Chapter 4. Biological Environment

This chapter addresses the biological resources and habitats found on Rose Atoll NWR. However, it is not an exhaustive review of all species occurring within the Refuge. The chapter begins with a discussion of biological integrity (historic conditions and ecosystem function), as required under the Administration Act. The bulk of the chapter is then focused on the presentation of pertinent background information for habitats used by each of the Priority Resources of Concern (ROC) and other benefiting species designated under the CCP. The background information includes descriptions, conditions, and trends of habitats and threats (stresses and sources of stress) to the habitats and/or associated ROC. This information was used to develop goals and objectives for the CCP.

4.1 Biological Integrity Analysis

The Administration Act, as amended, directs the Service to ensure that BIDEH of the Refuge System is maintained for the benefit of present and future generations of Americans. The elements of BIDEH are represented by native fish, wildlife, plants, and their habitats, as well as those ecological processes that support them. The Refuge System policy on BIDEH (601 FW 3) also provides guidance on consideration and protection of the broad spectrum of fish, wildlife, and habitat resources found on a refuge and in associated ecosystems that represent BIDEH.

Biological integrity lies along a continuum from a completely natural system to a biological system extensively altered by considerable human impacts to the landscape (which includes seascapes). No modern landscape retains complete BIDEH. We strive to prevent the further loss of natural biological features and processes. Maintaining or restoring biological integrity is not the same as maximizing biological diversity. Maintaining biological integrity may entail managing for a single species or community at some refuges and combinations of species or communities at other refuges. Maintaining critical habitat for a specific endangered species, even though it may reduce biological diversity at the refuge scale, helps maintain biological integrity and diversity at the ecosystem or national landscape scale.

On refuges, we typically focus our evaluations of biological diversity at the refuge scale; however, these refuge evaluations can contribute to assessments at larger landscape scales. We strive to maintain populations of breeding individuals that are genetically viable and functional. Evaluations of biological diversity begin with population surveys and studies of flora and fauna. The Refuge System's focus is on native species and natural communities such as those found under historical conditions (BIDEH policy). However, given the likely impacts of climate change (e.g., SLR, ocean acidification, ocean temperature) on reefs and atoll islands, maintaining historic conditions may not be possible in the future. The Service will continue to promote resilience by minimizing other anthropogenic effects to the Refuge so the species and habitats have improved chances of adapting to a changing climate. Additionally, we will incorporate new climate science into our management as it becomes available.

We evaluate environmental health by examining the extent to which environmental composition, structure, and function have been altered from historic conditions. Environmental composition refers to abiotic components such as air, water, and soils, all of which are generally interwoven with biotic components (e.g., decomposers live in soils). Environmental structure refers to the organization of abiotic components, such as atmospheric layering, aquifer structure, and topography. Environmental function refers to the processes undergone by abiotic components, such as wind, tidal regimes, evaporation, and erosion. A diversity of abiotic composition, structure, and function tends to support a diversity of biological composition, structure, and function.

Due to its remoteness and limited acreage, Rose Atoll is a far more natural system than most landscapes. The atoll has had very limited human contact and no development on it. Its distinctive CCA, declining *Pisonia* forest, terrestrial fauna, and unique assemblage of marine fishes and invertebrates in the lagoon are all critical components of BIDEH. The overarching BIDEH principles that were integrated into the CCP analysis included the Refuge purposes, Refuge System mission, and where appropriate, maintenance of BIDEH for wildlife and habitat, and BIDEH in a landscape context. The BIDEH for the Refuge is summarized in Table 4-1.

Table 4-1. Biological Integrity, Diversity, and Environmental Health

Habitats	Population/Habitat Attributes	Natural Processes Responsible for These Conditions	Limiting Factors
Lagoon	Lagoon floor (to ~98 feet depth) and back reef composed of carbonate sand and rubble, with low coral and CCA cover (< 1%). Hard-substrate pinnacles and patch reefs with moderate coral and CCA cover (>10%), supporting diverse fish assemblage and faisua Potential conservation species: faisua, sea turtles, candidate ESA coral species	Intact perimeter reef (present-day height, width, biotic construction) and ava (present-day depth, width, location unblocked flow) that regulate seawater exchange with surrounding ocean and seawater flow inside lagoon; natural breakdown of calcifying organisms providing carbonate sediment	Proliferation of cyanobacteria; illegal fishing and faisua poaching; reduced calcification linked to ocean acidification
Perimeter Crustose Coralline Algal Reef	Living reef dominated by CCA, with intact geomorphic structure providing mosaic of microhabitats for invertebrates including corals and sea urchins Potential conservation species: candidate ESA coral species	Growth of CCA and other calcifying organisms, and accretion of carbonate through biochemical processes, maintains constructional platform between open ocean and lagoon	Rate of SLR relative to natural capacities for growth and accretion; reduced calcification linked to ocean acidification; overgrowth by non-reef-building cyanobacteria
Ava	Unobstructed channel between lagoon and fore reef with present-day depth, width, and location Potential conservation species: faisua, sea turtles, candidate ESA coral species	Natural hydrological regimes of oceanic and lagoonal seawater flow	Impedance of natural flow patterns by boat grounding or other obstacles

Beach Strand	Beach strand habitat clear of invasive introduced plants and marine debris that provides nesting sites for ground-nesting seabirds and turtles and foraging sites for migratory shorebirds	Sand and rubble formed by the action of storms and bio-erosion of living CCA reef community is deposited and re-arranged by ocean waves. Plant community on the beach strand areas are kept at seral stage by repeated overwashing and storms Current sea level	Nonnative invasive species of plants and animals; human disturbance and trampling; interruption in the supply of gastropod shells from the reef that are used by land hermit crabs; sea level rise; reduced calcification linked to ocean acidification; increased storm frequency and intensity changing sediment distribution patterns
Littoral Forest	South Central tropical Pacific littoral forest with a native species composition typical of other intact habitats of similar rainfall and soil type. This forest provides nesting sites for arboreal and ground-nesting seabirds as well as native land crabs, insects, and migratory shorebirds	Nutrient input from seabird guano and precipitation favor pu’a vai and other species of plants dispersed by birds or ocean currents	Nonnative invasive species of plants, animals, and pathogens, human disturbance; SLR; reduced calcification linked to ocean acidification; increased storm frequency and intensity; changing sediment distribution patterns

4.2 Selection of Priority Resources of Concern

4.2.1 Analysis of Priority Resources of Concern

Wildlife and habitat goals and objectives were designed directly around the habitat requirements of species designated as Priority ROC (ROC are called conservation targets in conservation planning methodologies used by other agencies and NGOs). As defined in the Service’s Policy on Habitat Management Plans (620 FW 1), resources of concern are:

> “all plant and/or animal species, species groups, or communities specifically identified in refuge purpose(s), System mission, or international, national, regional, state, or ecosystem conservation plans or acts. For example, waterfowl and shorebirds are a resource of concern on a refuge whose purpose is to protect ‘migrating waterfowl and shorebirds.’ Federal or State threatened and endangered species on that same refuge are also a resource of concern under terms of the respective endangered species acts (620 FW 1.4G)…
>
> Habitats or plant communities are resources of concern when they are specifically identified in refuge purposes, when they support species or species groups identified in refuge purposes, when they support NWRS resources of concern, and/or when they are important in the maintenance or restoration of biological integrity, diversity, and environmental health.”

Therefore, ROC for a refuge may be a species or species group, or the habitat/plant community that supports a priority species/species group.

In developing its listing of Priority ROC, the planning team selected not only species mentioned in establishing documents for the Refuge, but also species that captured the ecological attributes of habitats required by larger suites of species. The ecological attributes of habitats should be analyzed to meet the life-history requirements of ROC, and are therefore critical to sustain the long-term viability of the ROC and other benefiting species. Ecological attributes of terrestrial habitats include vegetation structure, species composition, age class, patch size and/or contiguity with other habitats; hydrologic regime; and disturbance events (e.g., flooding, fire). Likewise, in the marine environment, ecological attributes include benthic structure; species composition and distribution; oceanographic regime (waves, tides, currents, upwelling); water quality parameters such as pH, temperature, salinity, light attenuation, nutrient levels; and disturbance events (e.g., tropical storms). These provide measurable indicators that strongly correlate with the ability of a habitat to support a given species.

Tables listing the desired conditions for habitat types found on the Refuge incorporate “desired” conditions that were based on scientific literature review and team members’ professional judgment. These desired conditions for specific ecological attributes were then used to help design habitat objectives, as presented in Chapter 2. However, not all ecological attributes or indicators were deemed ultimately feasible or necessary around which to design an objective. Other factors, such as feasibility and the Refuge’s ability to reasonably influence or measure certain indicators, played a role in determining the ultimate parameters chosen for each habitat objective. Thus, ecological attributes should be viewed as a step in the planning process. The ultimate design of objectives was subject to further discussion and consideration.

Limiting factors were also considered in developing objectives. A limiting factor is a threat to, or an impairment or degradation of, the natural processes responsible for creating and maintaining plant and animal communities. In developing objectives and strategies, the team gave priority to mitigating or abating limiting factors that presented high risk to ROC. In many cases, limiting factors occur on a regional or landscape scale and are beyond the control of individual refuges. Through the consideration of BIDEH, the Refuge will provide for or maintain all appropriate native habitats and species. Refuge management priorities may change over time, and because the CCP is designed to be a living, flexible document, changes will be made at appropriate times.

Early in the planning process, the planning team cooperatively identified priority species for the Refuge, as recommended under the Service’s 620 FW 1. These ROC frame the development of goals and objectives for wildlife and habitat. The ROC may be species, species groups, or features that the Refuge will actively manage to conserve and restore over the life of the CCP, or species that are indicators of habitat quality for a larger suite of species. Negative features of the landscape, such as invasive plants, may demand Refuge management effort, but are not designated as ROC.

The main criteria for selecting priority ROC included the following requirements:

- The resource must be reflective of the refuge’s establishing purposes and the Refuge System mission;
- The resource must include the main natural habitat types found at the refuge;
- The resource must be recommended as a conservation priority in the Wildlife and Habitat Management Review; or
- The resource must be federally or State/Territory-listed as a candidate for listing, or a species of concern.

Other criteria that were considered in the selection of the resources of concern included the following:

- Species groups or Refuge features of special management concern;
- Species contributing to the BIDEH of the ecosystem; or
- Species for which it is feasible to estimate population size (needed for future monitoring and adaptive management).

Table 4-2. Priority Resources of Concern

Focal Species	Habitat Type	Habitat Structure	Life History Requirements	Other Benefiting Species
Pu'a vai (*Pisonia*)	Littoral Forest	Sandy and phosphate soils with elevation sufficient to avoid overwashing in all but the largest storms (> 6.6 feet)	All	Tree-nesting seabirds fua'o (red-footed booby), atafa (lesser frigatebird), atafa (great frigatebird), gogo uli (black noddy), white tern (manu sina)
Littoral forest tree species – *Cordia subcordata, Tournefortia argentea, Hernandia nymphaeifolia, Terminalia samoensis, Neisosperma oppositifolium,* and *Hibiscus tiliaceus*	Littoral forest (mesic)	Sandy and phosphate soils with elevation sufficient to avoid overwashing in all but the largest storms (> 6.6 feet)	All	Matu'u (Pacific reef heron) for nesting habitat and aleva (long-tailed cuckoo) for wintering, molting, and foraging
Tava'e'ula (red-tailed tropicbird)	Littoral forest	Ground under vegetation in understory and base of trees; sites that provide adequate shade for nestling for the duration of the growth period	Nesting	Gogo (brown noddy), fua'o (brown booby)
Fua'o (red-footed booby)	Littoral forest	*Tournefortia* and *Pisonia* trees that provide appropriate structure for nest construction above the ground	Nesting	Atafa (lesser frigatebird), atafa (great frigatebird), gogo uli (black noddy)
Land hermit crabs *Coenobita perlatus* and *Coenobita*	Littoral forest	Sandy and phosphate soils, vegetation and shade protection from tropical sun	Reproduction – aquatic larvae, terrestrial adults, foraging, proximity to sea water source for	Tuli prey upon land hermit crabs. Entire forest community benefits from *Coenobita*

Focal Species	Habitat Type	Habitat Structure	Life History Requirements	Other Benefiting Species
brevimanus			osmoregulation and gill maintenance	acting as scavengers and nutrient recyclers
Gogo Uli (sooty tern)	Beach strand and littoral forest	Open beach habitat or forest sites with minimal understory that provide open access for landing and takeoff and visibility for these highly social nesters	Nesting	Gogosina (gray-backed tern), gogosina (black-naped tern), tuli, ruddy turnstones that prey on sooty tern eggs
Tuli (bristle-thighed curlew)	Beach strand and littoral forest	Open beach habitat or open forest	Wintering, molting, feeding	Tuli (ruddy turnstone), tuli (sanderling), tuli (wandering tattler), tuli (whimbrel), tuli (Pacific golden plover)
I'a sa (green turtle) and laumei uga (hawksbill turtle)	Beach strand/littoral forest/lagoon	Sand with access to the water but above the high tide line	Nesting (green turtle only), resting, feeding	
Tamole (yellow purslane, *Portulaca lutea*)	Beach strand	Open sand, no over story	All	
Malie (gray reef shark)	Lagoon, ava	Pinnacles, patch reefs, back reefs	All	Malie alamata (blacktip reef shark), whitetip reef shark (*Triaenodon obesus*), bumphead parrotfish, Maori wrasse, gatala-uli (peacock grouper), leopard grouper, coral hind, strawberry grouper, mata'ele (flagtail grouper), honeycomb grouper, gatala-aloalo (dwarf spotted grouper), masked grouper
Amu (stony corals) *Acropora, Astreopora, Cyphastrea, Favia, Leptastrea, Montastrea, Montipora, Pavona, Platygyra,*	Reef crest, back reef, lagoon pinnacles, and patch reefs	Hard substrate, depth and water clarity sufficient for light penetration, moderate temperatures, seawater immersion time sufficient to prevent desiccation, low nutrients, low algae and cyanobacteria, herbivorous fish and	All (growth, feeding [endosymbiosis, and plankton capture], reproduction)	Reef fish; other benthic invertebrates (soft corals, mollusks, crustaceans, worms, echinoderms, tunicates)

Focal Species	Habitat Type	Habitat Structure	Life History Requirements	Other Benefiting Species
Porites, Psammocora, Stylocoeniella spp.		invertebrates		
Faisua (giant clam) (*Tridacna maxima*)	Lagoon pinnacles and patch reefs	Hard substrate, water depth and clarity sufficient for light penetration	All (growth, feeding [endosymbiosis, and filter-feeding], reproduction	
Sea urchins (tuitui)	Reef crest, back reef, lagoon pinnacles, and patch reefs	Hard substrate, available holes for occupancy, algal films, and turf for grazing	All (growth, grazing, reproduction)	Corals, CCA
Turban shells (*Turbo crassus, Turbo setosus, Turbo argyrostomus*)	Reef and lagoon habitats	CCA reef flats with epilithic algae for grazing	Foraging (herbivores and detritus feeders)	Land hermit crabs (*Coenobita perlatus* and *C. brevimanus*) that use shells of these gastropods
Crustose coralline algae (*Porolithon* spp., *Hydrolithon* spp.)	Reef	Hard substrate, moderate temperatures, low cyanobacteria, herbivorous fish, and invertebrates	All (growth, photosynthesis, reproduction)	Stony corals

4.3 Habitat Types

An atoll is a reef formation atop a subsiding extinct volcano that includes a lagoon surrounded by a shallow perimeter reef, at least one emergent island, and regular surface water exchange between the lagoon and the open ocean (Woodroffe and Biribo 2011, Maragos and Williams 2011). Rose Atoll has all these major habitats and associated biological groups found on Pacific atolls. It supports island and marine species groups that are adapted to each of these habitats.

All biological communities and habitats at Rose Atoll are profoundly influenced by the ocean and associated climate. The early life cycle stages of most reef species at Rose are tiny and moved by tides, waves, and ocean currents. Water quality, motion, temperature, light, salinity, and substrate characteristics influence the behavior of these small organisms causing them to settle on or near favorable habitats to begin the transition to adult phases.

