An Ecological Assessment of Johnston Atoll

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Overview

Johnston Atoll was added to the United States National Wildlife Refuge system in 1926 to protect an important tropical ecosystem and the wildlife that it harbors. Johnston Atoll's ecosystem now includes extensive coral reefs and tropical terrestrial habitats on its four islands. Hundreds of thousands of seabirds inhabit and raise their young on the atoll and hundreds of migrating shorebirds spend their winters there. Extensive coral reefs are home to myriad tropical fish and invertebrates. Its location in the central Pacific also made it an important site for military activities beginning in World War II.

Concern about preserving Johnston Atoll's ecosystem prompted the original planners of the Johnston Atoll Chemical Agent Disposal System (JACADS), a demilitarization and incineration project, to arrange for scientists to monitor the birds and marine life of the atoll beginning 6 years before the project began and continuing throughout – a total of 20 years of research and monitoring.

Dr. Phil Lobel, a Professor of Biology (Ichthyology) with the Boston University Marine Program, Marine Biological Laboratory.

The preliminary 6 years of data provided a baseline of the health of the atoll and a goal to strive to preserve throughout the incineration process. Dr. Phil Lobel (Professor of Biology, Ichthyology, with the Boston University Marine Program, Marine Biological Laboratory) and Dr. Betty Anne Schreiber (Ornithologist with the National Museum of Natural History, Smithsonian Institution) carried out this important research and their results are presented here.

In their 20 years of extensive research Dr. Lobel and Dr. Schreiber did not document any adverse effect of the JACADS project on the wildlife and marine life of the atoll. Today, Johnston Atoll provides an excellent example of how military operations can be compatible with the ecosystem and both can thrive together successfully.

Dr. Betty Anne Schreiber, an Ornithologist with the National Museum of Natural History, Smithsonian Institution.

This research for Johnston Atoll is a contribution by the Department of Defense (DoD) and supports the goals and objectives of Executive Order 13089 on Coral Reef Protection. This Executive Order directs Federal agencies to study, restore, and conserve U.S. coral reef ecosystems. DoD is a member and active participant of the US Coral Reef Task Force.

History of Johnston Atoll

Johnston Atoll, which lies approximately 800 miles southwest from Hawaii, was first discovered on 2 September 1796 by a whaling ship, the brig Sally from Boston, Massachusetts. However, Captain Charles Johnston of the British ship HMS Cornwallis formally documented it on 14 December 1807 and it is for him that the atoll and main island are named.

Johnston Atoll has no natural source of freshwater; hence, Pacific islanders have never inhabited the atoll nor has evidence ever been found of long-term visitations prior to the 1800s. Ownership of Johnston Atoll was established in 1856 when the United States of America (US) passed the Guano Act that guaranteed US military protection to citizens establishing guano-mining operations on uninhabited and unclaimed guano-laden islands. Americans seeking fortune in collecting guano claimed Johnston Atoll on 19 March 1858; however, the Kingdom of Hawaii contested this claim. King Kamehameha proclaimed annexation of Johnston Atoll, which he called Kalama Atoll. The guano deposits were mined until the 1880s. The US Government annexed Hawaii in 1898 and with it gained undisputed claim to the atoll.

Johnston Atoll has an unusual geography unlike most atolls that are encircled by barrier reefs. Johnston Atoll has a semicircular emergent barrier reef only wrapped around the northern and western margins of the atoll platform. Reefs to the east and around the south are submerged from a few to several meters. The prevailing trade winds blow in from the east and, without an emergent reef barrier, drive current flow across the atoll.

Aerial photo of the present Johnston Atoll showing all four of the islands. The largest island is Johnston Island in the background.

Johnston Island in the 1940s.

The first scientific survey to Johnston Atoll was in 1923, led by Dr. Alexander Wetmore (biological survey for the US Government) and others, who were from the Bishop Museum, Honolulu, HI with support from the Department of Agriculture and the US Navy. They arrived by boat and landed on the largest island of the atoll, Johnston Island, on 10 July 1923. The report of the survey team described the incredible abundance and diversity of seabirds, fishes and other marine life. As a result, President Calvin Coolidge signed Executive Order No. 4467 on 29 July 1926 placing Johnston Atoll under the control of the Department of Agriculture as a breeding sanctuary for seabirds.

Intense military activity on Johnston Atoll began before World War II and increased in the 1960s with the start of the US nuclear testing program in the Pacific. To accommodate these operations, the atoll's islands were built up in size. Originally, Johnston Atoll consisted of two islands about 10 and 46 acres in area. The largest was named Johnston Island and the smaller one was called Sand Island. The islands were comprised of guano on dead coral and sand with no source of fresh water. Today, after years of engineering, the atoll's islands have been enlarged and two more islands added by dredging the atoll and filling shallow areas.

World War II brought many changes in the Pacific. President F. D. Roosevelt signed Executive Order No. 6935 on 29 December 1934, which placed Johnston Atoll under the Department of the Navy. At this time, the atoll included two islands, Johnston Island and the smaller, Sand Island. Sand Island was kept as a bird sanctuary under the Department of Agriculture. However, a buildup of military activity in the years from 1939 to 1941 included the construction of facilities on both islands, separated by a small shallow channel.

