variable island size can be given the dynamic nature of the environment. USFWS.

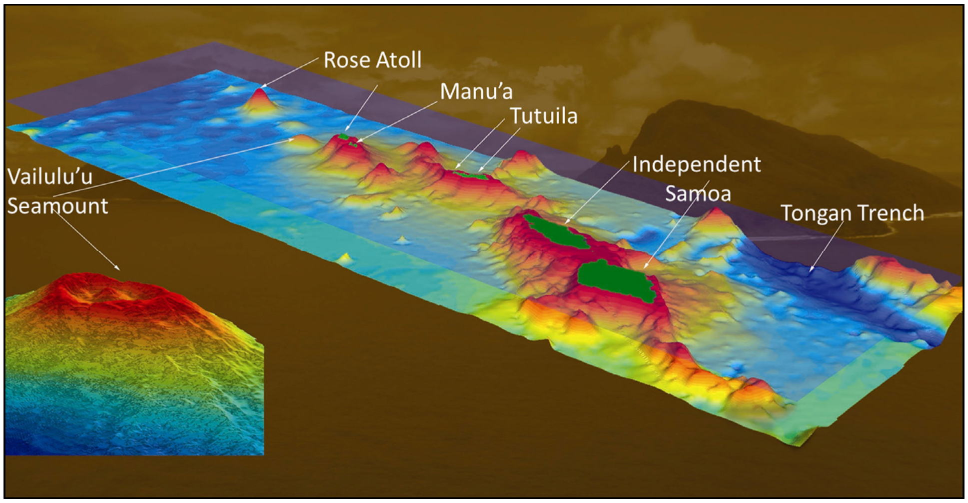
3.4 Geology and Geomorphology

The Samoan Island chain is a series of volcanic islands that are sinking back into the Pacific Ocean over millions of years. These islands are on the Pacific tectonic plate and surrounded by ocean which is mostly 2-3 miles deep. The Pacific plate is moving northwest averaging about 2-3 inches a year. About 100 miles south of the Samoan chain, part of the Pacific Plate sinks into the 6-mile-deep Tongan Trench and ultimately under the Australian Plate. As the plate moves, it bends and cracks creating volcanic hot spots where lava oozes out forming volcanoes and ultimately islands (Birkeland et al. 2008).

Most of the Samoan Island chain was created by a volcanic hot spot, presently located between Rose Atoll and Ta'ū under Vailulu'u seamount. The peak of this seamount is about 1,800 feet deep. Savai'i, is the westernmost island and the oldest with an estimated age around 5 million years. Ta'ū is the easternmost island and the youngest with an estimated age around 1 million years. There are seamounts west of Savai'i, some of which were likely islands that have sunk below the sea surface.

Rose Atoll is an anomaly in the Samoan Island chain. It is older than any of the other islands, but lies at the younger end of the chain. This is because Rose Atoll was not created by the same hot spot that created the rest of the Samoan Islands. It was created by volcanic activity that took place before the present hot spot became active (Birkeland et al. 2008).

Rose started as an ancient volcano that built up from eruptions beginning on the deep sea floor many millions of years ago. The ancient volcano eventually emerged as a volcanic island that eventually went extinct, leading to its subsidence due to the growing weight of the volcano pushing down on the ocean floor beneath it and natural erosion. The first corals and other reef-building organisms settled on the fringes of the volcano and continued to survive, grow, and die, leaving their skeletons behind and allowing younger reef builders to settle upon them and grow. This maintained proximity to the sea surface during the long period of subsidence. Over millions of years the upward growth rate of the reef kept pace with the downward rate of subsidence of the volcano, leading to the creation of a coral cap encircling and eventually covering the summit of the extinct volcano. Eventually the volcano disappeared altogether beneath the sea surface and was replaced by a lagoon, completing the transition from volcanic island with reefs fringing its coasts to an atoll.



Samoan Island Chain. National Park of American Samoa.