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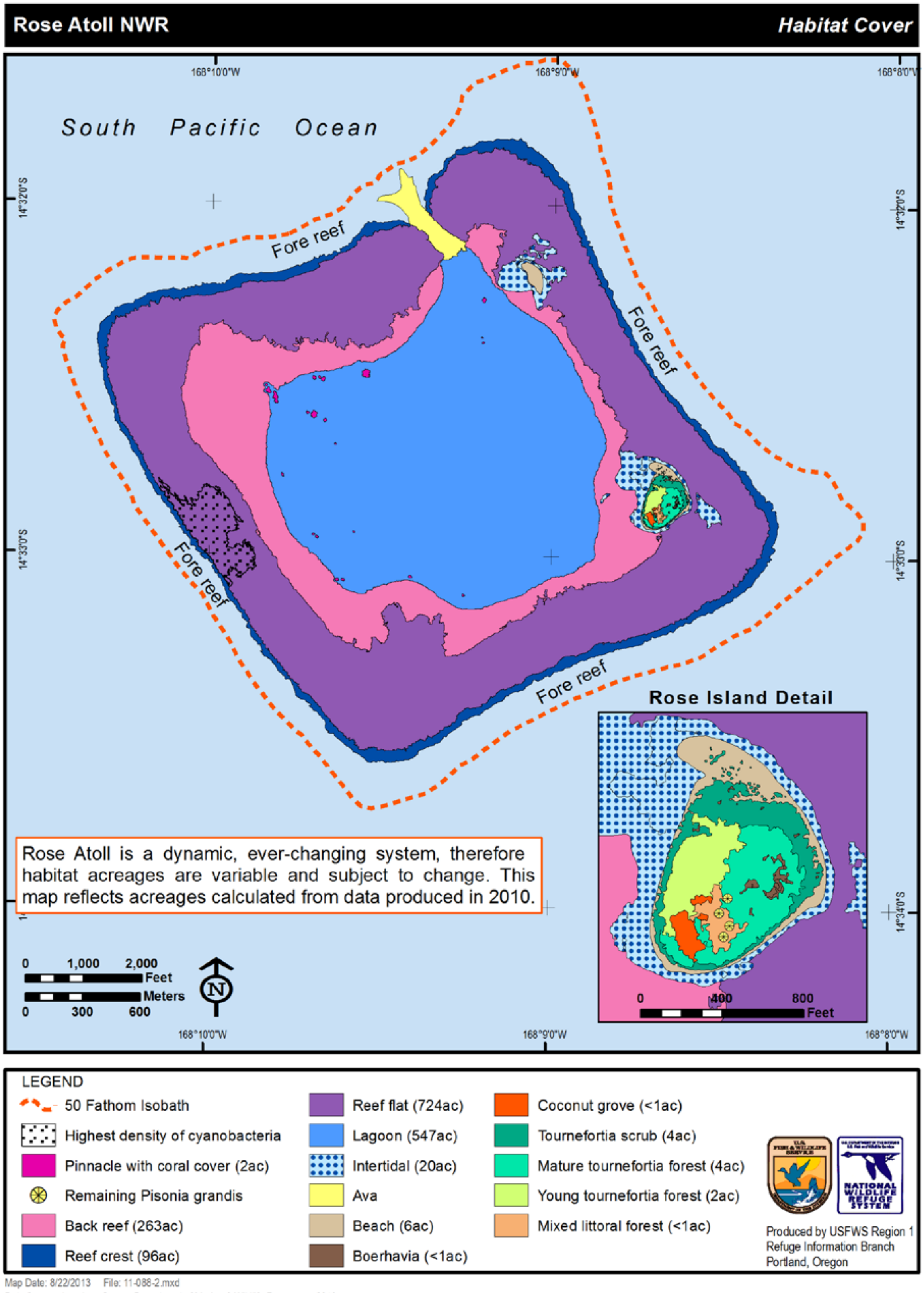
Figure 4-1. Habitats.



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4.3.1 Ava

The ava is a shallow (less than 50 feet) and narrow (130 feet) passage that connects the open ocean to the lagoon. The shape, size, and location of the ava is vital to maintaining the lagoon, reef, and island habitats. As ocean water spills into the lagoon over the sides of the reef, it is released out through the ava. Though water usually flows out the ava, tides and waves occasionally create a situation where water flows into the lagoon through the ava. A data-logging current meter deployed in the ava by NMFS PIFSC in 2002 showed that water flowed predominantly out of the ava from the lagoon, attaining flow rates of 3.3 knots, with only short periods of flow reversal (NMFS PIFSC unpubl. data 2011).

The elevation of the ava controls the water movement out of the lagoon, and plays a major role in the layering of lagoon water by temperature and salinity. Additionally, the shape and location of the ava is an important factor in the location and longevity of the islands on the atoll. Water movement inside the atoll creates currents that remove sand from some areas and deposit it in other areas. This sediment transport regime has created and maintained Rose and Sand Islands as dynamic islands in roughly the same location since Rantzau mapped Rose Atoll in 1873 (Rodgers et al. 1993). The ava is also the major passageway for fish and other organisms in and out of the lagoon, where species that require more shelter from rough water to breed or live may concentrate. Sharks and other predators congregate at the mouth of the ava waiting for prey. As such, the ava connects reef life on both sides of the perimeter reef at Rose Atoll.

In addition, the size and depth of the ava affect the amount of water exchange between the lagoon and the ocean, and indirectly the height and width of the perimeter reef crest and reef slopes surrounding the lagoon. In the case of Rose, the two islands are relatively small in relation to the total circumference of the open reef crests, allowing more water to enter the lagoon over the crests during high tides and heavy wave action. Because the ava is shallow and narrow, water exiting the ava is less than the amount of water entering over the perimeter reefs during tidal cycles. As a consequence, water levels in the lagoon remain higher than those on the ocean side except at the highest tides. This allows the perimeter reef crests to remain wet as water spills over them, and that allows the reef builders on the crests to grow slightly higher, to levels above mean low water. Over time, the crest of the perimeter reef can maintain itself above the surrounding ocean at low tides. As a result, water levels in the lagoon are higher than that of the surrounding ocean, and the quantity and velocity of water flowing “downstream” out the ava greatly exceeds that which enters the ava during rising tides.

Thus, any modification of the ava, such as widening or deepening it to facilitate better or larger boat passage, or having a large vessel disabled and blocking the flow of water through the ava, can have drastic effects on the biology of the lagoon and kill the reef builders on the crests of the perimeter reefs. Widening or creating boat channels through atoll reefs have degraded the lagoons of Kanton Atoll in the Phoenix Islands, atolls in Tuvalu, and several other atolls (Carpenter and Maragos 1989, Kaly and Jones 1991, Maragos 1993, 2011a, 2011b) and even the lagoons in some NWRs such as Johnston Atoll, Midway Atoll, and Palmyra Atoll.

The ava is used by Refuge staff to enter the atoll when conducting management. No active management of the ava is conducted other than regulating boat traffic through the pass.

4.3.2 Reef (Crest and Back)

Reef flat. Frank Pendleton/USFWS

The reef crest at Rose Atoll, constructed by countless generations of calcifying marine organisms whose remains have been cemented together over time by biochemical processes, varies from 1,000 to 3,000 feet wide. The predominance of CCA was noted by early scientific visitors (Mayor 1921, Setchell 1924) and has been reiterated many times. The reef crest is the living veneer of the ancient physical barrier separating the deep surrounding ocean from the shallow interior lagoon. By breaking the force of waves and currents, the shallow reef crest provides a sheltered environment inside which lagoon habitats have developed, and itself harbors a biotic assemblage adapted to shallow intertidal conditions. This living platform, which continues to accrete with successive generations of calcifying organisms, is resistant to physical- and bio-erosion, enabling formation and maintenance of the marine and terrestrial lagoon habitats in which other organisms exist. The reef crest is a vital habitat for Pacific reef herons and snowflake eels.

In the aftermath of the 1993 grounding, extensive damage resulted to CCA, corals, sea urchins, and other biota on the reef crest and neighboring lagoon back reef from mechanical abrasion and chemical release. Iron released by the deterioration of metallic debris stimulated cyanobacterial populations on the reef crest and neighboring back and patch reefs and caused them to spread to other parts of the atoll that were not directly affected by the grounding. Transects conducted on the reef crest from 1995 to 2010 showed continuing recovery of CCA cover.

The perimeter reef includes the back reef which consists of unconsolidated terrain encircling the lagoon, composed largely of rubble that slopes from the reef crest to the more interior, sandier benthos.

4.3.3 Lagoon

Rose has an almost completely enclosed lagoon, measuring less than 1.2 miles at its widest point, with only one ava at the northwest corner. Because the ava is shallow and narrow, the volume of water exiting the ava is less than the volume of water entering over the reef crest during tidal cycles. As a consequence, water levels in the lagoon remain higher than those on the ocean side except at the highest tides, and the volume and velocity of water flowing out the ava greatly exceeds that which enters at that site.

Lagoon with pinnacle. Kelsie Ernsberger/USFWS

The lagoon includes the more finely divided "shallow lagoon," "lagoon floor," and "lagoon pinnacles." Detailed bathymetry produced by NMFS PIFSC shows the lagoon floor maximum depth at 98 feet. Circulation and water mixing in tropical reef lagoons and back reef areas is restricted compared to neighboring fore reef slopes and surrounding oceanic surface waters. This restricted circulation frequently results in temperature differences of several degrees between the lagoon reservoir and the surrounding ocean. This effect is especially apparent in enclosed atoll morphologies during periods of high solar radiation and low winds. At Rose Atoll, interpolation of *in situ* surface water temperatures measured from conductivity/temperature/depth instruments and towed thermistors in February 2002 showed surface waters up to 5.5°F higher inside the lagoon and back reef areas compared to the cooler, relatively well-mixed waters in the fore reef area and surrounding ocean. Turbidity as indicated by short-term measurements of beam transmission was notably higher inside the lagoon compared with other areas outside the perimeter reef crest (NMFS PIFSC 2008). The lagoon also displayed higher values of Chlorophyll-*a*, NO_2, and SiO_2 when compared with the fore reef. Finally, the lagoon consistently registered the densest and most saline waters at Rose, especially below the sill depth (approximately 16 feet) of the ava. These elevated nutrient concentrations, coupled with increased or variable turbidity, suggest prolonged periods of mixing, flushing, and nutrient cycling within the surface-water layers of the protected shallow-water lagoon.


Coral cover on the lagoon pinnacles is dominated by the genera Favia, Montipora, Porites, *and* Astreopora.
Jean Kenyon/USFWS

Wave-induced lagoon circulation is tidally modulated as more wave set-up occurs during high tides and less during low tides. The net effect is that surface waters in the lagoon likely have a short residence time. The high-salinity and high-density subsurface waters in the lagoon, on the other hand, have no obvious means to circulate and flush out of the lagoon. Hence, lagoon bottom waters likely have much longer residence times.

While much of the lagoon floor consists of unconsolidated sand and rubble (Kenyon et al. 2010), a number of hard-bottom pinnacles are found rising toward the surface, providing substrate that supports corals, faisua, other macroinvertebrates, and diverse fish populations. Coral cover on the lagoon pinnacles is dominated by the genera *Favia, Montipora, Porites,* and *Astreopora*. Faisua density is highest at the base of the lagoon pinnacles. Small- to medium-sized fish are very abundant around several of the larger pinnacle patch reefs inside the lagoon, where parrotfish, snapper, emperor, goatfish, and jacks are common (NMFS PIFSC 2008).

4.3.4 Intertidal

The north end of Rose Island is characterized by an expanse of sand and rubble that is exposed at low tide. Large groups of terns (primarily brown noddies and sooty terns) form "clubs" here when the area is exposed, possibly because it is not being used for nest territories and offers good visibility for quick escape. Seabird clubs are ephemeral single-species groups of birds that congregate and socialize or rest together. Shorebirds such as wandering tattlers and ruddy turnstones also forage on the exposed sediment. When the tide comes in reef fish move in as well to forage in the shallow water.

4.3.5 Beach Strand

Whistler (1992) defines littoral/herbaceous strand (part of beach strand) as a narrow zone of vegetation occupying the upper portion of sandy or rocky beaches, limited inland by littoral forest or littoral shrubland, and seaward by the high-tide mark of the ocean. Littoral strand occupies the transition zone between the sea and the forest (Amerson et al. 1982). This community is dominated by herbaceous creeping vines, and shrubby species up to 6.5 feet or more in height (sometimes prostrate or dwarfed by the strong, salty sea winds). It also includes strand species found on coasts with exposed rocks within, or beyond, the reef (Amerson et al. 1982). The beach strand habitat is a harsh environment, subjected to dry conditions, high temperatures, salt spray, or occasional inundations by salt water. In addition, plants in this community must grow in direct tropical sunlight and grow on poor sandy or rocky soil.

Beach strand at Rose Island.
Kelsie Ernsberger/USFWS

Beach strand habitat is a result of dynamic, natural processes of waves washing away and rebuilding sediment on both Rose and Sand Islands. On Sand Island the habitat is often devoid of vegetation or sparsely vegetated while on Rose Island the habitat supports *Tournefortia argentea* (tree heliotrope) shrubs. The beach strand vegetation on Rose Island is dominated by *Boerhavia repens* and historically also consisted of tamole (*Portulaca lutea*) (Amerson et al. 1982, IUCN 1991, Setchell 1924). It is presently confined to a single boulder in the reef crest. These large coral blocks thrown up by extreme storm events serve as roosts for Pacific reef herons and brown boobies. It is likely that seeds of additional species regularly wash up on the beach and then die back as storm surges wash them away. In 1921 when Mayor described the atoll, Sand Island had absolutely no vegetation; however, some species would be established periodically until the next storm waves washed them away.

Portulaca lutea *growing on a block at Rose Atoll.* Jiny Kim/USFWS

Some native ground-nesting seabirds (i.e., sooty terns) thrive in this open habitat. Sooty terns, brown noddies, gray-backed terns, and black-naped terns use (mainly for nesting) the beach strand habitat on Rose and Sand Islands. Rose Atoll beach strand habitat is an important foraging, resting, and molting ground for six migratory shorebirds: the ruddy turnstone, sanderling, wandering tattler, whimbrel, bristle-thighed curlew, and the Pacific golden plover. Ghost crabs forage and dig their burrows in the beach strand and *Coenobita* (hermit) crabs traverse the sand at night to get to the water's edge for hydration. Due to overharvest, loss of beach habitat, incidental kills in fishing gear, and other reasons, green turtle numbers have declined worldwide and the beach strand at Rose Atoll provides a vital nesting area for this species. Present management of the beach strand includes removing marine debris and looking for and controlling invasive plants.



Left photo: Boerhavia*.* Jiny Kim/USFWS
Middle photo: Seabirds using beach strand habitat. Jiny Kim/USFWS
Right photo: Coenobita *crab.* Kelsie Ernsberger/USFWS

4.3.6 Littoral Forest

Littoral forest is a common vegetation type occurring on tropical shores. It often consists of a dense forest dominated by a single tree species. The major factor determining the distribution and extent of littoral forests is the ocean. Common characteristics for tree species in the community include tolerance of bright sunny conditions, dispersal by buoyant, salt-tolerant seeds (or hitchhiking on seabirds), and tolerance to salt spray and wind. However, most species are not tolerant of standing water or frequent incursions of saltwater (Amerson et al. 1982). Typically, the forest floor is open due to the lack of bright sunlight required for germination and growth of most herbs and shrubs on the beach strand (Whistler 1992). The limiting factor for tree species is substrate and soils (Amerson et al. 1982). The dominant tree species of Samoa include: *Barringtonia asiatica* and *Calophyllum inophyllum* in certain beach areas and historically pu'a vai on Rose Atoll. But other tree species that may also thrive in this forest type include *Hernandia nymphaeifolia*, *Terminalia catappa*, *Cordia subcordata*, *Neisosperma oppositifolium*, *Guettarda speciosa*, *Thespesia populnea*, *Tournefortia argentea*, and *Cocos nucifera*. Although common and sometimes dominant on Polynesian shores, coconut trees have presumably been planted or are remnants of former cultivation due to their presence mostly in or near villages and coastal plantations.

A map made in 1839 shows Rose Island extended across the width of the atoll rim and was covered by forests (Keating 1992). When Alfred Goldsborough Mayor did the first scientific account of Rose Atoll in 1920, he found the southern and southeastern half of Rose Island covered with a dense pu'a vai-dominated forest, with no other understory plants, except a single coconut tree. The largest trees were found near the southern end of the forest. Plant observations from 1974 to 1988 have documented at least 10 additional species that were established at one point (Wegmann and Holzwarth 2006). However, during the visit in 2010, eight species (*Boerhavia repens*, *Tournefortia argentea*, *Pisonia grandis*, *Portulaca lutea*, *Hibiscus tiliaceus*, *Nephrolepis hirsutula*, *Cocos nucifera*, *Cordia subcordata*) were documented. Appendix A lists the plant species of Rose Atoll, collections or first observations, and most recent information about current presence or absence. Rose

Atoll’s littoral forest is currently dominated by *Tournefortia argentea* which forms a forest up to 25 feet tall. Historically Rose Island supported a mature stand of pu’a vai.

Left photo: Rose Island from the sea in 1939, dominated by pu’a vai. National Archives
Right photo: Rose Island from the lagoon in 2007 with just a few unhealthy trees remaining. USFWS

Pu’a vai *(Pisonia grandis)*, found almost exclusively in Indo-Pacific islands from tropical Africa to eastern Polynesia and Micronesia, is spread by sticky fruits that become attached to seabirds. It is a shade-intolerant plant that thrives on sandy shores and islands, particularly in soil enriched with guano from seabirds. The distinct soil in the *Pu’a vai*grove on Rose Island consists of an upper layer of rich chocolate-colored humus, which extends to over 6 feet in depth (Mayor 1921, Lipman and Taylor 1924) overlying the calcium carbonate bedrock. *Pu’a vai* is considered “one of the most salt-tolerant plants of which we have record at present” that is able to inhabit the unusually high salt concentrations in the soil on Rose Island (Lipman and Shelley 1924). The lack of fresh surface water and the properties of the soil most likely explain the limited number of plant species that are on the atoll (Amerson et al. 1982).