Sand Island became the main occupied island while Johnston Island was expanded in size to make a Naval Air Station, which commenced operations in 1941. Executive order No. 8682, February 1941, designated the area out to 3 miles from the atoll as a Naval Airspace Reservation and a Naval Defense Sea Area. During this time, Pan American Airways used the airfield enroute between Hawaii and Asia.

US forces on Johnston Atoll came under cannon fire by Japanese naval vessels on 15, 21 and 22 December 1941. Facilities were damaged but there were no casualties. During the war, the atoll was a vital strategic site as a refueling station for planes and submarines patrolling the Pacific in defense of the Hawaiian Islands. During this time, Johnston Island was further expanded in size to accommodate a longer runway and additional aircraft.

After World War II, Johnston Atoll continued as an air station and in 1948 was transferred from the US Navy to the US Air Force. Dredging and crushing lagoon corals while also creating deeper and larger ship channels slowly expanded the size of the islands. Heavy use of Johnston Atoll continued throughout the Korean War. In 1960 a US Coast Guard Loran station was built on Sand Island. It was the master Loran station for the central Pacific until December 1992 when the Global Positioning Satellite navigational system became fully operational and rendered the Loran system obsolete.

During the Nuclear Test Era of the 1960s, Johnston Atoll became a prime test site and staging area. It was ideally located about eight hundred miles from Hawaii but still isolated in all directions from other inhabited islands. In 1962, the US commenced a series of atomic tests. The US Air Force released operational control of the islands to the Atomic Energy Commission (AEC) and their military counterpart, Joint Task Force Eight (JTF-8). The atomic test series code-named DOMINIC included four high altitude and five low altitude successful tests. These tests were followed by three THOR missile misfires. Radioactive contamination from the destruction of malfunctioning rockets resulted across the atoll. The Defense Special Weapons Agency (formerly the Defense Nuclear Agency) is responsible for continuing radiological surveys and cleanup.

Sand Island in the 1950s.

In the early 1960s the United States entered into an atmospheric nuclear test ban treaty with the former Soviet Union. Several conditions or safeguards were placed in the treaty, including Safeguard C which established Johnston Atoll as the United States contingency site to resume testing if the Soviets violated the treaty. As a result a final dredging operation was conducted to expand Johnston Island and Atoll to its final four island configuration. These operations increased the size of Sand Island from 10 to 22 acres and Johnston Island from 46 to 640 acres. Two new islands, North Island (Akau) and East Island (Hikini), were artificially created by dredging and crushing live coral and are 25 and 18 acres in size, respectively. The overall lagoon is about 30,000 acres (50 square miles).

In 1963-1964, a second series of scientific surveys of Johnston Atoll was conducted by the University of Hawaii.


Missile test launch from Johnston Island in 1960s.

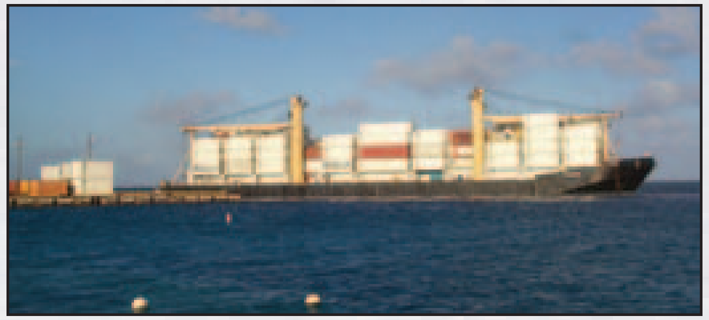
One focus of these studies was to evaluate the ecological impacts of lagoon dredging. The phenomenon called ciguatera was one of the main concerns. Ciguatera is caused by marine toxins produced by single-celled algae called dinoflagellates. These dinoflagellates live on the surface of other algae, which are eaten by herbivorous fishes. These fishes can then accumulate the toxin. Depending on the level of toxicity, humans eating ciguateric fishes can become mildly ill or die. One theory is that environmental disturbances such as dredging and severe storms can foster blooms of the ciguateric dinoflagellates.

In 1971, the US Army began using 41 acres of Johnston Island for chemical weapons storage in bunkers in an area known as the Red Hat Area. These weapons included nerve and blister agents contained in rockets, artillery shells, bombs, mines and ton containers. In 1972, the US Air Force brought about 25,000 55-gallon drums of the chemical, Herbicide Orange (HO) to Johnston Island that originated from Vietnam and was stored on Okinawa. During redrumming operations on Johnston Island an estimated 250,000 pounds accidentally leaked onto the soil of the former storage site on the northwest corner of Johnston Island. This stock of HO was incinerated at sea in 1977 aboard the Dutch ship, Vulcanus.


Chemical munitions were stored in bunkers in the Red Hat Area.

In 1976, a comprehensive study of the seabirds with extensive notes on other aspects of Johnston Atoll's natural history was published in the Smithsonian Institution's publication, Atoll Research Bulletin (Amerson and Shelton 1976). This publication also included a detailed history and summary of research findings up until that time.