Darwin's idea that atolls were perched atop sinking volcanos was verified when scientists drilled through more than 4,000 feet of calcium carbonate reef to hit basalt from an creation of ancient volcano. However, today we know that the creation of atolls is a more complex process, which has happened over the last several thousands of years, not over the millions of years that it takes a volcano to sink. The creation of atolls as we know them today, a ringed–reef surrounding a lagoon often with sand islets, is the result of changes in sea levels that have occurred during glacial and interglacial times. During the last glacial period about 20,000 years ago, sea level was over 100 meters (328.1 feet) lower than it is today. Reefs that had grown during times of higher sea level protruded out of the sea and were subject to thousands of years of erosion and subsidence. As the sea rose again these eroded reefs began to grow again, but now their centers had been eroded. Five thousand years ago, sea levels were about 2 meters (6.6 feet) higher than today, so these reefs grew higher than present day sea level. As sea levels have gone down, a few meters of reef have been exposed, and islands have formed on some of these newly exposed reefs (Dickinson 2009, Woodroffe 2007).

For most of the last 100,000 years Rose Atoll emerged out of the sea. The islands we see at Rose likely only existed since about 1,000 AD. The distinctive square shape of the reef structure today is thought to reflect the shape of the ancient volcano that had dikes of more resistant rock intersecting at a right angle. Although there is insufficient evidence to determine the thickness of the coral reef cap at Rose Atoll, coral drilling on Enewetak Atoll in the Marshall Islands has revealed coral reef cap attaining a thickness of over 4,000 feet in depth that began its growth more than 50 million years ago (Maragos 2011a).

Rose has a higher percentage of CCA than most atolls, and this gives Rose a pink hue (Brainard et al. 2008, Green et al. 1997, Mayor 1921). Aside from the main ring of the atoll, there is a series of blocks and pinnacles created by coral and CCA that provide habitat diversity in the lagoon and on the back reef.

Rose Atoll is one of about 500 surviving atolls in the Pacific today, but countless others have drowned well below the lighted (photic) zone of the ocean because their upward reef growth could not keep pace with the corresponding downward subsidence and sea level fluctuations during the Pleistocene.

3.5 Soils

The soils on Sand Island and the non-vegetated parts of Rose Island are composed of limestone sands and rubble of algal and coral origin surrounding and partially covering a core of paleoreef rock. This soil is considered to be a Fusi soil type (Amerson et al. 1982). These soils are non-consolidated sands that are often washed over during storm events. The sands shift around the rock island core with the wave and wind action making the shape and size of the islands dynamic. This is evident in the constant necessity to replace grid markers used for biological surveys during visits by Service personnel between 1980 and the present. Due to the large numbers of seabirds nesting on the islands, there is a substantial input of guano. All the seabirds at Rose forage over deep ocean thus there is a constant input of nutrients from outside the atoll system.

The description of the soil that follows is based on a 1924 survey under the *Pisonia* forest (Lipman and Shelley 1924). Changes may have taken place as the *Pisonia* trees have died back and been replaced by *Tournefortia argentea*. The soils in the *Pisonia* forest can be divided into a top organic layer of rich chocolate-colored humus, an intermediate layer of very porous, partially decomposed limestone, and a bedrock layer of compact, fine-textured, pure calcium carbonate without texture and no vital structure (also described as coquina). Lipman and Shelley (1924) also found high concentrations of salt and postulated that the toxic effects of the salts might be mitigated to some degree by the high content of organic matter. The soils analysis (from bedrock to soil) also indicated increasingly high percentages of aluminum, phosphorus, sulfur, sodium, and potassium, compared to decreasing percentages of calcium and magnesium, and little change in silicon. The increased sodium, potassium, and sulfur resulted from the large absorptive capacity of the soil, differential leaching, and contribution from ocean spray. Nitrate and nitrate producing bacteria were also present in the soils. Based on comparison of soils from *Pisonia* forests in the Marshall Islands, it was suggested that bird guano was acidified by humus as it washed down through the soil, leading to a lack of hardpan below the humus layer. Lipman and Shelley linked the fertility of Rose Island to the phosphatization, followed by bacterial nitrogen-fixation.

3.6 Environmental Contaminants

The Agency for Toxic Substance and Disease Registry, a Federal bureau of the U.S. Department of Health and Human Services, defines a contaminant as “a substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects” (ATSDR 2009). Contaminants commonly include pesticides and their residues, industrial chemicals, fertilizers, metals, and other toxic substances. By altering biological or physical processes, contaminants may produce adverse and even detrimental effects to an ecosystem.