Pisonia forests are declining throughout the Pacific. Historically, the best example of a *Pisonia* forest in American Samoa, Rose Island’s *Pisonia* forest has undergone several gradual periods of dieback and regeneration. The dieback was noted in the early 1970s but the forest was regenerating by 1976 (Amerson et al. 1982). The cause of this dieback was unknown, but thought to be disease, drought, or an insect attack (Amerson et al. 1982). First documented in 2002, the soft scale insect (*Pulvinaria urbicola*) is associated with the once healthy forest’s decline (Wegmann and Holzwarth 2006). In May 2004, 10 of the remaining 11 mature *Pisonia* trees were treated with injections of a systemic pesticide called imidacloprid (Trade name Imicide ®). Loss of trees continued so it appears the response may have come too late and this approach alone has not significantly deterred the scale infestation. Scale insect infestation is associated with significant loss of *Pisonia* forests worldwide (Queensland Parks and Wildlife Service 2006, 2007). Additionally, since the Polynesian rat was eradicated in 1993 coconut palms have been released from rat herbivory and have increased to a population size that threatens to shade out recruitment of native canopy trees.

Scale insect on Pisonia *leaf.*
Kelsie Ernsberger/USFWS

The *Pisonia* trees along with tree heliotrope serve as important nesting and roosting habitat for the red-footed booby, great and lesser frigatebird, gogo uli , and white tern, which prefer to nest above the ground on trees. Tree heliotrope also provides cover for red-tailed tropicbirds, brown noddies, sooty terns, and brown boobies, which nest directly on the ground. Shrubs and rock piles also provide shade and daytime cover for the numerous land hermit crabs that inhabit the island. Thick vegetation and rock crevices also provide shelter and protection for the largest land crab, the coconut crab (*Birgus latro*). This species seems to have increased in density since the eradication of rats at Rose Atoll. The relatively open understory of the *Pisonia* forest is also favored habitat for Pacific golden-plovers, wandering tattlers, and ruddy turnstones (Engilis and Naughton 2004). Littoral forests were at one time a common habitat in the Pacific; however, human alteration of island landscapes has limited this forest type. The eradication of rats from Rose Atoll by 1993 provides important habitat for plant species that will be able to recolonize the atoll and perpetuate the littoral habitats that are in decline throughout the Pacific region.

4.4 Threatened, Endangered, and Sensitive Species

One goal of the Refuge System is "to conserve, restore where appropriate, and enhance all species of fish, wildlife, and plants that are endangered or threatened with becoming endangered." In the policy clarifying the mission of the Refuge System, it is stated, "we protect and manage candidate and proposed species to enhance their status and help preclude the need for listing." In accordance with this policy, the CCP planning team considered species with Federal or State/Territory status, and other special status species, in the planning process.

4.4.1 Tuli'olovalu (*Numenius tahitiensis*) or Bristle-thighed Curlew

Tuli'olovalu breed in western Alaska and migrate during the winter to remote, small islands and atolls in the tropical Pacific Ocean (Marks and Redmond 1994). The beaches and littoral forest of the atoll are important wintering ground for tuli'olovalu . This rare shorebird is the only migratory species whose entire population is restricted to the insular Pacific (Hayman et al. 1986, Marks et al. 1990). Marks and Redmond (1996) documented the strong fidelity shown by tuli to wintering sites. At Laysan Island in the Northwestern Hawaiian Islands (NWHI), only 1 of 16 marked adult tuli'olovalu changed its wintering home range area in 3 years of study (Marks and Redmond 1996).

This species undergoes a molt-induced flightless period (unique in shorebirds) and leaves many birds more susceptible to predatory attacks during that time (Marks 1993, Marks and Redmond 1994). Therefore, predator-free islands to which these birds are adapted have become increasingly important as competition for space increases and less habitat is available due to an increasing human population. With a global population of approximately 10,000 individuals (Morrison et al. 2006), the Service (USFWS 2008) has designated the curlew as a Bird of Conservation Concern and it is also ranked as Vulnerable by the International Union for Conservation of Nature (IUCN) (Engilis and Naughton 2004, IUCN 2008). It is also highlighted as a globally threatened species in need of regional action by the South Pacific Regional Environmental Programme.

4.4.2 Tuli (*Pluvialis fulva*) or Pacific Golden Plover

The Pacific golden plover breeds in western Alaska and Siberia and winters throughout the Pacific Islands. Plovers foraging at Rose Atoll likely come from the Alaskan breeding population, however, these affinities are still poorly understood (Engilis and Naughton 2004). Tuli are widespread across the Pacific region in any open habitat from beach strands to upland pastures, occurring in good numbers on remote islands and atolls. Amerson et al. (1982) estimated 4,500 tuli in American Samoa, a small population number relative to the total United States Pacific Islands (USPI) populations (Engilis and Naughton 2004). Johnson et al. (2008) studied migration behavior of Pacific golden plover in American Samoa and were able to confirm that at least 1 of the 30 birds they tagged on Tutuila Island was breeding in Alaska. The birds departed Samoa for the northward migration in mid-April. The return of the plovers began in late August and peaked in mid-September. This represents at least a 5,594-mile trip from American Samoa. Johnson et al. (2008) estimated there were 500 tuli on Tutuila. The largest count of tuli recorded at Rose Atoll was 49 individuals in 1984. The USPI Regional Shorebird Conservation Plan identified the Pacific Golden Plover as a species of High Conservation Concern (Engilis and Naughton 2004).

4.4.3 I'a sa (*Chelonia mydas*) or Green Turtle

I'a sa is listed as threatened under the ESA. Adults can weigh up to 500 pounds and are often found living near tropical reefs and rocky shorelines. Females may lay up to 6 clutches per season in pits excavated in soft beach sand, with each clutch containing about 100 eggs. Hatchlings and juveniles live in pelagic waters. Little information exists on the feeding behavior of post-hatchlings and juveniles living in pelagic habitats, but most likely they are exclusively carnivorous (e.g., soft-bodied invertebrates, jellyfish, and fish eggs). Subadult and adult turtles residing in nearshore benthic environments are almost completely herbivorous; their common name is derived from the color of the animals' body fat, which is green from the marine algae and sea grasses they eat.

I'a sa swimming in Rose Atoll lagoon.
Kelsie Ernsberger/USFWS

I'a sa use the protected habitats of Rose Atoll for feeding and nesting. Their numbers have declined throughout the south Pacific due to the combined effects of habitat destruction, human harvest for meat and shells, depredation by introduced predators, and incidental drowning in fishing gear (Kinan 2005, Craig 2002). The isolated beaches on Rose Atoll provide an important nesting ground for i'a sa. The number of i'a sa nesting annually at Rose Atoll has been estimated at 24–36 (Tuato'o-Bartley et al. 1993). However, the total number of i'a sa using Rose Atoll as a nesting ground could actually be several fold higher, since females only nest every 2–5 years (Spotila 2004, NMFS and USFWS 1998a), and thus a different set of turtles nest each season. Given the scarcity of beaches where turtles can nest and their eggs hatch unmolested, the value of the isolated beaches at Rose Atoll is considerable, even if only 120 or so i'a sa nest there.

The Historical Summary of Turtle Observations at Rose Atoll, American Samoa, 1839–1991 (Balazs 1991) is a compilation of historical data and notations. The document lists a total of 47 entries for that time period, most of the earlier ones simply report presence or absence of turtles. From 1970 onward, turtle observations were more quantitative, if no less sporadic and opportunistic due to the expense of reaching the remote atoll. Aerial, land-based, and water-based surveys recorded the number of turtles, their tracks, nest pits, eggs, hatchlings, and nesting and mating behaviors (Balazs 1991). An estimated 200 turtles were seen in the lagoon during an aerial survey in August 1974, the highest value recorded. A total of 406 pits were counted on both Rose and Sand Islands during a survey in October 1976. A decade later, in fall 1985, biologists counted a total of 244 pits on both islands, and a decade after that, in fall 1992, the total count was 81 nesting pits. However, the problem with nest pit counts is that female turtles often dig test pits before actually laying eggs, and they lay multiple clutches the year they make the long migration to their natal nesting beach. Also, unless there is a major storm event that wipes the beach clean, it is difficult to reliably discern if a pit was dug that season or the season before (Ponwith 1990). These limitations, as well as uneven survey effort, should be taken into account when comparing pit counts from various years, and it should be recognized that pit counts are not the equivalent of a population count.

The i'a sa that visit Rose do so seasonally for reproduction, and spend the rest of their time in other parts of the south Pacific. Metal flipper tags were applied to a total of 46 nesting females from 1971 to 1996 in order to see where they traveled (Balazs 1991). Three of these tags were re-sighted after the turtles were killed for food or fatally injured from a hunting attempt. Two were located in Fiji at the time of tag recovery and one in Vanuatu (both island groups to the west of Samoa). A fourth turtle was re-sighted at Rose Atoll, 9 years after she was initially tagged (Ponwith 1990), making multiple visits to the beach to nest.

Given the limited re-sighting rate of flipper tags, satellite tagging was subsequently employed in an effort to better comprehend the migration routes of green turtles in the south Pacific (Craig et al. 2004). Seven females at Rose Atoll were outfitted with satellite tags during the nesting seasons of 1993 to 1995. After 2 months of nesting at Rose, six of the turtles traveled to feeding grounds in Fiji. The seventh turtle traveled due east to Raiatea, an island in French Polynesia. The turtles' migration route crossed 994 miles of ocean and took an average of 40 days. The route followed prevailing surface currents as recorded by satellite-linked ocean drifters deployed from Rose in February 2002, though the drifters traveled more slowly (net rate of 1.0 foot per hour) than the turtles (3.6 feet per hour). While these i'a sa spend the majority of their life in Fiji, accumulating the fat stores that will enable them to reproduce, the remote beaches at Rose Atoll provide invaluable undisturbed nesting habitat (Craig et al. 2004).

Unlike many places in their range, at Rose Atoll, turtles can approach the beach without risk of being harvested for meat or drowned in nets, and eggs and hatchlings are free from depredation by wild pigs, rats, dogs, and humans. Marine debris can also prove deadly when it entangles turtles or is mistaken for food and ingested. Plastics are particularly harmful as they may remain in the turtle's stomach for long periods of time, releasing toxic substances, and can clog the digestive system. Natural predators and dangers inherent to the human populated areas east of Samoa where the turtles feed continue to impact turtle populations. Craig et al. (2004) stresses the importance of working towards protection for turtles in their foraging waters east of Samoa, since this is where turtles spend 90% of their adult life. Continued monitoring of the nesting beaches at Rose Atoll will give researchers a proxy for population trends of i'a sa in the region.

4.4.4 Hawksbill Turtle (*Eretmochelys imbricata*)

Hawksbill turtles use the protected habitats of Rose Atoll. Similar to i'a sa, their numbers have declined throughout the south Pacific, reduced by the combined effects of habitat destruction, human harvest for meat and tortoise shell, depredation by introduced predators, and incidental drowning in fishing gear (Kinan 2005; Craig 2002). Although it is not clear if hawksbills nest at Rose Atoll, they are consistently sighted using the lagoon and open water habitats around the atoll.

The hawksbill turtle is listed as endangered under the ESA. It is one of the smaller turtles and takes its species name (*imbricata*) from the overlapping plates on its upper shell and its common name from the shape of its hooked jaw. The carapace (top shell) of an adult ranges from 25-35 inches in length and has a "tortoiseshell" coloring, ranging from dark to golden brown, with streaks of orange, red, and/or black. Hawksbill turtles use different habitats at different stages of their life cycle, but are typically found around coastal reefs, rocky areas, estuaries, and lagoons. Their narrow head and jaws, shaped like a beak, allow them to get food from crevices in tropical reefs. They eat sponges, anemones, squid, and shrimp. Hawksbills have been consistently reported at Rose Atoll in historical accounts (Setchell 1924), as well as more recent surveys (Sekora 1974, Ludwig 1981, Amerson et al. 1982, Morrell et al. 1991, Flint 1992, NMFS PIFSC 2006).

4.4.5 Faisua (*Tridacna maxima*) or Giant Clam

The colloquial term "giant clam" refers to eight species of marine bivalves found in two genera (*Hippopus* and *Tridacna*) of the molluscan subfamily Tridacninae. Surveys of faisua populations at Rose Atoll have identified a single species, *Tridacna maxima* (Wass 1981, Green and Craig 1999). Less than a third of the size of the "true" giant clam *Tridacna gigas*, *T. maxima* is commonly referred to as the "small giant clam," with shells generally not exceeding 9 inches in length. Found living on the surface of reefs or sand, or partly embedded in coral, the faisua occupies well-lit areas, due to the symbiotic relationship with single-celled photosynthetic algae (zooxanthellae) found in its fleshy mantle that require sunlight for energy production. Faisua also filter-feed on phytoplankton extracted from seawater siphoned through their body.

Mature faisua are hermaphrodites that reproduce by broadcast spawning, releasing sperm first, followed by eggs. The fertilized egg develops into a larva within 3 hours and passes through two additional larval stages before undergoing metamorphosis after 8-10 days into a juvenile, sessile faisua that acquires zooxanthellae. Reproductive and growth studies at Rose Atoll (Radtke 1985) showed the clams reach maturity at about 10 years of age corresponding to a shell size of 3–5 inches. Young faisua are male and put most of their energy into growth, becoming hermaphrodites upon maturity and accompanied by a slower growth phase. Reproduction is stimulated by the lunar cycle, the time of day, and the presence of others eggs and sperm in the water. Faisua lifespan at Rose Atoll is estimated to be approximately 28 years.

*Faisua (*Tridacna maxima*) embedded in* Astreopora *coral.*
Kelsie Ernsberger/USFWS

Tridacna maxima has the widest geographic range of all giant clam species. It is found in the oceans surrounding east Africa, India, China, Australia, Southeast Asia, and the islands of the Pacific. Although classified as Least Concern on the IUCN Red List, this culturally and ecologically important marine animal has declined precipitously from overharvesting in many populated areas including the high islands of American Samoa, but remains abundant at Rose Atoll (Green and Craig 1999). *Tridacna maxima* is listed under Appendix II of CITES meaning it is not necessarily threatened but that trade must be controlled in order to avoid use incompatible with its survival.

The first survey of faisua at Rose was undertaken by the American Samoa DMWR in an attempt to quantify the resource in response to requests by the Samoans that they be allowed to harvest the clams (Wass 1981). The study found faisua to be uncommon in the ava and fore reef but abundant in the lagoon. Distribution in the lagoon was patchy, with faisua abundant on solid substrate in the shallow, relatively clear parts of the lagoon, but with lower densities in the southern lagoon and below approximately 45 feet where water became more turbid. Constraints of time as well as the uneven distribution of suitable clam substrate in the lagoon made density determinations difficult, with the single transect survey in the southwestern lagoon yielding an average density of 0.33 clams per square yard. Size frequency data were collected at four lagoon locations; shell measurements ranged from 0.4 to 9 inches, with approximately 31% being greater than 5.5 inches, the size at which all clams are fully hermaphroditic.

More extensive transects by Radtke (1985) in various habitats showed marked differences related to depth and substrate. Lagoon patch reefs in 20–40 feet of water were concluded to be prime habitat for faisua, with densities of 3.6–7.2 clams per square yard and 40–50% of the area colonized. Smaller coral patches (with up to 3.6 clams per square yard) and lagoon substrate (with up to 6 clams per square yard) were colonized at approximately 20%. Shell measurement ranged from 0.4 to 9 inches, with bimodal peaks around 1–2 inches and 6–7 inches. Radtke's total estimated number of faisua in the lagoon was approximately 1,338,000. Unlike Wass (1981) Radtke did not favor controlled harvesting, stating, "they have a respectable number of organisms in this ecosystem, but due to their slow growth would have a small sustainable yield … quantitative balance of production of *Tridacna maxima* at Rose Atoll does not appear to be within the scope of rational exploitation and exploitation could endanger the perpetuity of the unique environment."

A pivotal study by Green and Craig (1999) highlights the importance of Rose Atoll as a refuge for faisua. From 1994 to 1995 they surveyed all 6 islands of American Samoa and recorded a total of 2,853 clams in survey transects, 97% of which were found at Rose. The majority were located in the lagoon, with faisua favoring areas at the base of pinnacle patch reefs. Roughly a quarter of the clams were mature in size, and mortality was estimated as being very low, due mostly to natural causes. The largest clam recorded was 11 inches across the widest part of the shell. Given the mean density of faisua, the population at Rose was estimated to be approximately 27,800 clams. The dramatically lower estimate than that provided by Radtke (1985) was considered to be the result of differences in sampling design rather than a population decline. The authors theoretically considered Rose to be a potential source of faisua recruits to other islands in the Samoan archipelago, given larval longevity (approximately 8 days, range 5–15 days) and water currents flowing westward from Rose at 16 miles per day.