During the years 1970 to 1985, the population of the island averaged about 300 people, including both military and civilian personnel. The building of JACADS, the world's first full-scale chemical munitions facility, began in 1986 and with its completion, the island population grew to about 1,200 personnel. The US Fish and Wildlife Service (FWS) stationed a refuge manager on the island full-time with US Army funding in 1990 to help manage the natural resources. The increased number of people on the island also resulted in the increased exploitation of fish and marine invertebrates. Some species such as white-tip sharks and certain marine snails (with pretty shells) were severely overcollected. Shark fishing and coral/shell collecting activities have since been banned.


Shipping barge at Johnston Island Wharf. Supplies were barged to the island and wastes were barged from the island.

The main base of operations today is on Johnston Island and includes an administrative organization with officers and representatives from several armed services plus the US FWS. The US Air Force, Pacific Command at Hickam AFB, Oahu, HI, owns the land.

Island management and overall military control is currently under a US Air Force Colonel who leads a joint operational service of the Department of Defense (DoD). The Colonel is the Base Commander responsible for supervising base operations and managing the infrastructure. A base contractor maintains the utility and maintenance facilities necessary to support the atoll's population. Freshwater is made by a desalination plant and power is generated from burning JP5 jet fuel in generators. Today there are about 300 buildings and facilities in operation on Johnston Island.


Johnston Atoll Chemical Agent Disposal System (JACADS) plant from across runway.

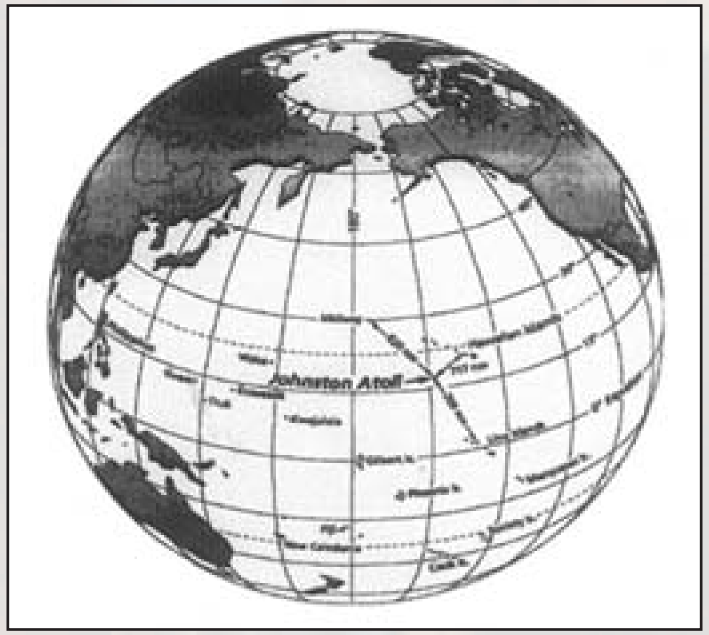
The US Army's Chemical Materials Agency (CMA) oversees the overall incineration business and operations. The JACADS plant was built and operated by Washington Demilitarization Company (a division of Washington Group International). JACADS is the nation's first environmentally sound chemical weapon incineration plant. JACADS began destroying chemical weapons in 1990 and completed its mission in 2000. The JACADS facility has safely and successfully destroyed over 2,000 tons of nerve and blister chemical agents contained in more than 410,000 various munitions. By using sophisticated pollution abatement systems and other engineering controls, the successful destruction of these weapons of mass destruction without any leakage of chemicals into the reef environment has been completed.


Creating a coral cap over the former site of the Munitions Demilitarization Building (MDB).

Cleanup and closure of the facility is progressing under the oversight of the Environmental Protection Agency (EPA) Region 9, the National Academy of Sciences' Research Council, the United States Fish and Wildlife Service, the Department of Health and Human Services, and other organizations to ensure that the highest levels of protection are provided to the environment and the public. The expected cleanup and closure completion of JACADS is in 2004. For more information about JACADS, see the Army's website http://www.cma.army.mil.

Location

Johnston Atoll, an unincorporated territory of the US, is an active military installation located approximately 800 miles southwest of Honolulu, Hawaii in the Central Pacific Ocean (16°45'N, 169°31'W). The nearest landfall is French Frigate Shoals, approximately 500 miles north in the Northwest Hawaiian Islands. The atoll is a shallow platform of approximately 50 square miles of reef habitat that supports 301 species of reef fishes and 28 coral species. Johnston Atoll is also a remote National Wildlife Refuge managed by the US Fish and Wildlife Service, primarily for the protection of 13 species of nesting seabirds.



Unique Ecological Resources

In the Pacific Ocean, there are only two atolls which have been protected from commercial exploitation of reef fisheries: Johnston Atoll and Wake Atoll. Both are Department of Defense (DoD) facilities. Obviously, some areas of the reefs were damaged by dredging, however, most of the lagoon habitat is nearly untouched by human impacts. Johnston Atoll is unique by virtue of its location midway between the Hawaiian Islands and Line Islands (on the equator). This places it in a very strategic location with respect to monitoring global climate and oceanographic processes (e.g., El Niño events), marine animal biogeography and population processes.