3.6.1 Military Use in WWII

On February 14, 1941, the territorial waters surrounding the islands of Rose Atoll were established and reserved as the Rose Island Naval Defensive Sea Area. These airspaces over the territorial waters and islands were set apart and reserved as the Rose Island Naval Airspace Reservation (Executive Order 8683). In 1943 the 4th Marine Base Defense Wing was given permission to use Rose Atoll as a dive bomb practice area. In 1996 the Army Corps of Engineers completed a Defense Environmental Restoration Project for Formerly Used Defense Sites (FUDS) for Rose Atoll (USACE 1996). In the Army FUDS investigation, the only reported ordnance was a single MK-23 practice bomb and two 0.30-caliber cartridge casings found by biologists. They found no paperwork indicating that Rose was ever used for bomb practice. It is also believed that it was not used for storage of fuel or other hazardous materials. The FUDS report states, "No land-based evidence of OEW (Ordnance or Exploded Wastes) or other military remnants were observed during visual reconnaissance of Rose Atoll …. The site was otherwise unremarkable with no signs of Ordnance and Explosive Waste (OEW) or environmental stress attributable to former military use" (USACE 1996).

3.6.2 Wreck of the *Jin Shiang Fa* 1993

Jin Shiang Fa. USFWS.

On October 14, 1993, the Taiwanese long-line fishing vessel *Jin Shiang Fa* ran aground on the southwest arm of Rose Atoll spilling 100,000 gallons of diesel fuel, 500 gallons of lube oil, and 2,500 pounds of ammonia. The vessel broke up before a salvage tug could reach the atoll, depositing 200 tons of iron on the reef as well as miles of fishing line and other materials from the ship (Green et al. 1997).

The contaminants spilled over a 6-week period were washed over the reef and into the lagoon by waves and currents. Traces of fuel and oil were detected in sediments 22 months later (USFWS and DMWR 2001). The spill killed the coral and CCA, which created openings on the reef for opportunistic cyanobacteria and turf algae to colonize. Ultimately this led to a phase shift from a CCA-dominated reef community to a cyanobacteria/turf algae-dominated reef community (USFWS and DMWR 2001). Early observations at Rose Atoll also suggested that fish populations may have been affected and large numbers of faisua and tuitui died (Green et al. 1997). The iron scattered about the reef from the wreck has promoted the continued prevalence of cyanobacteria and turf algae in the reef flat community.

Debris clean up. Jim Maragos, USFWS.

Though iron removal from the ship wreck continued until 2007, monitoring of the site continues. The natural resource damage assessment, restoration, and monitoring being done by the Service was funded by the Oil Spill Liability Trust Fund, established by the Oil Pollution Act of 1990 and managed by the U.S. Coast Guard National Pollution Funds Center.

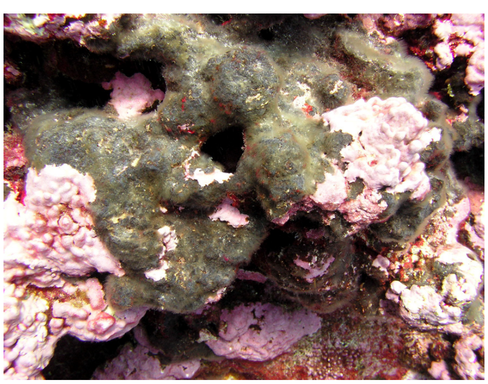
Disarticulated engine block and scrap metal on coral. USFWS.

3.7 Air Quality

Being over 2,700 miles to Sydney, Australia; 4,700 to Los Angeles, California; and 6,000 miles to Peru, Rose Atoll is a long way from any major source of air pollution. No known air quality sampling has taken place, however, due to the lack of human presence and on-site vehicles (other than boats used for Refuge management 1-2 times a year), distance to air polluted areas, and trade winds, air quality is thought not to be impaired.

3.8 Water Quality

Though little water quality monitoring has been done at the Refuge, given its remote location, it is anticipated that ocean water quality is not impaired. Water quality testing was conducted after the *Jin Shiang Fa* ran aground on the atoll in 1993 spilling 100,000 gallons of diesel fuel and other contaminants into the waters in and around Rose Atoll. Shortly after the grounding, the majority of the vessel hull was removed from the reef. Despite the removal of much of the metallic debris from the fore-reef slope, there was a sufficient source of dissolved iron seaward of the reef edge to sustain elevated iron levels in the water flowing over the reef platform. In 2002, concentrations of iron were still elevated 5-10 fold above background levels (approximately 0.6 nanomoles) within a plume of water approximately 557 yards wide flowing onto the reef platform. However, peak concentrations within the plume in 2002 were only half of the peak values found in 1998.