Towed-diver surveys conducted by NMFS PIFSC in 2006 recorded more than 1,100 giant clams on 30 linear miles of transect, with approximately 95% recorded on reefs inside the lagoon (NMFS PIFSC 2006). Researchers have noted that the pinnacle just inside the ava had a markedly lower density of faisua than the rest of the lagoon and it seems likely that this is where illegal harvesting has taken place (Wegmann and Holzwarth 2006).

4.5 Seabirds

Rose Atoll's importance to seabirds in the South central Pacific is disproportionately large relative to the size of its islands because some of the seabird species have been extirpated on most other islands in the region. There are very few uninhabited islands in the region so Rose provides breeding habitat for species that do not thrive in proximity to human settlements. Seabirds and migratory shorebirds are the numerically dominant terrestrial vertebrates. Since 1975, 16 species of seabirds have been recorded on land and 12 species are known to breed there. Efforts to eradicate the island of Polynesian rats began in 1991, with eradication declared in 1993. This enhanced the value of the atoll for seabird conservation and has increased the possibilities that other Pacific seabird species that are currently threatened from habitat loss, predation, and invasive species, such as ta'i'o (wedge-tailed shearwaters), Christmas shearwaters, Bulwer's petrel, Phoenix petrel, and the Polynesian storm petrel, might someday colonize the site. Social attraction methods may accelerate or facilitate this process of recruitment. Rose Atoll falls into the North American Bird Conservation Region called "Other U.S. Pacific Islands" and is now considered separately from sites in the Caribbean (USFWS 2008).

For most if not all of the seabirds, listed terrestrial threats such as habitat destruction, invasive weeds, disturbance, ungulates, and introduced predators limit populations (Metz and Schreiber 2002). Introduced predators such as rats, mongooses, and cats have reduced populations at many sites worldwide (Harrison 1990).

Seabirds using terrestrial habitats at Rose Atoll all forage in the pelagic zone typically in association with large epipelagic subsurface predators such as skipjack (*Katsuwonus pelamis*) and yellowfin tunas (*Thunnus albacares*). These fish concentrate and force prey to the surface in the course of their own foraging and also make it available to foraging seabirds (Au and Pitman 1988). El Niño-Southern Oscillation conditions can cause total or partial breeding failure in some locations (Schreiber and Schreiber 1989, Schreiber 1994, Orta 1992b) when changes in the temperature of water masses in proximity to the breeding sites change and force tuna to move elsewhere to find their preferred thermal conditions. A reduction in the biomass of these subsurface predators may render the preferred prey of tropical pelagic seabirds unavailable or difficult for the birds to detect. The relationships between these species is complex and poorly understood but it is a reasonable probability that exploitation of populations of large epipelagic fish by fishing may also affect the breeding success and survival of seabirds at Rose Atoll by reducing opportunities for this type of feeding interaction. The trophic relationships and effects on reproductive performance in this complex system have not been well quantified.

4.5.1 Tava'e'ula (*Phaethon rubricauda*) or Red-tailed Tropicbird

The tava'e'ula is a medium-sized bird with shining pinkish-white feathers and red tail plumes. They breed mainly on oceanic islands and coral atolls in the Indian and Pacific oceans. Breeding adults are mostly sedentary; however, they avoid land when not breeding and are among the most pelagic and solitary of seabirds (Schreiber and Schreiber 1993, Harrison 1990, Harrison et al. 1983). At sea, tava'e'ula are evenly distributed throughout their range (Schreiber and Schreiber 1993, King 1970). Little is known about their movements outside the breeding season.

The world population is estimated at 17,000–21,000 pairs; with an estimated 12,000–14,000 pairs in the Pacific (Schreiber and Schreiber 1993, Gould et al. 1974). Small colonies exist in American

Samoa and other remote Pacific islands. The largest number of active nests observed at Rose on any particular visit was 38 in 2002. The world population seems stable in many areas and may be increasing in some areas, but there is a lack of information on past population estimates so comparisons are difficult (Schreiber and Schreiber 1993). Within the USPI, tava'e'ula populations appear stable overall.

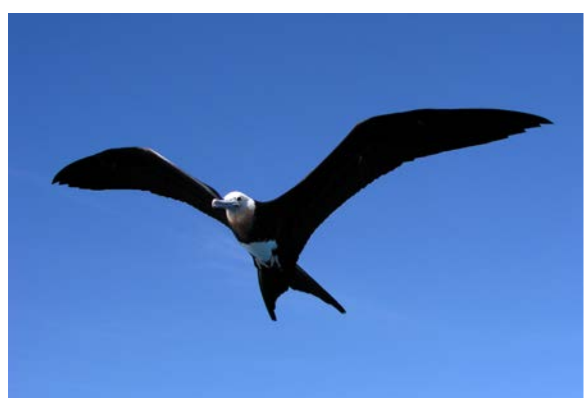
Tava'e'ula nest on the ground under vegetation in the understory and base of trees, among rocks, roots, or logs and less commonly in the cavities of cliff faces (Schreiber and Schreiber 1993, Orta 1992a). At Rose, red-tailed tropicbirds choose to nest under *Tournefortia* or *Pisonia* (Morell and Aquilani 2000). Nests are scrapes that vary from a shallow depression in the sand to more elaborate structures consisting of twigs and leaves (Schreiber and Schreiber 1993, Harrison 1990, Fleet 1974). Breeding occurs annually, but timing varies depending on locality (Schreiber and Schreiber 1993, Harrison 1990). First breeding usually occurs around 2–4 years (Schreiber and Schreiber 1993, Harrison 1990). The oldest-living bird recorded was 23 years (Klimkiewicz and Futcher 1989).

Tava'e'ula are attracted to ships, presumably because flying fish, their main prey, are scattered by ships (Harrison et al. 1983). Previously the tava'e'ula also nested on Tutuila, however the abundance of introduced animals such as rats, cats, and dogs that attack ground-nesting birds likely led to their extirpation. Introduced ants have been recorded attacking incubating adults, chicks, and eggs at some colonies in the Pacific.

4.5.2 Atafa (*Fregata minor*) or Great Frigatebird

The atafa has a pantropical distribution that overlaps with lesser frigatebirds (Orta 1992b) and breeds mainly on small remote islands, typically within regions with tradewinds in the tropical Atlantic, Indian, and Pacific Oceans. At sea, birds can be found any distance from land but they are most abundant within 50 miles of breeding and roosting sites (King 1967). Adults, juveniles, and nonbreeders disperse widely throughout the tropical seas.

The world population is estimated at 500,000-1,000,000 birds (Orta 1992b). A small population of fewer than 50 pairs nests on Rose Island. They are colonial nesters, often constructing platform nests in the tops of bushes and trees. At Rose Island they nest in *Tournefortia* and *Pisonia* trees. Breeding occurs throughout the year depending on locality, with egg laying primarily in the dry season (Orta 1992b). Great frigatebirds are sexually dimorphic; females tend to be 25% heavier than males (Orta 1992b) and males are almost entirely black, with varying amounts of dark metallic green and purple feathers and a large, red gular pouch that they inflate during courtship. Females are black with a white breast patch. Atafa are seasonally monogamous; it is extremely rare for pairs to remain together for subsequent breeding attempts (Orta 1992b). Females breed biannually, sometimes every 3–4 years (Orta 1992b). Post-fledging care, which continues for up to 18 months, is provided by females. Sexual maturity begins around 8–10 years and most birds return to the natal colony to breed (Orta 1992b).



Atafa. Jim Maragos/USFWS

Atafa usually feed in mixed-species flocks over tuna schools (Orta 1992b, King 1967). Their diet consists mostly of flying fish and squid which they capture at or above the water's surface (Harrison et al. 1983). Frigatebirds are notorious for their kleptoparasitism (a form of feeding where one animal takes prey from another that has caught or killed it), but most of their food is obtained by fishing (Harrison et al. 1983). Tuna fisheries exploitation likely could lead to the decrease in availability of prey for atafa (Metz and Schreiber 2002).

4.5.3 Atafa (*Fregata ariel*) or Lesser Frigatebird

The lesser frigatebird is also called atafa and has a pantropical distribution that coincides with, but is smaller than, that of the great frigatebird (Orta 1992b, Clements 2000). At sea, birds are most abundant within 50 miles of breeding and roosting islands although they can be found any distance from land (King 1967). Juveniles and nonbreeders disperse throughout tropical seas (Harrison 1990).

The species' world population is estimated at several hundred thousand birds (Orta 1992b). Small colonies exist in American Samoa (Amerson et al. 1982) with fewer than 100 pairs nesting at Rose Atoll. Within the USPI, lesser frigatebird populations have significantly declined due to the introduction of cats and rats; however, eradication of cats at Howland Island and Jarvis Island NWRs seems to have resulted in an increase in lesser frigatebird populations at those sites (USFWS 2005, Rauzon et al. 2011). Human exploitation of tuna fisheries could potentially affect prey availability for lesser frigatebirds because they rely upon the large subsurface predators to push the species on which they feed to the surface (Orta 1992b).

Breeding takes place on small, remote tropical islands. Nests and stick platforms are constructed on trees and bushes (e.g., *Pisonia* and *Tournefortia* bushes and trees on Rose Island), but when suitable vegetation is not available birds nest on bare ground (Orta 1992b). Lesser frigatebirds are sexually dimorphic; females tend to be heavier than males and males have a scarlet gular pouch that is inflated during courtship displays (Orta 1992b). They are seasonally monogamous; it is unlikely that pairs remain together for future breeding attempts (Orta 1992b). If successful, females can only breed successfully every 2–3 years since post-fledging care is provided by the female and can last 4–6+ months (Orta 1992b). Age to sexual maturity is unknown (Orta 1992b) but probably similar to that of great frigatebird at 8–10 years.

Lesser frigatebirds feed in pelagic waters, usually in mixed-species flocks over tuna schools (Orta 1992b, King 1967). Their diet consists primarily of flying fish and squid that they capture at or above the water's surface (Nelson 1976). Lesser frigatebirds are also notorious for kleptoparasitism but obtain most of their food by direct capture (Nelson 1976).

4.5.4 Fua'o (*Sula dactylatra*) or Masked Booby

Masked boobies have a pantropical distribution (Anderson 1993, Woodward 1972). There are four subspecies; *S. d. personata* breeds on islands in the central and western Pacific (Clements 2000). Within the USPI, the largest colonies are on Howland, Baker, and Jarvis Islands, but a significant portion of the population nests in the Northwestern Hawaiian Islands. Birds forage in offshore and pelagic waters (King 1967). They are most abundant in the vicinity of breeding islands, but they can be encountered far out at sea (King 1967). During nonbreeding periods, adults may visit sites 622–1,243 miles from breeding colonies (Woodward 1972, Clapp and Wirtz 1975, O'Brien and Davies 1990).

The world population is widely distributed and therefore difficult to estimate but is thought to be several hundred thousand birds (Anderson 1993). Within the USPI, there are approximately 8,300 breeding pairs with 1,200 pairs on Jarvis Island and over 1,500 pairs each on Howland and Baker Islands (Forsell 2002). Small colonies occur in American Samoa and Palmyra Atoll (Woodward 1972, King 1967, Anderson et al. 1982), and Wake Atoll was recently recolonized by birds banded at Johnston Atoll (Rauzon et al. 2011). Rose Atoll is home to approximately 25 pairs.

Masked boobies breed on oceanic islands and atolls. They tend to nest on open ground often near a cliff edge or on low sandy beaches or rocky ground (Anderson 1993, Harrison 1990). At Rose Atoll, they nest in open areas on the ground. They also form "clubs" or aggregations of nonbreeding birds on the fringe of breeding colonies (Woodward 1972). Breeding is fairly synchronous but timing varies depending on locality (Harrison 1990). Masked boobies are seasonally monogamous and at least 45% of pairs at Kure Atoll retained their mates through a second breeding season (Kepler 1969). Two eggs are laid but broods are typically reduced to one chick by siblicide (Anderson 1993). Sexual maturity begins around 3–4 years and most birds return to their natal colony to breed (Anderson 1993, Nelson 1978, Kepler 1969). Adults sometimes skip a year between breeding attempts (Woodward 1972, Harrison 1990).

Masked boobies feed by plunge-diving and can be found more than 93 miles from land (Harrison 1990). They forage singly or in mixed-species flocks associated with schooling tuna (King 1967, Harrison et al. 1983). In Hawai‘i, fish constituted greater than 97% of the diet and squid less than 3%; flying fish and jacks were the most important prey (Harrison et al. 1983). The oldest-known bird was 25 years. On Kure Atoll, annual adult mortality was less than 8.6%; mortality between independence and age 4 was 72% (Harrison et al. 1983).


Fua'o chick testing its wings. Jiny Kim/USFWS

Masked boobies breed on a few islands with human populations but they are vulnerable to human disturbance (Anderson 1993). Depletion of tuna due to fishing could potentially have an impact on the availability of prey (Harrison 1990). Commercial-size mackerel scad were important in the diet of masked boobies at some locations, and potential effects of commercial fisheries are unknown (Harrison 1990).

4.5.5 Fua'o (*Sula leucogaster*) or Brown Booby

Fua'o have a pantropical distribution (Schreiber and Norton 2002). There are four subspecies; *S. l. plotus* breeds on islands in the central and western Pacific (Clements 2000). In the USPI, brown boobies occur in the greatest numbers in the Hawaiian Islands. Breeding adults are mostly sedentary and juveniles disperse throughout the tropical seas (Carboneras 1992, Harrison 1990). At sea, they occur more nearshore than the other booby species (*Sula dactylatra*) and they are rarely seen over 50 miles from the nearest land (King 1967). Little is known of movements during nonbreeding periods but adults have been found up to 1,802 miles from breeding sites (Schreiber and Norton 2002).

Worldwide, the number of brown boobies is estimated at 221,000–275,000 pairs, which includes 50,000–70,000 pairs of *S. l. plotus* (Schreiber and Norton 2002). About 3,700 pairs nest in the USPI; approximately 700 nest in American Samoa. At Rose there are approximately 375 breeding pairs of brown boobies. The world population has declined dramatically over the past 200 years and possibly only 1–10% of historic populations remain (Schreiber and Norton 2002). Currently the USPI population appears stable, with populations on Wake Atoll and Howland and Baker Islands gradually rebounding following eradication or control of cats (Rauzon et al. 2011).

Fua'o breeding range overlaps with that of the other two species of booby on oceanic islands and atolls (Carboneras 1992, Harrison 1990). Nesting occurs on flat ground, often on cliff ledges, but they will also nest on sandy islands and bare coral atolls (Schreiber and Norton 2002). At Rose Atoll, brown boobies nest on the ground under the canopy of *Pisonia* and *Tournefortia* trees. Nests vary from a scrape in the sand to a fairly well-formed pile of twigs and grasses. Breeding is synchronous but timing varies depending on locality and occurs throughout the year (Schreiber and Norton 2002). Brown boobies are monogamous but maintenance of long-term pair bonds varies by location (Schreiber and Norton 2002). Pairs lay two (vary rarely three) eggs but the brood is often reduced to one chick as a result of siblicide (Schreiber and Norton 2002). Age of first breeding is typically 4–5 years (Schreiber and Norton 2002, Harrison 1990).

Fua'o feed by plunge-diving and feeding is often solitary, but they may be found in feeding flocks with other species (Schreiber and Norton 2002, Harrison 1990). They forage in nearshore waters, ranging from 5 to 44 miles from land, and feed mostly on flying fish, squid, mackerel scad, juvenile goatfish, and anchovy (Harrison 1990, Harrison et al. 1983). The oldest-known bird was 26 years, but they probably live to at least 30 years (Schreiber and Norton 2002, Simmons 1967). Adult survivorship was 93.2% at Kure Atoll (Tershey 1998). At Johnston Atoll, survival from fledging to breeding ranged from 30 to 40% in an 18-year study (Schreiber and Norton 2002).

Brown and red-footed boobies. USFWS

A major threat to fua'o has been the loss of habitat to development and human disturbance; newer pairs are especially vulnerable at the beginning of the breeding season (Schreiber and Norton 2002). In American Samoa, hunting pressure on brown boobies was high during historic times and this may still occur on occasion (Amerson et al. 1982).

4.5.6 Fua'o (*Sula sula*) or Red-footed Booby

Red-footed boobies have a pantropical distribution that overlaps other booby species (*S. dactylatra* and *S. leucogaster*) (Schreiber et al. 1996, Carboneras 1992). There are three subspecies; *S. s. rubripes* breeds in the central and western Pacific (Clements 2000). Red-footed boobies nest throughout the USPI. Distribution is pelagic; feeding flocks occur hundreds of miles from land (Harrison 1990). Breeding adults are mostly sedentary but juveniles roost near colonies on islands other than their natal island (Schreiber et al. 1996, Harrison 1990). Little is known about adult movements outside of the nesting season (Schreiber et al. 1996).

The world population was estimated at less than 300,000 pairs in 1996 (Schreiber et al. 1996). In the USPI, there are approximately 19,000 pairs. Approximately 2,000 pairs nest in American Samoa

(Amerson et al. 1982). Rose Atoll hosts 700 pairs of this species. The world population has been severely reduced over the last two centuries (Schreiber et al. 1996) and few data exist on current numbers (Cao et al. 2005). Cao et al. (2005) suggest the present day population size has declined to 10% of their historical values.