Johnston Island is basically a two mile long airstrip. At one time it had facilities to house about 1,200 people. During 2003 and 2004, as part of the cleanup of Johnston Atoll, most of the buildings are being removed. The island will be returned to its original avian inhabitants.

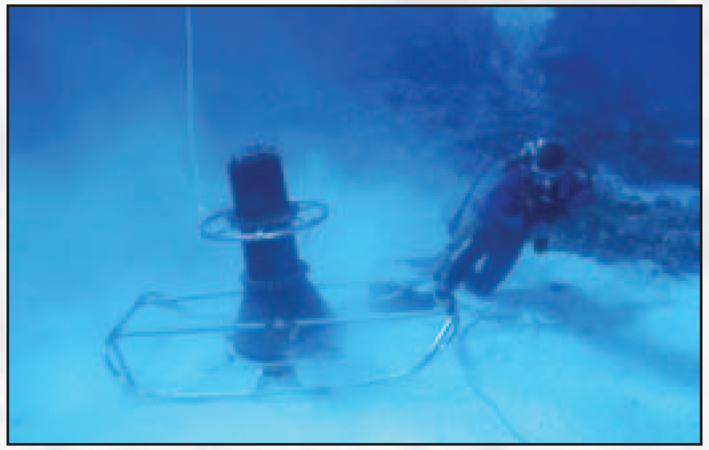
Johnston Atoll's characteristics as a location suitable for longterm studies of coral reef biology include:

- Long history of baseline research conducted as part of the ecological risk assessments for DoD.
- Easy accessibility of reef areas from the island marina.
- The absence of a civilian population means that equipment and experiments can be setup in the field and left unattended without risk of theft.
- Prior designation as a US Fish and Wildlife Refuge under the Department of the Interior (DOI).
- Easy access by boat to the deep ocean with depths greater than 3,000 meters for oceanographic and atmospheric studies.

This satellite photo shows Johnston Atoll is a small area (approx. 30,000 acres) surrounded by deep ocean. This makes small ship access to deep sea conditions easy and quick. This is ideal for many oceanographic and blue water naval experiments (e.g. low frequency sonar).

The original land mass of Johnston Atoll (2 small islands; see page 3) provided about 56 acres of habitat for nesting seabirds. Military operations increased the land mass to four islands and about 705 acres. Once the military closure is completed in 2004, this acreage will be available for birds to use. This is a significant contribution to the well being and future nesting success of seabirds in the Pacific Ocean where the majority of their nesting islands have been inhabited by humans and compromised by introduced predators.

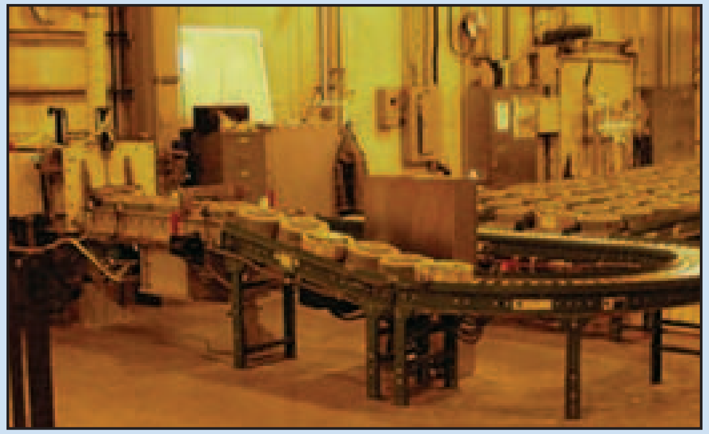
At one point in the 1950s, Sand Island was shore to shore buildings and people. When Johnston Island was fully constructed by 1965, all facilities moved there and Sand Island was occupied only by the US Coast Guard LORAN Station, which was closed in 1992. The rest of the island was recolonized by seabirds and the bird population soon was back to natural densities.



This underwater radiation survey device was used to assess residual radioactivity from atmospheric nuclear tests in the lagoon at Johnston Atoll. Radiation studies were conducted as part of the baseline ecological survey conducted prior to JACADS operations.

Army Chemical Munitions Mission

Beginning in the 1970s, the Johnston Atoll military mission became the storage of chemical munitions. In 1971, the United States Army Technical Escort Unit escorted the transfer of two thousand tons of chemical munitions from Okinawa to Johnston Atoll under the code name "Operation Red Hat". Phase I of "Operation Red Hat" involved the movement of chemical munitions from a depot storage site to Tengan Pier, eight miles away, by trailers. Phase II of "Operation Red Hat" moved the munitions to Johnston Atoll by ship. The US Army unit was renamed the United States Army Chemical Activity, Pacific (USACAP) in 1990, and chemical munitions were moved from West Germany to Johnston Atoll by ship, under the code name "Operation Steel Box". A small stock of chemical artillery shells were transferred to Johnston Atoll from the Solomon Islands in 1991.



Mines on conveyers in the unpacking area are being transported to the explosion containment room for processing during the mine campaign.

All of these chemical munitions were stored in bunkers in the farthest downwind corner of Johnston Island known as the Red Hat Area. These munitions included rockets, bulk containers, projectiles, bombs and mines, which totaled more than 6.6% of the nation's total stockpile of chemical munitions. These munitions were filled with either nerve agents (GB or VX) or blister agent (HD, commonly known as mustard). As these chemical munitions aged in storage, there was an increased likelihood that some of the munitions would leak, which underscored the need to destroy the munitions quickly and safely.