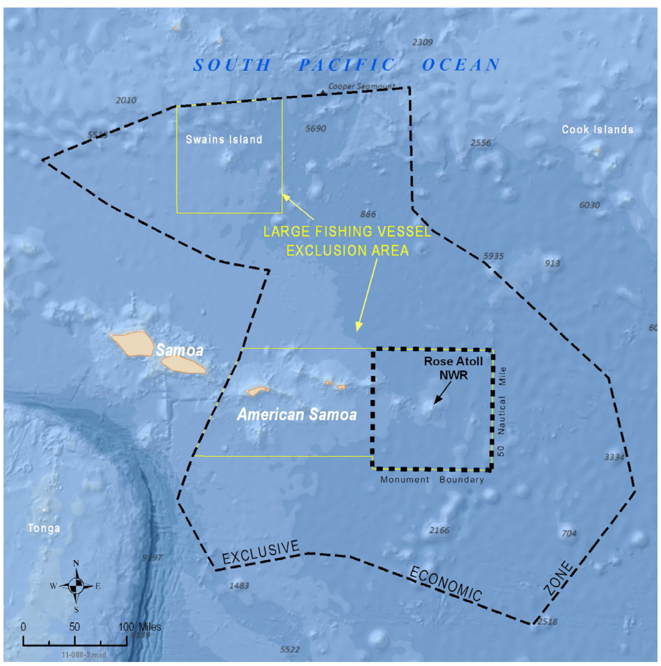


Cyanobacteria overgrows pink crustose coralline algae. Jean Kenyon, USFWS.

Iron is a limiting element in atoll marine environments that are far from continental margins, and this increased iron resulted in higher cyanobacterial growth near the wreck site (Green et al. 1997). There have been several cleanup operations funded to remove the remaining pieces of the ship, and by 2007 all major pieces had been removed. Measurements of iron concentration in the water upstream and downstream of the wreck site continue as part of the monitoring program evaluating recovery from the *Jin Shiang Fa* grounding. Monitoring is ongoing and new strategies for active restoration of the area are being evaluated.

Storm wash over and sand erosion on the two islands may periodically lead to temporary turbidity in near shore waters. Storm wash and rainfall could also lead to nutrient enrichment from bird guano in the marine environment. The nutrient budgets of coral reef systems adjacent to healthy seabird colonies and areas where seabird populations have been extirpated is currently an area of active investigation in tropical regions around the world.

3.9 Surrounding Land Use



Surrounding land use: the Monument, Exclusive Economic Zone, and Large Fishing Vessel Exclusion Zone. USFWS.

In 2009, Presidential Proclamation 8337 created the Monument which overlays the Refuge and extends out 50 nautical miles covering a total of 13,451 square miles. There is no commercial fishing allowed in the Monument, and large vessels (greater than 50 feet) are excluded from fishing in an area roughly 50 nautical miles from all the islands and atolls of American Samoa per NMFS regulations (Federal Register 2012). The Refuge and the Monument are in the American Samoa Exclusive Economic Zone.

While commercial fishing is prohibited in the Monument, at the time of this writing, the Western Pacific Regional Fisheries Council and NMFS are developing proposed Monument non-commercial fishing regulations that include establishing a 0 to12-nautical mile (nmi) no-take area around the Refuge and propose to establish regulations that permit sustenance and traditional indigenous fishing and recreational fishing in the 12-50 nmi zone of the Monument. Additionally, ONMS has initiated the process of bringing the areas of the Monument (excluding the Refuge) into the National Marine Sanctuary System.

Given the remoteness of Rose Atoll NWR, there is very little use of this area. However, Service staff have seen recreational sailboats accessing the area. In June 2009, the *Paul Eric* entered the Refuge as an emergency stop to repair its engine. Unfortunately, as the vessel weighed anchor in preparation to depart, strong winds and currents pushed the vessel aground on the shallow eastern reef near Sand Island. During the removal of the *Paul Eric* from the reef, a second large yacht, the *Southwest* was seen approaching Rose from the south.