This species of booby is the smallest of the booby species and breeds on oceanic islands and atolls (Schreiber et al. 1996, Carboneras 1992). Unlike the masked and brown boobies, these boobies roost and nest on shrubs and trees but will use bare ground or low piles of vegetation (Schreiber et al. 1996, Carboneras 1992, Harrison 1990). On Rose Island, red-footed boobies build nests in *Tournefortia* and *Pisonia* trees. Nests are made of twigs, grass, and other vegetation. Breeding is fairly synchronous but occurs throughout the year and timing varies by locality (Schreiber et al. 1996, Harrison 1990). Several color phases exist, ranging from all brown to all white (Schreiber et al. 1996, Nelson 1978). The most common color morph at Rose is the intermediate form. They are monogamous and generally retain their mates throughout subsequent breeding seasons (Schreiber et al. 1996). They lay 1 egg and continue to feed the young 1–2 months after fledging (Schreiber et al. 1996, Carboneras 1992). Sexual maturity begins around 3–4 years and most birds return to their natal colony to breed (Schreiber et al. 1996, Harrison 1990). Adults usually breed every year but sometimes take a “rest” year (Schreiber et al. 1996, Harrison 1990).

Red-footed boobies feed on flying fish, squid, mackerel scads, saury, and anchovies (Harrison 1990). Red-footed boobies often depart the colony to feed well before daylight and most return to the colony to roost at night (Carboneras 1992, Harrison 1990). Red-footed boobies feed by plunge-diving and may feed solitarily or in mixed-species foraging flocks (Au and Pitman 1986). They forage further from land than other boobies except possibly the masked booby (Nelson 1978). Annual adult survival was estimated at 90% in a 2-year study at French Frigate Shoals in the NWHI (Hu 1991). At Johnston Atoll, survival of chicks to breeding ranged from 27 to 52% depending on the year (Schreiber et al. 1996). The oldest-known bird was 22 years (Clapp et al. 1982).

The large areas of mangrove forests destroyed in American Samoa may have once been important habitat for this species. Introduced scale insects and other factors at Rose Island are destroying the *Pisonia* forest. Human predation on adults, chicks, and eggs may occur in parts of American Samoa (Amerson et al. 1982). El Niño-Southern Oscillation conditions can cause total or partial breeding failure in some locations (Schreiber and Schreiber 1989, Schreiber 1994).

4.5.7 Gogo Uli (*Anous minutus*) or Black Noddy

Nesting gogo uli. USFWS

The gogo uli is an abundant and gregarious, medium-sized bird with a pantropical distribution (Gauger 1999, Clements 2000). Adults are sooty black with a white cap on the top of the head. There are seven recognized subspecies and at least three breed in the USPI: *A. m. melanogenys* in the main Hawaiian Islands; *A. m. marcusi* in the NWHI, Wake, and throughout Micronesia; and *A. m. minutus* in Samoa (Gauger 1999, Gochfeld and Burger 1996). Breeding adults are mostly sedentary remaining at colonies year-round and foraging within approximately 50 miles of nesting islands

(Gauger 1999, Ashmole and Ashmole 1967, King 1967). Juveniles probably remain at breeding colonies or travel to nearby roosting sites (Gauger 1999).

The world population is estimated to be 1,000,000–1,500,000 pairs (Gauger 1999). In the USPI, there are approximately 22,400 pairs. An estimated 12,000 pairs nest in the Hawaiian Islands, and smaller colonies exist in American Samoa, Palmyra, Johnston, and Wake Atolls, and the Marianas. Approximately 750 pairs use Rose Atoll. Worldwide population trends are unknown.

The gogo uli nest on oceanic and offshore islands (Gauger 1999). They place their nests on trees and bushes (Howard and Moore 1984, Harrison 1990); the nests on Rose Island are in *Tournefortia* branches. Breeding is asynchronous and aseasonal. Birds are monogamous, mate retention is high, and pairs retain their territory from year to year, often reusing the same nest (Gauger 1999, Schreiber and Ashmole 1970). The gogo uli are capable of producing more than one brood per year and some lay a second egg while still tending the first chick (Gauger 1999). Sexual maturity begins around 2–3 years (Gauger 1999). The oldest-known bird was 25 years (Gauger 1999).

Black noddies feed by hover-dipping and contact-dipping, and typically forage in multi-species flocks over schools of predatory fish, especially tunas and jacks (Ashmole and Ashmole 1967). They feed mainly inshore (<6 miles from shore) and sometimes within several feet of the shoreline (Harrison 1990, Gauger 1999). Black noddies eat fish almost exclusively and very small amounts of squid and crustaceans (Gauger 1999). In the central Pacific, flying fish, blennies, mackerel, and anchovies are important components of the diet (Gauger 1999).

Predation by introduced mammals in the breeding colonies limits populations and depletion of large predatory fish density due to fishing may reduce feeding opportunities (Gauger 1999).

4.5.8 Gogo (*Anous stolidus*) or Brown Noddy

The brown noddy is a medium-sized tern with a pantropical distribution (Chardine and Morris 1996), dark brown in color all over except for the whitish-gray cap on the top of its head. There are five subspecies; *A. s. pileatus* breed in the central and western Pacific (Harrison and Stoneburner 1981). Brown noddies have been shown to breed more than once per year in the NWHI (Megyesi and Griffin 1996). Breeding adults remain within sight of the colony, foraging in waters several tens-of-miles from the colony (Morris and Chardine 1992, Clements 2000). During nonbreeding periods, brown noddy have been shown to stay within 62 miles of colonies (Clapp et al. 1983, Harrison 1990) or to migrate out of the area for several months (Murphy 1936, Morris and Chardine 1992). Little is known of the movements of juveniles (Chardine and Morris 1996).

Nesting gogo. USFWS

The world population is estimated at 500,000–1,000,000 pairs (Chardine and Morris 1996). Within the USPI, there are about 135,000 pairs (Harrison et al. 1983). Approximately 9,000–11,000 pairs nest in American Samoa, the Marianas, and Johnston Atoll (Amerson et al. 1982, Reichel 1991). Approximately 200 pairs nest at Rose Atoll. The population trend is probably stable, but increasing in areas where predators were removed (e.g., Midway, Kure) (Chardine and Morris 1996).

Brown noddies usually nest in loose groups or colonies and are flexible in nesting behavior. Nests are on the ground, often on open slopes or under vegetation but the brown noddy also nest on cliffs and in trees, especially where introduced mammalian predators are present (Harrison 1990, USFWS 1983). Brown noddy pairs stay together throughout the year, but there is little information on mate retention in subsequent years (Chardine and Morris 1996). Sexual maturity begins around 3–7 years and it is unknown whether birds return to their natal colony to breed (Chardine and Morris 1996, Harrison 1990). The oldest-known bird was 25 years (Chardine and Morris 1996).

Brown noddies feed by hover and contact-dipping in nearshore and off-shore waters (Harrison et al. 1983). They often feed in association with tuna schools and can be found in mixed-species feeding flocks.

The greatest threat is introduced predators, and where there are predators, brown noddy often nest in trees (Chardine and Morris 1996, Harrison et al. 1983). Predation by introduced mammals, such as the Polynesian rat, has contributed to the extirpation of brown noddy from islands where they formerly nested (e.g., Lehua) (VanderWerf et al. 2004). Disturbance of the colonies can lead to increased predation by native predators: unprotected eggs are taken by atafa and shorebirds, especially when adults are flushed from nests by human disturbance.

4.5.9 Manu Sina (*Gygis alba*) or White Tern

Nesting manu sina with egg on Tournefortia *branch.*
USFWS

The manu sina is small and entirely white, with a pantropical distribution (Niethammer and Patrick 1998, Gochfeld and Burger 1996). The manu sina has adapted well to human-altered landscapes better than many other seabirds. It is perhaps the most familiar bird in Samoa (Craig 2002). There are four subspecies; *G. a. alba* breed in the central and western Pacific (Gochfeld and Burger 1996, Clements 2000). Breeding adults remain close to colonies, foraging primarily inshore in shoals and banks but sometimes in offshore waters (Niethammer and Patrick 1998). During nonbreeding periods they disperse from breeding grounds to sea but their range is unknown (Niethammer and Patrick 1998). Some adults are year-round residents on the colony (Harrison 1990). Little is known of the movements of immature manu sina.

World population is unknown but probably exceeds 100,000 pairs (Gochfeld and Burger 1996). In the USPI, there are about 17,000 pairs. Large colonies exist in American Samoa (3,900 pairs) (Amerson et al. 1982). Rose Atoll supports at least 60 pairs. World and USPI population trends are unknown.

Manu sina nest on volcanic pinnacles, cliffs, rocky slopes, in large bushes or trees, or on artificial substrates (Niethammer and Patrick 1998, Rauzon and Kenyon 1984). They do not build nests but lay a single egg on a suitable depression, sometimes precariously balancing on small tree branches. Manu sina are monomorphic and monogamous, and partners remain together for several seasons, often returning to the same nest site (Niethammer and Patrick 1998, Harrison 1990). Clutch size is one egg and some breeding pairs may successfully raise two or even three broods within a nesting season (Niethammer and Patrick 1998, VanderWerf 2003, Miles 1985).

Manu sina feed primarily by dipping- and surface-diving (Niethammer and Patrick 1998). They often occur in mixed feeding flocks and usually in association with predatory fish (Niethammer and Patrick 1998, Harrison 1990). Prey items include juvenile goatfish, flying fish, squid, needlefishes, halfbeaks, dolphinfishes, and blennies (Niethammer and Patrick 1998, Harrison et al. 1983).

Although manu sina exhibit lower vulnerability to introduced predators than most seabirds because of their ability to use inaccessible (e.g., trees and sheer cliffs) nesting sites, introduced predators such as rats and cats have been the primary factor affecting populations (Niethammer and Patrick 1998). Scale insects have been introduced to Kure, Rose, and Palmyra Atolls where they attack native vegetation and reduce the number of nest sites in the native forest; the effects on manu sina nesting populations are not known. Depletion from fishing of large predatory fish stocks that drive prey to the surface may reduce foraging opportunities for manu sina (Niethammer and Patrick 1998, Gochfeld and Burger 1996).

4.5.10 Gogosina (*Onychoprion fuscatus*) or Sooty Tern

Sooty terns have a pantropical distribution (Gochfeld and Burger 1996, Clements 2000, Schreiber et al. 2002). There are eight subspecies; *O. f. oahuensis* breed in the central and south Pacific (Gochfeld and Burger 1996, Clements 2000). Breeding adults remain relatively close to colonies and forage up to 311 miles from breeding islands (Flint 1991, Gould 1974). During nonbreeding periods, they are highly pelagic and tend to avoid regions with cold-water upwelling (Gochfeld and Burger 1996, Schreiber et al. 2002). Juveniles disperse widely after fledging and remain at sea, sometimes not touching land for several years (Schreiber et al. 2002).

The world population is estimated to range from 60 to 80 million pairs with 18–23 million pairs breeding each year (Schreiber et al. 2002). In the USPI, there are approximately 3.2 million pairs. A large colony of more than 100,000 pairs breeds at Rose Atoll (Amerson et al. 1982). Sooty tern nest on oceanic islands and atolls in large dense colonies (Gochfeld and Burger 1996, Schreiber et al. 2002). A colony usually consists of several subcolonies and each subcolony breeds very synchronously. Sooty tern nest on the ground in sandy substrate with sparse vegetation (Schreiber et al. 2002). On Rose Island sooty terns also move into the forest and lay eggs in the open understory there. Sexual maturity begins around age 4–10 years (Schreiber et al. 2002, Harrington 1974). The oldest-known bird was 32 years (Harrison 1990).

Gogosina. Jiny Kim/USFWS

Sooty terns, the most pelagic of the tropical terns (King 1967), feed mainly by aerial-dipping, contact-dipping, and aerial capture, although they will plunge-dive (Gochfeld and Burger 1996, Schreiber et al. 2002). Sooty terns tend to feed in large flocks with other species in association with predatory fishes, such as yellowfin and skipjack tunas

(Schreiber et al. 2002, Harrison 1990, USFWS 1983). El-Niño-Southern Oscillation conditions can cause breeding failure in the Pacific (Schreiber and Schreiber 1989).

Native predators such as atafa and tuli take chicks and eggs (Schreiber et al. 2002, Harrison 1990). Sooty terns are vulnerable to oil pollution from tankers and spills. Depletion of tuna by fisheries could potentially have an impact on the availability of prey (Schreiber et al. 2002).

4.5.11 Gogosina (*Onychoprion lunatus*) or Gray-backed Tern

Gray-backed terns are endemic to the tropical and subtropical Pacific but are most common in the Central Pacific (Mostello et al. 2000, Harrison 1990). Breeding adults are mostly sedentary and forage up to 230 miles from land (Harrison 1990, Dixon and Starrett 1952). During nonbreeding periods, they are highly pelagic and occur far from breeding colonies, but their range is unknown (Mostello et al. 2000). At sea, gray-backed terns are found in highly saline waters (Ainley and Boekelheide 1983). There are limited data on movements, but juveniles travel great distances after leaving the natal colony (Mostello et al. 2000).

The world population size is unknown but possibly on the order of 70,000 pairs (Mostello et al. 2000). Lack of adequate information on breeding phenology in many areas complicates estimates (Mostello et al. 2000). In the USPI there are approximately 48,000 pairs and 30 pairs nesting on Sand Island at Rose Atoll. The global population trend is difficult to assess, but probably has declined since some colonies have been extirpated (Mostello et al. 2000). In the USPI, the population appears stable or increasing, but historical declines occurred at remote Pacific islands due to introduced predators. Trends in the USPI may be increasing with the removal of predators such as cats from many islands and places such as Howland, Jarvis, and Wake Atoll (Rauzon et al. 2011).

Gray-backed terns breed on remote islands and atolls, on rocky ledges or sandy beaches often along vegetated edges bordering open areas (Amerson 1971, Ely and Clapp 1973). Their nests are shallow depressions in sand or gravel. Breeding occurs throughout the year. The clutch is one egg and chicks are semi-precocial when hatched (Mostello et al. 2000). Fledglings may remain at the colony up to 6 weeks after first flight (Harrison 1990). The oldest-known gray-backed tern was 25 years (Mostello et al. 2000).

Gray-backed terns feed mainly by plunge-diving or contact/hover-dipping. They are described as an inshore, offshore, or pelagic feeder due to the geographical and seasonal differences in foraging habitat (Mostello et al. 2000). Gray-backed terns eat five-horned cowfish, juvenile flying fish, goatfish, herring, dolphinfish, squid, crustaceans, mollusks, and marine and terrestrial insects (Harrison 1990). Gray-backed terns can be found foraging in mixed-species flocks, especially with sooty terns and sometimes with ta'i'o (Gould 1971).

In the USPI, their gravest threat is predation by introduced mammals such as rats and cats (Harrison 1990, Woodward 1972, Harrison et al. 1983). They are sensitive to disturbance, leaving their eggs when humans approach (Harrison 1990). Unattended eggs and chicks are vulnerable to predators such as atafa and ruddy turnstones and curlews (Mostello et al. 2000). Gray-backed terns tend to nest near the surf zone and nests are often lost to storm tides (Mostello et al. 2000, Harrison 1990).

4.5.12 Gogosina (*Sterna sumatrana*) or Black-naped Tern

Gogosina (black-naped tern) in flight.
Joshua Fisher/USFWS

The black-naped tern is a white, small-sized bird with grayish-white back and wings and black beak and legs. This species has only recently (2010) been observed at Sand Island when a single adult individual was seen acting as if it might have a nest territory. No egg or chick was found. They breed on tropical and subtropical islands throughout the Indian and western Pacific Oceans. Breeding takes place on small offshore islands, reeds, sand spits, and rocky cays (Bird Life International 2011). Breeding season depends on locality (Bird Life International 2011) but have been recorded at breeding stations throughout the year, suggesting mainly sedentary habits (Harrison 1985). Colonies of 5–20 pairs are formed, but sometimes up to 200 pairs can be formed (Bird Life International 2011). Colonies tend to be linear, or parallel to the water's edge, (Hulsman and Smith 1988) in the sand or gravel pockets on coral banks close to the high tide line and monospecific (del Hoyo et al. 1996). They are also known to form colonies on shipwrecks (Hulsman and Smith 1988). One to two eggs, but occasionally three, are laid in either a shallow scrape on open ground or no nest is made (Hulsman and Smith 1988). Hulsman and Smith (1988) found that pebbles and small debris were thrown up toward the nest, having the effect of building up the nest edge, during nesting relief ceremonies.

Black-naped terns hunt singly or in loose groups (Hulsman 1979) in atoll lagoons and nearshore, but they occasionally join flocks of black noddies when predatory fish are active near the reef (Hulsman and Smith 1988). Black-naped terns feed predominantly by plunging or air diving directly onto prey (Hulsman and Smith 1988, Bird Life International 2011), but become only semi-submerged (Harrison 1985).