The Johnston Atoll Chemical Agent Disposal System (JACADS) was the world's first full-scale operational chemical munitions disposal facility. It was built and operated on Johnston Island by the Washington Demilitarization Company. JACADS began demilitarization and incineration activities in 1990, and was managed by the US Army's Chemical Materials Agency.

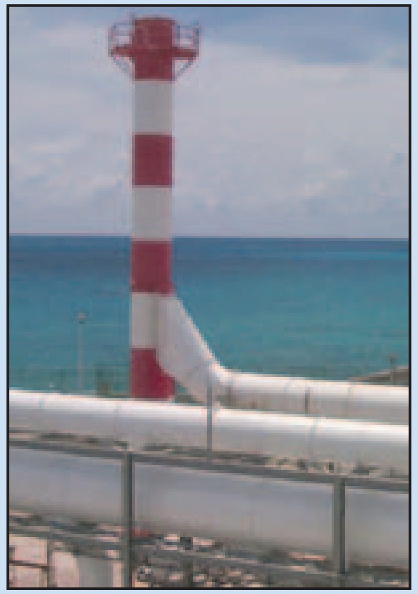
Workers in demil protective ensemble (DPE) during the carbon micronization and incineration campaign.

JACADS consisted of specially designed automated munitions disassembly equipment for the various chemical munitions, and four different incinerators for various materials (dunnage, explosives, liquids and metal parts). During the JACADS processing, the USACAP military personnel removed the chemical munitions from the storage bunkers in the Red Hat Area, and delivered them to the JACADS plant. JACADS plant workers removed the munitions from their pallets and placed them on process feed conveyors. The automated equipment (i.e., BDS - bulk drain station, MDM - munition demil machine, MIN - mine machine, RSM - rocket shear machine, etc.) would drain the liquid chemical agent from the munition, and disassemble the munitions. The explosive components were removed from the munitions by the PMD (projectile/mortar disassembly machine) in an explosive containment room with steel reinforced concrete walls.

Thermally decontaminated (5X) munitions storage area. Thermally decontaminated munitions were barged from Johnston Island.

Chemical agents were then incinerated at high temperatures in the Liquid Incinerator (LIC), explosive components were destroyed in the Deactivation Furnace System (DFS), and the munitions casings were thermally decontaminated to a 5X level (5X is the US Army's terminology for thermally clean munitions) in the Metal Parts Furnace (MPF). These 5X munitions casings along with other 5X scrap metal were barged from Johnston Island.

The incinerators and disassembly equipment were contained inside an engineering controlled building called the Munitions Demilitarization Building (MDB), which prevented any vapors from leaking outside to the atmosphere. The interior of the MDB was ventilated through large carbon filter units, which were an important safety feature for both the workers and the environment.


Aerial view of Munitions Demilitarization Building (MDB) filters exhaust stack.


Thermally decontaminated (5X) waste incineration containers and scrap metal to be barged from Johnston Island.


Thermally decontaminated (5X) ton containers, waste incineration containers, and metal boxes of tools to be barged from Johnston Island.

JACADS also consisted of control and alarm systems, and associated pollution control equipment, which were important in maintaining the operation within the environmental safeguards. The JACADS environmental safeguards are governed by an Environmental Protection Agency permit under the federal hazardous waste law, Resource Conservation and Recovery Act.

JACADS completed ten years of operation and the destruction of the last chemical munition on Johnston Atoll in November 2000. JACADS disposed of more than four million pounds of nerve and blister agents, including over 410,000 obsolete chemical weapons. The destruction of these chemical munitions was mandated by Congress, and the Chemical Weapons Convention, and was a major milestone for the US Army, and CMA.

JACADS is the first chemical munitions disposal facility to close under modern environmental regulations. The US Army and CMA worked closely with the EPA Region 9, which administers the Resource Conservation and Recovery Act (RCRA) permit, to establish and maintain cleanliness criteria for the buildings, structures and associated equipment at JACADS. The RCRA permit requires that all associated hazardous wastes generated at JACADS be removed from the island. Prior to final closure, analyses are being performed to ensure that the established cleanliness criteria are met.

The cleanup and closure of the facility is progressing, and the expected completion is in 2004. For more information about JACADS, see the Army's website http://www.cma.army.mil.

Avian Ecological Studies

Introduction

Johnston Atoll provides a safe-haven for hundreds of thousands of nesting seabirds and migrating shorebirds. There are few safe nesting sites left in the world for seabirds, where they are not disturbed by man or eaten by introduced predators (goats, cats, rats, snakes, etc.). Because of man's interference, an estimated 90-99% of the seabird populations of the Pacific have been destroyed (Steadman, 1995, 1997). Johnston Atoll has served as a highly productive, safe nesting area over the years because the military presence has kept tourists and leisure sailors away, and prevented the introduction of predators such as cats or rats.