Both parents feed their young and make frequent flights to hunting grounds and young. Hulsman (1979) found anchovy to be a main food source for adults, but adults also consumed flying fish, mullet, barracuda, trevally or jack, tuna, damselfish, sardines, dolphinfish, grubfish, goby, blennies, and wrasse. Chicks were fed principally on the silver schooling fish belonging to the hardyheads and sprats, anchovies, and garfish.

Black-naped terns are sensitive to human disturbance, either in terms of reduced breeding success or colony desertion. Black-naped terns nest in the open, which exposes their eggs and young to the weather. Adults must, therefore, shelter their eggs and chicks from the wide range of weather conditions experienced in tropical and sub-tropical areas. On two islands in Australia, the major causes of mortality of eggs and chicks were predation by gulls and flooding of nesting areas (Hulsman and Smith 1988), indicating that any introduced predators or excessive human disturbance would cause birds to flush, rendering chicks vulnerable to nonnative predators as well as native birds like tuli or atafa.

4.6 Shorebirds and Wading Birds

The Pacific Island Region functions as an essential migratory habitat for maintaining global shorebird populations. Rose Atoll is an important wintering ground for shorebirds in the Pacific. Seven species have been recorded at Rose Atoll. The most common migratory shorebirds are the Pacific golden plover, ruddy turnstone, and wandering tattler. Some shorebirds primarily use the beach strand habitat; however, the littoral forest also serves as important habitat. The Pacific golden plover is the most abundant of the shorebird species in American Samoa (Engilis and Naughton 2004) and also the species that has been seen in largest numbers at Rose Atoll.

Information on the status, trends, and ecology of shorebirds in the Pacific and their use of Rose Atoll is lacking in published literature (Engilis and Naughton 2004). Information needs include assessment of population sizes and trends; assessment of the timing and abundance of birds at key wintering and migration stopover sites; assessment of habitat use and requirements at wintering and migration areas; exploration of the geographic linkages between wintering, stopover and breeding areas; and evaluation of habitat restoration and management techniques to meet the needs of resident and migratory species (Engilis and Naughton 2004).

Many shorebirds wintering in the Pacific migrate over 2,486–7,458 miles of open ocean. Based on banding recoveries, patterns of distribution, and species assemblages, the following three flyways have been proposed: Asiatic-Palauan Flyway (birds move from Asia to Western Pacific and Philippine Sea Islands), Japanese-Mariana Flyway (mostly Asian birds move through Japan into the Mariana Islands and Caroline Islands), Nearctic-Hawaiian Flyway (birds breeding in Alaska and Eastern Siberia [Beringia] move through Hawai‘i to Marshalls and Polynesia) (Baker 1953).

The Service developed the USPI Regional Shorebird Conservation Plan (Engilis and Naughton 2004) over concerns of declining shorebird populations and loss of habitat. Threats to shorebirds in the Pacific region include loss of habitat, nonnative plants, nonnative animals (predation, disease, and competition), human disturbance, and environmental contaminants.

Conservation and restoration of shorebird habitats in the USPI is a growing effort and essential for the protection of endangered and declining shorebird populations. Wetlands, beach strand, coastal forests, and mangrove habitats are particularly vulnerable on Pacific islands due to increasing development pressures and limited acreage.

Table 4-3. Shorebirds and Wading Birds of Primary Conservation Importance in the U.S. Pacific Region

Species	Regional Trend	Conservation category
Pacific golden plover	Unknown	High concern
Bristle-thighed curlew	Unknown	High concern
Sanderling	Unknown	High concern (?)
Wandering tattler	Unknown	Moderate concern
Ruddy turnstone	Unknown	Low concern
Pacific reef heron	Unknown	IUCN Least Concern

Source: Engilis and Naughton 2004; USFWS 2008.

4.6.1 Tuli (*Arenaria interpres*) or Ruddy Turnstone

The ruddy turnstone is a common shorebird throughout the Pacific Islands; however, it is recognized as a species of Low Concern (Engilis and Naughton 2004) because the vast majority of its world population uses other areas for wintering grounds. Remote sandy islands appear to support the largest numbers of turnstones in the USPI, but there are no available survey estimates for the wintering population at American Samoa (Engilis and Naughton 2004). The largest group ever recorded at Rose Atoll was 45 in 1982. Ruddy turnstones use sandy and rocky beaches, reefs, and mudflats.

4.6.2 Tuli (*Calidris alba*) or Sanderling

The sanderling is widespread and locally common throughout the Pacific Islands. In the USPI, the sanderling is less often seen than wandering tattlers and tuli. The USPI Regional Shorebird Conservation Plan (Engilis and Naughton 2004) designated this shorebird as a species of limited importance in the Pacific Islands since the vast majority of sanderlings overwinter in other regions of the world. They are usually found on the water’s edge in small groups where they run back and forth from the waves to feed on the small invertebrates exposed by the retreating waves.

4.6.3 Tuli (*Tringa incana*) or Wandering Tattler

The wandering tattler is nowhere common but is ubiquitous throughout the Pacific region. Predominantly nearctic breeders, wandering tattlers migrate from their breeding grounds in Alaska and northwest Canada (Gill et al. 2002) to islands throughout the Pacific. During winter, they are solitary or occur in small groups of two to three birds throughout the Pacific Basin (Gill et al. 2002). They are most common on rocky beaches but they also use a wide range of habitats including exposed reefs, sandy beaches, and mudflats (Engilis and Naughton 2004, Gill et al. 2002). The USPI Regional Shorebird Conservation Plan (Engilis and Naughton 2004) estimated the total population of wandering tattlers between 10,000 and 25,000 individuals. There are an estimated 900 wandering tattlers wintering in American Samoa (Amerson et al. 1982).

4.6.4 Matu’u (*Egretta sacra*) or Pacific Reef Heron

The matu’u is a common bird in Samoa, with long legs and a long neck that is often curved in an S-shape. There are three color morphs: dark gray, pure white, or a combination of both colors in patches, and all have been observed at Rose Atoll. The herons forage across the reef crest for a wide variety of reef fish, crabs, and snails, as well as freshwater streams for food. Matu’u construct their large nests in trees that are safe from predators. At Rose Island nests have been found in niu and *Cordia* surrounded by thick ferns (*Nephrolepis hirsutula*). In the 2010 field visit to Rose Atoll, there were two nests, one with two chicks and one with one chick. The white and dark color morphs were both seen on this visit. Population numbers in American Samoa are not known.

4.7 Land Birds

Rose serves as nonbreeding habitat for one austral migrant, the long-tailed cuckoo or aleva (*Eudynamis taitensis*). Vagrant birds are those that occasionally are blown off course by storms or by faulty directional decision during migration. Three vagrant species have been sighted at Rose Atoll: the cattle egret (*Bubulcus ibis*), snowy egret (*Egretta thula*), and the wattled honeyeater (*Foulehaio carunculata*).

4.7.1 Aleva (*Eudynamis taitensis*) or Long-tailed Cuckoo

The aleva migrates from New Zealand in the winter and forages toward the southwest Pacific. The center of its winter range lies in central Polynesia (Kepler et al. 1994). On Rose Island, its habitat is in dense and thick cover of the littoral forest. Single birds have been sighted 1976, 1980, 1990, and 1992. Two were observed in 1984. The very cryptic and stealthy behavior of this species makes it likely that it is more common than field observations would indicate and on some visits the bird is heard but not seen as in 2010.

4.8 Invertebrates

4.8.1 Tuitui (Sea Urchin)

Tuitui are marine animals that belong to the phylum Echinodermata (meaning “spiny skin”), a group that includes sea stars (also called starfish), sea cucumbers, sand dollars, brittle stars, and sea feathers. All tuitui are in the Class Echinoidea. Sea urchins are important herbivores in reef and other marine habitats, grazing on a variety of benthic algae. An urchin’s mouth lies on the undersurface of its hard shell; the jaws of the mouth are made from five teeth held in a muscular sling. Together these teeth form a five-pointed beak that is very effective at scraping algae from rocks and other hard surfaces. The scraping jaws of rock-boring urchins are also used to enlarge natural cavities or holes in the hard substrate, providing the animal with shelter from the full force of waves on exposed reef flats and the wave-swept surge zone.

Tuitui. Jean Kenyon/USFWS

Tuitui feeding has two important consequences. First, their grazing reduces the total amount of fleshy algae on a reef, which enables corals and CCA (which compete with algae and cyanobacteria for space and sunlight) to grow better. Second, when they scrape algae from the substrate, they create vacant spaces that can then be colonized by the larvae of other bottom-dwelling marine animals. This helps to keep the diversity of marine animals high. In the absence of such grazing, reefs may become overgrown with algae, and the diversity of reef animals may be reduced. The important ecological role of tuitui became apparent on Caribbean reefs after a disease outbreak in 1983–84 killed more than

93% of the long-spined urchins (*Diadema antillarum*). During the following years, coral abundance decreased and reefs were covered with unprecedented levels of algal growth.

Tuitui in the genera *Heterocentrotus, Diadema, Echinometra, Echinothrix,* and *Echinostrephus* have been recorded from Rose Atoll (Swerdloff and Needham 1970, Green et al. 1997, NMFS PIFSC 2008). Following the longliner grounding in 1993, biologists documented an extensive area where oil caused high mortality to tuitui as well as CCA, marine snails, and faisua. Surveys in 1993 revealed that boring tuitui were extirpated from a zone 295 feet north and 197 feet south of the spill site (Molina 1994, Green et al. 1997). Surveys conducted in 1995 and 1996 revealed that tuitui densities had declined along the atoll's entire southwest arm (Green et al. 1997). As of 1997, the tuitui population continued to be reduced within 3,279 feet of the grounding site, and remained depressed as of 2001 (USFWS and DMWR 2001). With the clean-up of the shipwreck completed, the area is recovering, and it is likely that tuitui numbers are rebounding as well.

4.8.2 Terrestrial Invertebrates


Coconut crab. USFWS

With the exception of scale insect documentation in reports from 2002 to 2005, few observations of terrestrial invertebrates were reported by visitors to Rose Atoll. In his 1980 trip report, Shallenberger notes that Darrell Herbst collected "various insects" while on Rose and Sand Islands. Shallenberger also states that the strawberry hermit crab (*Coenobita perlatus*) gather under the *T. argentea* during the day, and forage across the island at night. Strawberry hermit crabs were observed foraging on dead birds, fish, coconut meat, and bird eggs (Shallenberger 1980). Though found in smaller numbers than the strawberry hermit, purple hermits (*Coenobita brevimanus*) were also extremely common until the mid-90s when densities of both hermit species appeared to decline.

With the coincident decline in overall numbers came a change in the quality of the gastropod shells these crabs were using. It became more common to see highly worn shells and a lower proportion of the favored *Turbo* shells in the population. The largest terrestrial arthropod on earth, the coconut crab (*Birgus latro*), ranges throughout the tropical Indo-Pacific. Due to its popularity as a food source, coconut crabs are rare or absent on most inhabited islands (Kepler and Kepler 1994). A single small coconut crab was captured in a live trap set for rats in 1991. Possibly related to the elimination of rats and the subsequent increase in niu, two dens and a large adult *Birgus* was observed on Rose Island during the 2010 Refuge visit. Terrestrial invertebrates also observed on a Service trip to Rose Atoll led by Flint (Flint 1990) documented fruit flies, crickets, scales, wasps, houseflies, ants, earwigs, beetles, moths, cockroaches, orb-weaving spiders, wolf spiders, jumping spiders, and red spider mites. However, they were not collected or identified to species.

In April 2012 a team of five entomologists from the U.S. Geological Survey, American Samoa Community College (ASCC), DMWR, and the Service spent 5 days surveying invertebrates on Rose Island. They set out a variety of traps in about 100-foot grids covering the island. The final report of their findings was not yet available at the time of this writing.

4.9 Reef Building Species

Coral reefs can be considered geologic structures built by countless generations of corals, coralline algae, and other calcifying marine organisms. While coral reefs are the world's largest structures made by living organisms, an individual coral polyp is a tiny animal. What many people think of as a single coral is actually a colony of hundreds to thousands of tiny coral animals living side by side on a colonial skeleton they have excreted. Because many of these organisms are attached to the substrate, their skeletons remain in that position after they die. Loose pieces of coral, shells, and other hard building blocks can be cemented together by coralline algae to build the reef. New reef organisms settle on or grow over the remains of the previous generation and deposit their skeletal material over the older surface. By this process a wave-resistant reef builds upward and outward.

*Each small bump on the branches of this coral colony (*Acropora humilis*) is a corallite that protects a soft-bodied polyp inside.* Jean Kenyon/USFWS

Due to the critical symbiosis between stony corals and their photosynthetic zooxanthellae, reef construction requires warm, clear, well-lighted marine waters. Coral reefs are mostly found between 30^{o}N and 25^{o}S latitude where the surface water temperature ranges between 77^{o} and 86^{o}F throughout the year. In deep water (164-328 feet), where much of the sunlight is filtered out, the number of reef-building species of corals is greatly reduced, and at deeper depths (greater than 328 feet) most reef builders disappear altogether.

Atolls vary in the degree to which their annular reef encloses the central lagoon and are sometimes further described on a gradient of "open" to "classical" as the perimeter reef becomes more fully enclosing. An operational definition of a classical atoll, therefore, is a reef formation atop a subsiding extinct volcano that includes a lagoon surrounded by a shallow perimeter reef, at least one emergent island, and regular surface water exchange between the lagoon and the open ocean (Woodroffe and Biribo 2011, Maragos and Williams 2011). In this regard, Rose Atoll, despite its small size, meets this definition of a classical atoll and also has all the major habitats and associated biological groups found on Pacific atolls:

- Perimeter (annular) reef enclosing the lagoon;
- Reef crest (reef flat);
- Back reef (slopes facing the lagoon);
- Lagoon;
- Lagoon reefs;
- Islands;
- Natural channel (ava); and
- Fore reef (slopes facing the ocean).

4.9.1 Coral

Corals and reefs in many regions of the world are reported to be in a state of decline due to numerous local and global anthropogenic stressors including coastal point source pollution, agricultural and land use practices, overuse for commercial or recreational purposes, disease and predation, and impacts of climate change including increased sea surface temperature and ocean acidification (Wilkinson 2004). While the reefs of Rose Atoll have been spared many of the anthropogenic threats and impacts that afflict reefs located closer to human population centers, some threats such as climate change are very widespread and challenge the ability of protected areas to limit their effects. Veron et al. (2009) state that "reefs are likely to be the first major planetary-scale ecosystem to collapse in the face of climate changes now in progress".

Taxonomy. Stony corals are marine invertebrates in the phylum Cnidaria that secrete a calcium carbonate exoskeleton. The basic soft body form of a coral is called a polyp, consisting of a sac-like cavity with only one opening that serves as both mouth and anus. This opening is surrounded by tentacles that have stinging cells called nematocysts. The skeleton secreted by an individual polyp is called a corallite. Some corals are solitary, consisting of a single polyp and its corallite, but most are colonial, consisting of multiple interconnected polyps that developed by a process of budding from an original parent polyp.

From a taxonomic perspective, stony corals include members of both the Class Hydrozoa (fire corals) and the Class Anthozoa, Order Scleractinia (true stony corals). From a functional perspective, corals that contain single-celled, endosymbiotic, photosynthetic algae known as zooxanthellae in their gastrodermal tissues are called hermatypic or reef-building corals. The rapid calcification rates of these corals have been linked to their mutualistic association with the zooxanthellae.

One hundred forty-five stony corals (143 scleractinian and 2 hydrozoan) (Appendix A) have been reported from the Refuge and the adjoining fore reef slopes (Kenyon et al. 2010, 2011). Higher coral diversity than expected at Rose Atoll may result from its proximity to the high islands in American Samoa where 326 scleractinian species have been recorded (Birkeland et al. 2008) and from its additional lagoon habitats compared to those islands.

Of these 145 stony coral species at Rose Atoll, 21 are listed as Vulnerable according to the IUCN Red List Categories and Criteria. These criteria have been widely used to classify, in an objective framework, the extinction risk of a broad range of species and rely primarily on population size reduction and geographic range information. Categories used to classify species for which adequate data exist range from "Least Concern" (with very little probability of extinction) to high risk "Critically Endangered." The categories collectively considered as "threatened" (Vulnerable, Endangered, Critically Endangered) are intended to serve as one means of setting priority measures for biodiversity conservation (Carpenter et al. 2008). Of these 21 species at Rose Atoll listed as Vulnerable, 19 were evaluated by NOAA NMFS for possible listing in accordance with the ESA, in response to a petition in 2009 from the non-governmental organization (NGO) Center for Biological Diversity (Kenyon et al. 2011). On November 30, 2012, NOAA found 12 of these species warranted listing as threatened and initiated a 90-day public comment period. Of the remaining 124 stony coral species at Rose Atoll, 36 are listed by the IUCN as "Near Threatened," 78 as "Least Concern," 2 as "Data Deficient," and 8 are not found in the Red List.

The fore reef slope supports a diverse assemblage of corals, other invertebrates, and coralline algae.
Jean Kenyon/USFWS

For coral reef ecosystem species, Essential Fish Habitat (EFH) (MSFCMA; 16 U.S.C. 1855(b)) (§305(b)) has been designated as the water column above the reefs and all bottom out to 328 feet depth across all the USPI. Federal agencies which fund, permit, or undertake activities that may adversely affect EFH are required to consult with the NMFS regarding the potential effects of their actions on EFH.

Zooxanthellae. In addition to enhancing calcification, zooxanthellae provide a substantial phototrophic contribution to the coral's energy budget and give the coral most of its color. Those corals that lack zooxanthellae deposit mineralized skeletal materials at a lower rate and are called ahermatypic or nonreef-building corals. The largest colonial members of the Scleractinia help produce the carbonate structures known as coral reefs in shallow tropical and subtropical seas around the world. Stony corals with massive and branching growth forms are the major framework builders and a source of carbonate sediment on the reef. Corals provide substrate for colonization by other benthic organisms, construct complex protective habitats for a myriad of other species including commercially important invertebrates and fishes, and serve as food resources for a variety of animals.

Rose Atoll Coral Distribution. Coral cover and composition naturally vary among atoll habitats because species show differential growth and survivorship responses to different environmental circumstances including wave energy, depth and turbidity (light penetration), and temperature range tolerance. In 2002, average coral cover derived from quantitative analysis of imagery recorded during towed-diver surveys that circumnavigated the Rose Atoll fore reef in 3 depth strata was 23% (Kenyon et al. 2010); average coral cover was highest (38%) on the deep (greater than 59 feet) southeast fore reef slope but lowest (13%) on the same slope at moderate depths (30–59 feet). Site-specific transect and photoquadrat surveys show that *Pocillopora*, *Montipora*, and *Montastrea* are the most abundant genera on the fore reef. Along the soft, unconsolidated floor of the lagoon, coral is found only on isolated patches of firm substrate, averaging only 0.9% cover. Average coral cover on the sloping rubble back reef inside the lagoon is also low (0.1%). Coral cover is higher on the limestone pinnacles scattered within the lagoon, averaging 10%, with the genera *Favia*, *Montipora*, *Porites*, and *Astreopora* as the primary components.

Reproduction. Corals reproduce both sexually and asexually. Sexual reproduction involves the process of gametogenesis (generation of gametes), which may require from a few weeks for sperm to more than 10 months for eggs. The dominant reproductive mode of scleractinian (true stony) corals in the Pacific Ocean is broadcast spawning of gametes followed by external fertilization. Subsequent cell divisions of the fertilized eggs result in small, dispersive propagules (planula larvae) which may settle, metamorphose, and develop into primary polyps. The phenology of spawning and degree of synchrony within and between species can vary widely among locations and along latitudinal gradients, ranging from annual multi-species mass spawning events on the Great Barrier Reef in late austral spring to little apparent synchrony among species in Hawai'i or the Red Sea**.**

Relatively little is known of the phenology of coral spawning in American Samoa. Seven species have been observed spawning off Tutuila in the week following the October or November full moon (Itano and Buckley 1988, Mundy and Green 1999), and measurements of the sizes of developing eggs from two additional species off Tutuila also suggest spawning occurs after the October or November full moon (Kenyon, unpubl. data 2008). However, egg size data from several other species sampled off Tutuila suggest spawning is more spread out through the year and that some species may have at least two spawning periods in different seasons.

Limited sampling of four *Acropora* species on the back reef and fore reef at Rose Atoll in late February revealed that colonies of one species would spawn within the following month, two other species were nearing maturity, and one species had no gravid polyps (Kenyon, unpubl. data 2002). Clearly, much remains to be determined concerning coral spawning cycles at Rose Atoll and within the larger region of American Samoa.

The gametes and developing embryos of most broadcast-spawning corals are positively buoyant and therefore vulnerable to natural and anthropogenic disturbances that can substantially impact successful reproduction, including lowered salinity, extremes of temperature or irradiance, turbidity, eutrophication, and pollution. The capacity to maintain or renew genetically diverse coral populations through sexual reproduction is a key attribute of reef resilience; consequently, reef managers' understanding of regeneration and recovery processes is informed by knowledge of the timing of coral sexual reproduction.

Asexual reproduction from coral fragments is a common process of colony replication. Asexual reproductive results in a new coral colony that is genetically identical to the parent colony (a clone). Colonies started from fragments have the advantages of large initial size and locally adapted genotypes. The ability of some species of *Acropora* to survive fragmentation and rapidly fill space has led to an interest in using these species for programs of reef restoration.

Threats to Corals at Rose Atoll

Cyanobacteria stimulated by the 1993 shipwreck continue to overgrow the substrate.
Jean Kenyon/USFWS

The grounding of a large steel-hulled Taiwanese long-line fishing vessel in October 1993 resulted in a fuel and ammonia spill and break-up of the ship into thousands of pieces during the following years. The cumulative impacts included massive kills of corals and coralline algae from the spills and subsequent invasion of cyanobacteria that were increasingly stimulated by the corrosion and release of dissolved iron from the metallic components of the wreckage. The invasive cyanobacteria also displaced other indigenous marine species over a broader area including reef areas beyond the spill and grounding zone. Collectively the ship grounding and its breakup fueled the demise of many species in the affected habitats concentrated along the southwest perimeter reef and adjacent lagoon where the ship struck the reef.

From 1999 to 2007, seven visits to the Refuge by Samoan salvagers, supported by NWR funds and the Oil Spill Liability Trust Fund Act managed by the USCG, succeeded in removing more than 99% of the ship debris. Monitoring efforts since 1999, coinciding with debris cleanup efforts as well as cooperative surveys conducted with NMFS PIFSC, have revealed slow but persistent recovery of corals, coralline algae, and echinoderms that normally dominate the affected reef crests, shallow fore reefs, back reefs, and lagoon reefs near the grounding site (Green et al. 1997, Maragos 1994, Schroeder et al. 2008, Kenyon et al. 2010).

Rose Atoll before the grounding (left) and Rose Atoll after the grounding (1994). Note the discoloration (circled in yellow) where the cyanobacteria impacted the CCA. USFWS

Maragos (1994) noted widespread bleaching of numerous species of scleractinian corals in several environments at Rose Atoll in March 1994 to depths of 66 feet. Concurrent widespread bleaching at Tutuila suggested the bleaching was a regional phenomenon related to increases in surface water temperatures associated with ENSO rather than the result of local perturbations caused by the October 1993 ship grounding and chemical spill. Nonetheless, bleaching was most pronounced along the southwest fore reef, and its severity increased slightly when moving towards the wreckage, a sign that stress to corals from the shipwreck may have contributed to the severity of the bleaching event.

Though quantitative observations of the severity and geographical extent of bleaching at Rose Atoll could not be made during the 1994 event, qualitative snorkeling observations revealed that most of the outside perimeter of the atoll reef was consistently bleached to depths of 66 feet (Maragos 1994). Although the extent of subsequent mortality is unknown due to a hiatus in scientific surveys between 1994 and 1999, quantitative observations from NMFS PIFSC monitoring surveys in 2002 and 2004 indicate coral populations in the early stages of recovery from both the 1993 ship grounding and 1994 bleaching event (Kenyon et al. 2010). Although the bleaching event did not result in chronic damage to the reefs at Rose Atoll, some reef communities shifted to other species from what was observed in 1994.

The size and depth of the ava connecting the lagoon to the ocean is very important to maintaining the coral and other communities of Rose Atoll. Any modification to the ava would change the water flow regime and could exacerbate the effects of climatic warming and lead to permanent losses of corals during future bleaching events, especially within the lagoon where ambient temperatures are naturally slightly higher than deeper waters on the ocean side of the atoll (NMFS PIFSC 2008). This type of occurrence has already been documented at Palmyra Atoll (Williams et al. 2010). There were no bleaching events reported at Rose between 1995 and 2011.

Pacific-wide, there is growing concern pertaining to the threat of increased prevalence, geographic distribution, and host range of coral diseases. Disease is defined as any impairment that interferes with or modifies the performance of normal physiological functions, including responses to environmental factors, toxicants, and climate; infectious agents; inherent or congenital defects; or a combination of these factors (Wobeser 2006). Quantitative coral disease assessments conducted by NMFS PIFSC at 40 different U.S. Pacific coral islands, banks, and atolls between 2006 and 2007 revealed Pacific-wide mean disease prevalence (proportion of colonies affected) was low (regional means less than 5%), but site-specific hotspots occurred at Rose Atoll (11.7%) and four other islands/atolls (Vargas-Ángel and Wheeler 2008). In addition to minor bleaching, white syndrome, pigmentation responses, and other lesions were documented, with algal/cyanophyte infestions accounting for greater than 75% of all disease cases, most notably abundant in the vicinity of the 1993 shipwreck site.

4.9.2 Coralline Algae

Crustose coralline algae are an important component of reef systems, and the reefs at Rose Atoll are dominated by CCA. Together with hard corals, CCA represent a major source of reef limestone. The CCA cement and consolidate carbonate material, thus contributing to the growth and persistence of tropical reef structures. The capacity of coral communities on fore reefs to recover from disturbances is probably partially a result of the ability of CCA to bind loose rubble into a stable substratum (Birkeland et al. 2008). Settlement and metamorphosis of many key benthic reef elements, including scleractinian corals and octocorals, are induced by external biochemical cues associated with live CCA (Heyward and Negri 1999, Harrington et al. 2004). In addition, CCA are important sources of primary production. Water temperature and motion, light availability, sedimentation, and predation represent major influential factors determining patterns of CCA distribution, abundance, and zonation on tropical reef ecosystems (Littler and Doty1975, Fabricius and De'ath 2001).

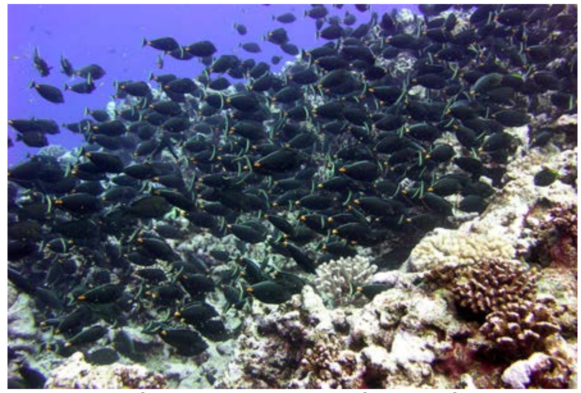
A diver conducts a quantitative survey of corals and CCA along a transect line.
Jean Kenyon/USFWS

Although the critical importance of CCA to the formation and ecology of tropical reefs is well documented, many aspects of the biology, ecology, and taxonomy of this flora are still poorly understood (Chisholm 2003). The CCA only live in marine waters, and they are hard because of calcareous deposits contained within the cell walls. They are typically pink or some other shade of red. Coralline algae are in the order Corallinales, in the red algal division Rhodophyta. Coralline algae have typically been divided into two groups based on their morphological form (though this division does not constitute a taxonomic grouping): the geniculate (articulated or connected by a flexible joint) corallines and the nongeniculate (nonarticulated) corallines. Geniculate corallines (e.g., *Jania* sp.) are branching, tree-like plants that are attached to the substratum by calcified, root-like holdfasts. The plants are made flexible by having noncalcified sections (genicula) separating longer calcified sections (intergenicula). Nongeniculate corallines range from a few micrometers to several-centimeter-thick crusts; there are more than 1,600 described species of nongeniculate coralline algae. Those with a growth habit that closely adheres the thallus to the substrate are commonly called CCA (*Porolithon* sp., *Hydrolithon* sp., *Lithothamnion* sp.).

Mayor (1924) noted that the exceptionally well-developed shallow calcareous algal ridge at Rose Atoll had the densest growth of calcareous algae he had encountered anywhere, and suggested it could be called a "*Lithothamnion*-atoll rather than a coral atoll". Observations following the 1993 longliner grounding indicated that the reef flat coralline algal community was severely affected and significantly altered by the petroleum released during the grounding. A massive die-off of CCA, extending 3,279 feet along the reef flat and reef margin, occurred on the southwest arm of the atoll where the vessel grounded (Maragos 1994). The large-scale die-off of the CCA was accompanied by a bloom of invasive cyanobacteria that were previously uncommon on the atoll. Within a year, the cyanobacteria had spread across the atoll's entire southwest arm and had begun to invade adjacent areas of the lagoon as well as portions of the northwest arm (Green et al. 1997). Quantitative surveys of CCA and cyanobacteria cover using transects along the seaward, mid-reef, and lagoon edge of the southwest arm of the reef flat were conducted in 1995, 1996, 1998, and 2002. In contrast to other arms of the atoll, which are pink in color due to the dominance of CCA, in 1995, 2 years after the spill, the southwest arm had very low abundance (less than 20% cover) of this key algal group. On the outer (seaward) reef edge, CCA was absent except at the northern end of the arm. In 1996, 1998, and 2002 CCA abundance had steadily increased on the outer edge, except near the wreck site; an area of low CCA cover (approximately 10%) had persisted near the wreck even following debris removal efforts. On the inner (lagoon) edge of the reef flat, cover of CCA was highly variable in the survey years and in 2002 had dropped to low levels (less than 30%), especially at the southern end of the southwest arm (Burgett 2003). Removal of remaining visible metallic debris from the grounding was completed in 2007, and the last transect surveys to monitor whether a more natural algal community is developing on this arm of the reef flat were done in 2010.

Although the fore reef slopes are not included within the Refuge boundaries, its biological communities serve as sources of colonizing propagules to those protected within the Refuge. In 2002, average CCA cover derived from quantitative analysis of imagery recorded during towed-diver surveys that circumnavigated the Rose Atoll fore reef in 3 depth strata was 48% (Kenyon et al. 2010), more than twice the average cover provided by corals (23%). Mean CCA cover was highest (65%) on the shallow (less than 30 feet) southwest fore reef slope and lowest (27%) on the deep (greater than 59 feet) northeast fore reef. On all four fore reef exposures (northeast, southeast, southwest, northwest), mean CCA cover decreases as depth increases from shallow to moderate (30–59 feet) to deep depth strata (Kenyon et al. 2010).

The distinctive crustose coralline algal reef crest, with Rose Island in the background (left photo). Close up of CCA (right photo). Jean Kenyon/USFWS



Herbivorous fishes (here, a school of surgeonfishes) are abundant where cyanobacteria and turf algae have proliferated as a long-term response to shipwreck metallic debris. Jean Kenyon/USFWS

Although there is growing consensus pertaining to the increased threat of disease to corals, little is known about coralline algal disease distribution, abundance, and the potential implications to declining CCA flora. Quantitative coral disease assessments conducted by NMFS PIFSC at 42 different U.S. Pacific coral islands, banks, and atolls between 2006 and 2008 revealed the highest average CCA percent cover occurred at Rose Atoll (Vargas-Ángel 2010). In 2006, of the islands/atolls in American Samoa, Rose Atoll had the lowest ratio of the number of cases of CCA disease relative to percent cover (0.1), but in 2008 this ratio had significantly increased to 0.8. While this U.S. Pacific-wide study could not make clear large-scale patterns linking CCA disease occurrence with natural reef physiographic or geomorphological features (e.g., carbonate vs. volcanic islands; windward vs. leeward wave exposures), the author noted that at Rose Atoll and a few other locations, leeward and protected habitats exhibited 60% more CCA disease cases when compared to exposed windward sites.

4.10 Fish

The number of reef fish species at Rose Atoll is estimated to be 272, based upon surveys conducted from 1981 to 2004 (Wegmann and Holzwarth 2006) (Appendix A). While this is a subset of the 991 reef fish species listed for all of American Samoa and Samoa in Wass (1984), the proportion found at Rose is substantial given that the atoll has less than 1% of the total reef habitat in the archipelago. Reef fish living amongst or in close proximity to tropical reefs have evolved many specializations adapted to survival on the reef. Their range of feeding strategies includes herbivores that graze on benthic algae, corallivores that feed on coral polyps, generalized carnivores that feed on a variety of animal prey, and specialized carnivores with more focused animal prey preferences such as zooplankton.

Reef fish surveys at Rose Atoll have documented an assortment of reef fish families and genera similar to other central Pacific shallow reefs (Green 1996, Whaylen 2005, NMFS PIFSC 2008). Damselfishes, surgeonfishes, wrasses, and parrotfishes were the most common families of small (less than 8 inches total length [TL]) to medium (8–20 inches TL) reef fish encountered. Snappers (Lutjanidae), groupers (Serranidae), and jacks (Carangidae) were the most common large (greater than 20 inches TL) reef fishes observed at Rose Atoll. Sharks (Carcharhinidae) were present but uncommon, mainly seen in shallow water on the fore reef just below the surf.