The JACADS bird research project began in earnest in January of 1984 and continued through 2003, providing 20 years of consistently gathered data on the birds of the atoll. Concerns for the birds included not only 1) potential emissions from the incinerator, but also 2) the increased human population on the atoll and its possible effects on the birds, and 3) increased dumping of wastes into the reef ecosystem.

Bird studies included all species on all four islands of the atoll. Because of the small size of the atoll, Dr. Schreiber and her team of researchers were not just sampling the population, but were able to monitor complete population sizes of all species over the 20 years and determine if birds were moving away from one island or area because of disturbance or contaminants. Before incinerator operations began, the researchers established baseline data for adult size and mass, egg size, and reproductive success of all species. Thousands of birds were banded to track individuals and study survival throughout the incineration process. Over 1800 nests were marked to track movements of individuals.


Seabirds are relatively fearless of man and nested successfully all around the buildings on the atoll throughout incineration.

Objective of the Bird Study

The objective of this study was to gather the necessary data on the birds breeding on Johnston Atoll in order to monitor the stability and health of the populations in conjunction with the three previously stated concerns: JACADS incinerator operation, human disturbance to birds and increased dumping of waste in the surrounding water.

Seabirds tend to nest in remote areas, often little visited by man. Few studies have been carried out on them, and even fewer have lasted for more than 1-3 years on more than one species. This 20 year study of the seabird populations of Johnston Atoll is essentially unique in the world.


Brown Boobies and Brown Noddies spend 6-8 months on the atoll each year raising their chicks.

Interestingly, during this 20-year period the population size of all seabird species increased, attesting to the health of the local ecosystem (see bar graphs of changes in population sizes from 1984-2002, pages 12-15). Birds also experienced consistently high nest success over the twenty years.

The research was designed to monitor all possible parameters (end points) in the birds that might be affected, and to do the monitoring from year to year in a very consistent manner to ensure that data were comparable among years.

Parameters (endpoints) monitored were:

- *Egg size.*
- *Adult mass.*
- *Growth and development of chicks.*
- *Rate of occurrence of deformities in chicks.*
- *Nest site fidelity.*
- *Survival of adults from year to year.*
- *Chick survival to breeding age.*
- *Reproductive success.*
- *Population size.*

Since incinerator stack emissions contained heavy metals, scientists were concerned that they could accumulate in birds nesting around and downwind of the incinerator. Once plant operations began, two study areas were set up:

1) in the potentially contaminated area around the plant (downwind), and

2) in a control area away from any possible effects of the plant (upwind).

Monitoring the 9 listed parameters would determine whether any perturbation was occurring to the birds. Additionally, having a control site on the same atoll so that comparisons between the two areas could be made, further assured that scientists would be able to detect any change in the above parameters owing to the incineration's process (Burger 1995, Furness and Camphuysen 1997). Changes in measured biological parameters are considered the best indicator of any potential problem stemming from contaminants (Burger and Gochfeld 2002).

In addition to emissions from the incinerator, natural factors could affect the nesting seabirds, such as seasonal weather patterns, the occurrence of El Niño events, one nesting species interfering with another, changes in food availability, and age of the birds. The scientific studies were designed to account for these factors and separate them from any effects of the incinerator.

Being a top level predator (fish eater), seabirds make a good, sensitive indicator of the health of the surrounding environment - more sensitive than man since they are much smaller. Scientists expect to see a problem occur in the birds before it appears in man, as occurred with DDT contamination. Monitoring seabirds during the incineration process provided a 'coal-mine-canary' that could assure people that the operation was safe.

A male Great Frigatebird expands his red pouch to attract a mate, while two other males incubate their eggs. In all seabirds, males and females share incubation and chick rearing.

Red-footed Boobies nest on bushes and after a time, destroy the bush with guano deposits and by ripping the branches off for nesting material. Tropicbirds are dependent on bushes for shade in order to nest successfully. Over 1,000 Tropicbird pairs have lost their nest site over the years when Red-footed Boobies moved in to nest on their bush. Many of these Tropicbirds never nested again.

Throughout the incineration, no effect of any type could be documented in the bird populations. Owing to space restrictions, results of the studies that are presented here cover only a small portion of the research done and only that carried out on two of the species. Covered in detail are Red-tailed Tropicbirds (the species most likely affected by the incinerator since they nest all around it) and Brown Boobies (since they feed closer in to the atoll than do most species, they could have been affected by any contaminants in the water). *For more information on the birds of Johnston Atoll contact Dr. Schreiber at SchreiberE@aol.com*

A Red-tailed Tropicbird sits on nest under a bush. White numbered stake marks the nest site.

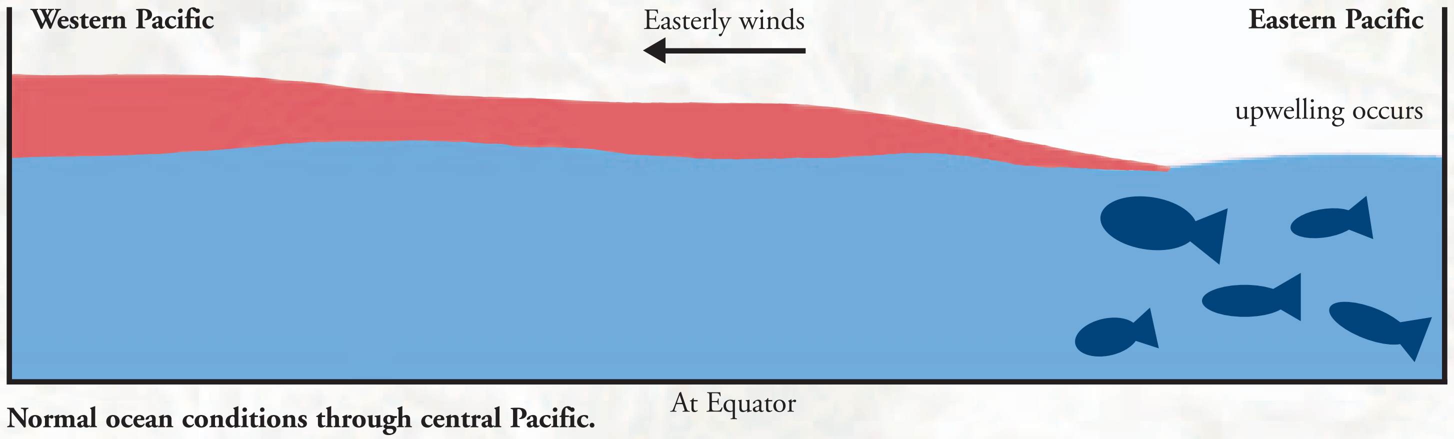
Effects of Weather Patterns on Seabirds

Tropical seabirds can be seriously affected by the occurrence of El Niño events. In this study scientists had to be able to separate the effects of these events from potential problems caused by the JACADS incinerator. Seabirds feed over the open ocean and during normal weather conditions, they know exactly where to go to find food around their nesting colonies. They typically feed at oceanographic features such as upwellings and current shears. These areas bring cold nutrient rich, deep waters up near the surface where they are in the photic zone (receiving good sunlight). High productivity in this zone attracts feeding fish and squid – the food eaten by most seabirds.

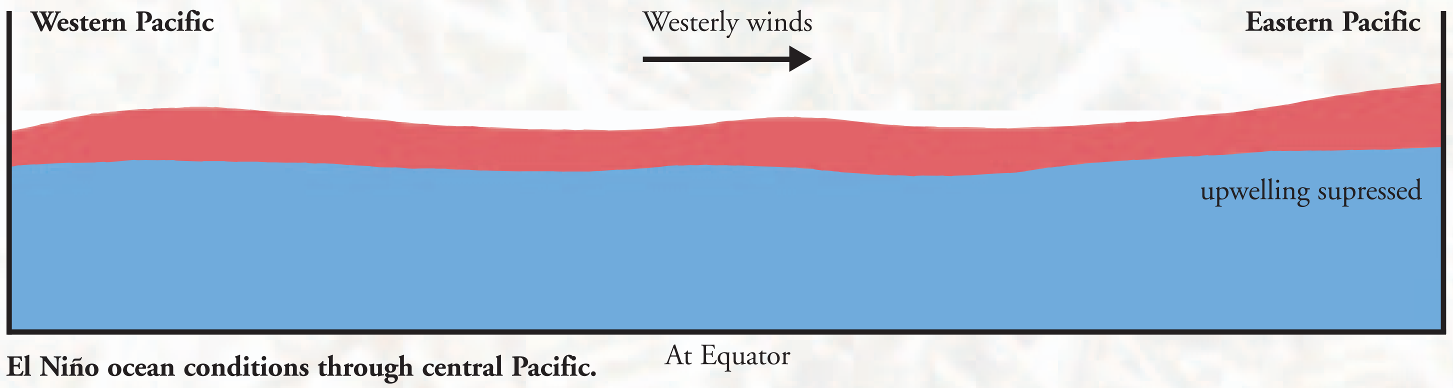
When weather patterns change, such as occurs during an El Niño event, normal feeding areas disappear and seabirds have to go in search of food. This can cause dramatic affects on the population and reproductive success.

The cause of El Niño events is not well understood. Normally the spinning of the earth causes there to be easterly winds (from the east) across the central Pacific. This wind pushes surface water up against the west side of the Pacific basin, where it is warmed by the tropical sun, creating a higher sea surface level and a pool of warm water (See below). On the eastern side of the Pacific, surface water is stripped away to the west by the prevailing wind, allowing upwelling of the cool waters beneath. These upwelled waters are rich in nutrients and support a food chain leading to the fish being eaten by seabirds. Millions of seabirds feed along the central coasts of Ecuador and Peru in this rich upwelling. During an El Niño the normal easterly winds die down and even reverse, the warm pool of water in the western Pacific, no longer held there by the wind, sloshes back across the Pacific (Wyrtki 1975, Cane 1983). It suppresses normal upwellings and current shears as it goes and eventually hits the coast of South America (See below). The result is that the normal feeding grounds of seabirds disappear and they must go in search of food elsewhere. They spend added time searching for food and often do not find it. Effects on seabirds occur worldwide as weather patterns become disrupted.