Reef fish surveys conducted by NMFS PIFSC using standardized methods showed that mean fish biomass per reef area at Rose Atoll is higher than at Tutuila but significantly lower than at other Pacific Remote Island refuges distant from human population (Howland, Baker, and Jarvis Islands, Johnston, Palmyra, and Wake Atolls, Kingman Reef) (Williams et al. 2011). At Rose Atoll, fish biomass appears to be highest inside the lagoon and on the southwest fore reef compared to other areas of the atoll (NMFS PIFSC 2008). Small to medium-sized fish were very abundant around several of the larger pinnacle patch reefs inside the lagoon, where parrotfish, snapper, emperor, goatfish, and jacks were common. Herbivores (surgeonfish, parrotfish, and angelfish) were abundant on the southwest fore reef, with significantly greater numbers and biomass at the site of the 1993 longliner grounding than at neighboring sites (Schroeder et al. 2008). This greater abundance of herbivores at the impact site was associated with significantly greater substrate cover of turf algae and cyanobacteria. The highest densities of large fish (greater than 20 inches TL), such as jacks and barracuda, were recorded just outside the ava along the northwest fore reef. This may be a preferred site for feeding on prey or plankton flowing out of the lagoon or may be a preferred site for spawning activity (NMFS PIFSC 2008).

Of concern is the conservation status of two species previously found at Rose Atoll: the Maori wrasse, *Cheilinus undulatus,* and the bumphead parrotfish, *Bolbometapon muricatum*. Both of these species have been subject to heavy fishing pressure. However, in response to a listing petition under the ESA, NOAA NMFS recently completed a status review of the bumphead parrotfish and determined that listing as an endangered or threatened species was not warranted. (77 Fed.Reg. 66799 November 7, 2012).

Malie alamata in Rose Atoll lagoon. Kelsie Ernsberger/USFWS

The peppered moray (*Gymnothorax pictus*) is commonly found in shallow water up on the reef flat at Rose where it feeds on crustaceans and fish (Lieske and Myers 1994). Its size, (up to 4.5 feet long), its abundance at Rose, and habit of coming out of the water in pursuit of prey makes it a good candidate for long-term monitoring. It is distributed throughout the Indo-Pacific and Eastern Pacific: East Africa to the Galapagos, Cocos, and Clipperton islands; north to the Hawaiian and Ryukyu islands; and south to Australia and the Kermadec Islands (Chen et al. 1994).

Sharks are a group of fishes characterized by a cartilaginous skeleton and 5–7 gill slits on the sides of the head. There are more than 440 species of sharks belonging to 8 taxonomic orders. The three species of shark that have been recorded at Rose Atoll NWR (gray reef shark, blacktip reef shark, and whitetip reef shark; *Carcharhinus amblyrhychos*, *Carcharhinus melanopterus,* and *Triaenodon obesus*, respectively) belong to the order Carcharhiniformes, family Carcharhinidae, commonly known as requiem sharks. They are distinguished by an elongated snout, a nictitating membrane that protects the eyes during an attack, and viviparity (live birth). These three species are the most common sharks inhabiting Indo-Pacific reefs.

Divers from NMFS PIFSC conduct surveys for reef-associated fish along transect lines. Jean Kenyon/USFWS

The gray reef shark, which is found as far east as Easter Island and as far west as South Africa, is most often seen in shallow water near the drop-offs of coral reefs, and less commonly within lagoons or open ocean. They are agile predators that feed primarily on bony fishes and cephalopods (e.g., octopi, squid). Despite their moderate size, their aggressive demeanor enables them to dominate many other shark species on the reef. Many gray reef sharks have a home range on a specific area of the reef to which they continually return. Gray reef sharks were the first shark species known to perform a threat display, a stereotypical behavior warning that it is prepared to attack. The display involves a hunched posture with dropped fins and an exaggerated, side-to-side swimming motion. They do so if they are cornered by divers, indicating they perceive a threat. This species has been responsible for a number of attacks on humans, so should be treated with caution, especially if they begin to display. They are caught in many fisheries and are susceptible to local population depletion due to their low reproductive rate (litters of 1–6 pups are born every other year) and limited dispersal. As a result, the IUCN has assessed this species as Near Threatened (Smale 2009).

The malia alamata (blacktip reef shark), found throughout the nearshore waters of the tropical and subtropical Indo-Pacific, prefers shallow, inshore waters. It is usually found in water only a few yards deep and can often be seen swimming close to shore with its black-tipped dorsal fin exposed. Younger sharks prefer shallow, sandy flats, while older sharks are most common around reef ledges and near reef drop-offs. A tracking study off Palmyra Atoll in the central Pacific found the malie alamata had a home range of about 0.21 square mile, among the smallest of any shark species (Papastamatiou et al. 2009). Often the most abundant apex predator in its ecosystem, the malie alamata plays a major role in structuring inshore ecological communities. Its diet is composed primarily of small bony fish, though cephalopods are also consumed. Sharks off Palmyra Atoll have been documented preying on seabird chicks that have fallen out of their nests into the water (Papastamatiou et al. 2009). Under most circumstances, the malie alamata has a timid demeanor and is easily frightened away by swimmers. However, its inshore habitat preferences bring it into frequent contact with humans, and thus it is regarded as potentially dangerous. Though it remains widespread and common overall, substantial local declines due to overfishing have been documented in many areas. This species has a low reproductive rate, with a litter size of 2–5 pups, limiting its capacity for recovering from depletion. The IUCN has assessed the malie alamata as Near Threatened (Heupel 2009).

The whitetip reef shark, which is found as far east as Central America and as far west as South Africa, is typically found on or near the bottom in clear, shallow water. The habitat preferences of this species overlap those of the malie alamata and the gray reef shark, though it does not tend to frequent very shallow water like the malie alamata or the outer reef like the gray reef shark. Unlike other requiem sharks, which rely on ram ventilation and must constantly swim to breathe, the whitetip reef shark can pump water over its gills and lie still on the bottom. During the day whitetip reef sharks spend much of their time resting beneath overhangs or in caves, emerging at night to hunt bony fishes, octopi, and crustaceans. Individual whitetip reef sharks may stay within a particular area of the reef for months to years, returning time and again to the same shelter. Females give birth to 1–6 pups every other year. Whitetip reef sharks are rarely aggressive towards humans, though they may investigate swimmers closely. The IUCN has assessed the whitetip reef shark as Near Threatened, noting that its numbers are dwindling due to increasing levels of unregulated fishing activity across its range (Smale 2005). The slow reproductive rate and limited habitat preferences of this species renders its global populations vulnerable to over-exploitation.

4.11 Invasive and Nuisance Species

Invasive species displace native vegetation, alter the composition and structure of vegetation communities, affect food webs, and modify ecosystem processes, resulting in considerable impacts to native wildlife. For the purpose of this CCP, “invasive” is a subset of nonnative species or indigenous species that have started to proliferate and modify the species composition or function of the existing native community, typically due to some human action. An invasive species is defined as a species whose migration and growth within a new range is causing detrimental effects on the native biota in that range. These species become invasive because their population and growth are no longer balanced by natural predators or biological processes that kept them in balance in their native ecosystems. In the absence of these restraints, invasive species have the potential to compete with native species for limited resources, alter or destroy habitats, shift ecological relationships, and transmit diseases. The cyanobacteria previously discussed is an example of a native species that has become invasive.

Invasive species are one of the most serious problems in conserving and managing natural resources. In particular, the ecological integrity of Pacific Island environments is greatly threatened by invasive species. Islands which have existed in isolation for millions of years are ideal environments for invasive species. Most native species have evolved without the necessity for defense and therefore lost their natural defense mechanisms and are more vulnerable to introduced species. Island ecosystems are key areas for conservation of global biological diversity. While islands make up only about 3% of the earth’s surface, they are home to 15–20% of all plant, reptile, and bird species (Whittaker 1998). Small population sizes and limited habitat availability make species endemic to islands especially vulnerable to extinction and their adaptation to isolated environments makes them particularly vulnerable to aggressive introduced species (Diamond 1985, Diamond 1989, Olson 1989). Of the 484 recorded animal species extinctions since 1600, 75% were species endemic to islands (World Conservation Monitoring Center 1992).

4.11.1 Mammals

The impacts from invasive predatory mammals are one of the leading causes of species extinction on islands (Blackburn et al. 2004, Duncan and Blackburn 2007). Rats living in close association, or commensally, with humans (Norway rat, *Rattus norvegicus*; black rat, *R. rattus*; and Polynesian rat, *R. exulans*) have been introduced to about 90% of the world’s islands and have a pronounced effect on island ecosystems (Towns et al. 2006). In addition, the extinction of many island species of mammals, birds, reptiles, and invertebrates have been attributed to the impacts of invasive rats (Andrews 1909, Daniel and Williams 1984, Meads et al. 1984, Atkinson 1985, Tomich 1986, Hutton et al. 2007), and estimates of 40-60% of all recorded bird and reptile extinctions globally were directly attributable to invasive rats (Atkinson 1985, Island Conservation n.d.).

Even if species are not extirpated, rats can have negative direct and indirect effects on native species and ecosystem functions. For example, a comparison of rat-infested and rat-free islands, and pre- and post-rat eradication experiments have shown that rats depressed the population size and recruitment of birds (Campbell 1991, Thibault 1995, Jouventin et al. 2003), reptiles (Whitaker 1973, Bullock 1986, Towns 1991, Cree et al. 1995), plants (Pye et al. 1999), and terrestrial invertebrates (Bremner et al. 1984, Campbell et al. 1984). In particular, rats have significant impacts on seabirds, migratory shorebirds, and other birds by preying upon eggs, nestlings, chicks, and adults and causing population declines, with the most severe impacts on burrow-nesting seabirds (Atkinson 1985, Towns et al. 2006, Jones et al. 2008). Ground- and burrow-nesting seabirds are particularly vulnerable to rat predation.

In addition to preying on seabirds, introduced rats feed opportunistically on plants, and alter the floral communities of island ecosystems (Campbell and Atkinson 2002); in some cases degrading the quality of nesting habitat for birds that depend on the vegetation. Small, oceanic islands have simplified seed dispersal systems that generally lack mammalian vectors and are vulnerable to disruption by invasive species (Drake et al. 2002). Rats can disrupt seed dispersal mutualisms by depositing seeds in microhabitats that are ill-suited for germination or subsequent growth. Native crab species prey on seeds as well, although they only eat the fleshy pulp, leaving the seed coat intact, allowing the seed to germinate. Rats are able to consume the fleshy pulp and chew through the seed coat killing the existing seed and preventing germination and recruitment of native plants. It is possible that rats can also indirectly reduce plant fitness by reducing the effectiveness or numbers of native dispersers through competition and predation (Wegmann 2009).

On Tiritiri Matangi Island, New Zealand, ripe fruits, seeds, and understory vegetation underwent significant increases after rats were eradicated from the island, indicating the rats' previous impacts on the vegetation (Graham and Veitch 2002). At Palmyra Atoll, in a very similar *Pisonia*-dominated coastal strand forest ecosystem, an eradication project to eliminate *Rattus rattus* was implemented in June 2011. By August of that year total counts of all tree seedlings in 56 transects had increased significantly, including those of native pu'a vai changing from no seedlings detected before eradication to 12.3 seedlings per transect post-eradication. Seedling censuses under five rare native tree species showed significant increases between 2004 and post-eradication, including the first ever documentation of seedling *Cordia subcordata* at Palmyra. This species was first detected at Rose in 1994 after *Rattus exulans* was removed there (USFWS 2011).

Rats are also documented to directly affect the abundance and age structure of intertidal invertebrates (Navarrete and Castilla 1993), indirectly affect species richness and abundance of a range of invertebrates (Towns et al. 2009), and contribute to the decline of endemic land snails in Hawai'i (Hadfield et al. 1993), Japan (Chiba 2010), and American Samoa (Cowie 2001).

Polynesian rats are speculated to have been a contributing factor in the large-scale extinctions of Hawaiian bird species during Polynesian settlement prior to European contact. Rats also consume plants, insects, mollusks, herpetofauna, and other invertebrates (Olson and James 1982, Brisbin et al. 2002, Engilis et al. 2002, Mitchell et al. 2005).

Polynesian rats and humans are the only known terrestrial mammals to reach Rose Atoll. The rats were first documented in 1920 (Mayor 1924). Rats have a varied diet that includes seabirds and turtle eggs and hatchlings as well as a variety of plants and their seeds. The population of rats on Rose Island was estimated to be 1,000–1,600 in 1990. Rats were eradicated in an operation beginning in 1991 by the Service under the guidance of U.S. Department of Agriculture Wildlife Services using live traps, kill traps, and bait stations armed with Talon ® anti-coagulant rodenticide containing brodifacoum spaced 82 feet apart over the entire island. No rats have been detected on the island since.

Subsequent to the eradication of Polynesian rats at Rose, the number of plant species has increased from only four species on Rose Island in 1990 to at least eight species in 2010. While it is likely that rat eradication provided a beneficial effect for all nesting seabirds at Rose, the only species for which adequate pre- and post-eradication data exist to demonstrate a statistically significant effect was the red-tailed tropicbird (Wegmann and Holzwarth 2006).

4.11.2 Reptiles

Reptiles have not been well studied at Rose Atoll. There are at least two species of gecko on Rose Island: the Oceanic gecko (*Gehyra oceanica*) and the mourning gecko (*Lepidodactylus lugubris*) (Amerson et al. 1982), which were likely introduced by humans but are indigenous to the central tropical Pacific and at present do not show signs of posing a threat to BIDEH.

4.11.3 Invertebrates

Invasive ants and scale insects (*Pulvenaria urbicola*) have contributed to mortality of Pu’a vai at Rose Island. These insects work together to invade and feed on sap from the leaves and petioles of the trees. The ants defend the scale insects and “farm” them for the concentrated liquid that they exude. This weakens the trees and may cause them to repeatedly shed their foliage until they eventually die. In 1994 Rose Island was covered with a thick forest of pu’a vai, but by 2005, all but about 11 trees had perished. The surviving trees were treated with systemic imidacloprid. In 2010, three of the treated trees remained alive but not healthy. The ants and scale invaders may have reached Rose Island on plantings and food or packing material of human visitors in recent decades.

4.11.4 Vegetation

Coconut trees were first observed on Rose Island in the mid-19th century and were likely planted by Samoan visitors (Setchell 1924). Mayor’s 1920 scientific account of Rose Atoll recorded about 6 coconut trees remaining of about 15 that were planted in 1902 and 1920 by Governors Tilly and Terhune (Mayor 1921). Amerson and colleagues (Amerson et al. 1982) mapped 13 trees on the island in the mid-1970s. The Department of Agriculture visited Rose Atoll in 1957 and planted 50 coconut seedlings (Swerdloff and Needham 1970). In 1987, a DMWR expedition mapped 30 coconut trees on Rose, including several trees planted around the island by a “vessel crew” the previous year. Several trip reports make note of the coconut infestation and call for management (Shallenberger 1980).

Oceanic gecko. USFWS

The elimination of rats in 1991 allowed many more nuts to germinate. In 2005, Hurricane Olaf uprooted many of the native canopy trees on Rose Island. Three dense patches of adult coconut trees survived and by 2010 had spread. Niu are very aggressive in displacing indigenous shrubs and trees because the nuts form an impenetrable mat over the ground and form a shading canopy monoculture that prevents the recruitment of native canopy trees. In 2010, Refuge and DMWR staff and contractors removed and destroyed 1,038 sprouted nuts, 94 green nuts from the trees, and 38 young palms. An additional 42 large palms were treated by drilling holes in the stem and applying glyphosate. They left one large coconut tree undisturbed in each of the three patches.

In 1994, patches of the nonnative grasses *Cenchrus echinatus* and *Chloris barbata* were removed from Rose Island (Craig et al. 1994), and a few individuals have had to be removed since then. No plants of either species were detected in 2010.

4.12 Wildlife and Habitat Research Inventory and Monitoring

Several scientific expeditions to Rose Atoll took place during the 1930s. In 1937 and 1938, Wray Harris, a scientist at the Bishop Museum, visited Rose Atoll to collect samples of mollusks and plants (Sachet 1954). The USCG brought a group of scientists to Rose Atoll in 1938; the observations were published by E.H. Bryan in 1939 and 1942 and W. Donaggho in 1953. In 1939, the U.S.S. *Bushnell* conducted a survey of islands in the Pacific and 11 days were spent collecting specimens of fish from Rose Atoll (Sachet 1954). Under Executive Order 8683, President Franklin Delano Roosevelt designated Rose Island as a Naval Defense Sea Area on February 14, 1941. The United States Navy Hydrographic Office published a map of Tutuila, the Manu’a Islands, and Rose Island in 1941. The data were gathered between 1901 and 1939 (Hudson and Hudson 1994).

In February 1953, the Office of the Territories, DOI conducted a fishing survey at Rose Atoll (Sachet 1954). In 1968, Rose Atoll was proposed as an “Island for Science” under the International Biological Programme (UNEP and IUCN 1988, IUCN 1991). The ASG sponsored a 1970 survey of Rose and Sand Islands, the reef flats, and the surrounding lagoon. The 1970 survey stressed the importance of Rose Atoll to breeding seabirds and i’a sa and recommended the atoll be designated a wildlife preserve (Swerdloff and Needham 1970). Between the years 1973 (the Refuge’s establishment) and 2005, 49 documented expeditions visited Rose Atoll (Wegmann and Holzwarth 2006). The Service and ASG have cooperated on scientific visits and aerial reconnaissance trips to the Refuge. Between 2002 and 2012, the NMFS PIFSC organized and conducted biennial American Samoa Reef Assessment and Monitoring research cruises.