Back in the seabird colony various effects are noticed: 1) some birds don't come in to nest, reducing nesting numbers, 2) others that have laid eggs may desert the nest, 3) some remain and try to find enough food but their young grow very slowly since they are underfed, or they die of starvation, or 4) adults may die (Ainley et al. 1988, Schreiber and Schreiber 1989). Birds on Christmas Island (South of Johnston Atoll) suffer massive reproductive failures (Schreiber and Schreiber 1989). Johnston Atoll is slightly north of the most severe effects of an event in the central Pacific, and the effects on its' birds are noticeable but mild. The exact effects are discussed later as they occur in the data collected by scientists.



Normal ocean conditions through central Pacific.



El Niño ocean conditions through central Pacific.

Breeding Bird Species and Population Sizes

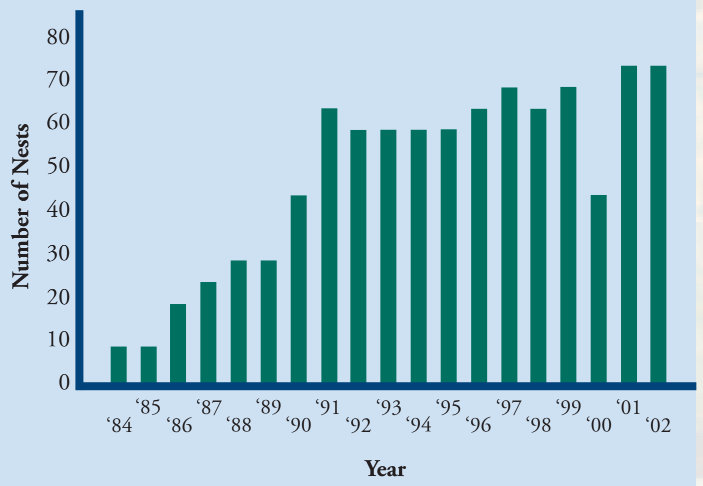
Three orders of seabirds nest on Johnston Atoll. They all commonly live 20-40 years, raise one chick and are a top-level predator, similar to man – feeding on fish and squid.

Changes in population size are one of the most common parameters, or endpoints, monitored to determine the health of a species. The tables of population size changes over 20 years illustrate the dramatic increase in all populations over the 20 year period. Minor annual fluctuations in numbers were caused by El Niño events.

Petrels and Shearwaters – Order Procellariiformes

Bulwer's Petrel – *Bulweria bulwerii*

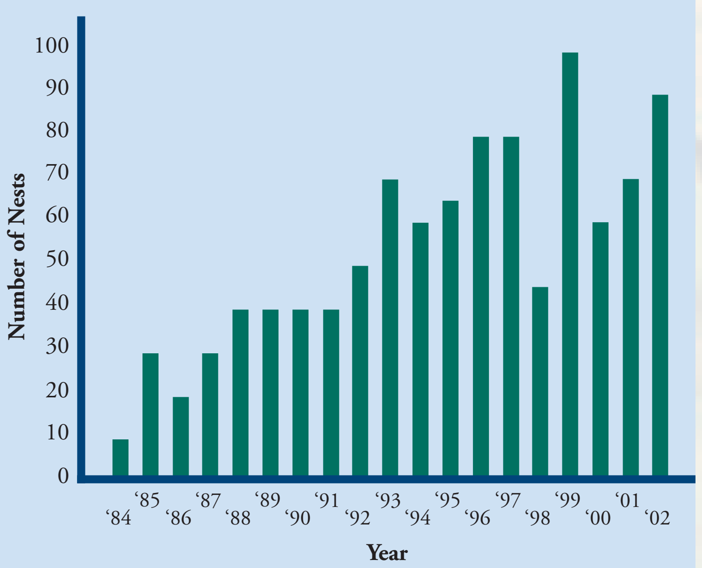
Nest in burrows or under dense grasses. Lay one egg.



Number of nesting pairs of Bulwer's Petrels by year.

Christmas Shearwater – *Puffinus nativitatus*

Nest mainly in tunnels under long grasses. Lay one egg.

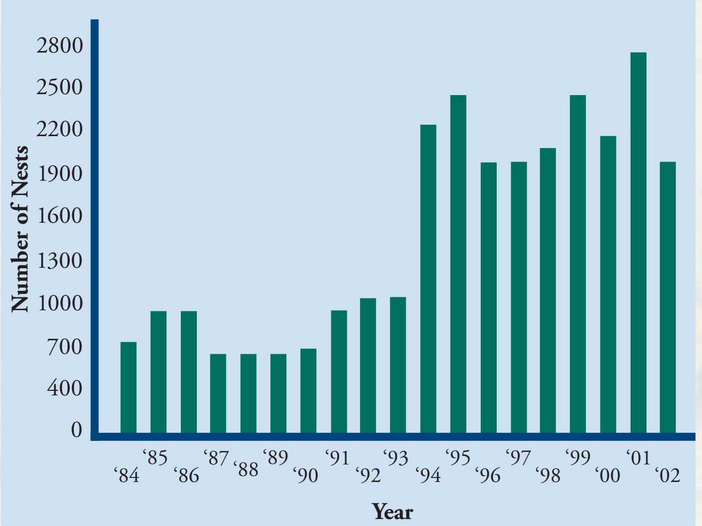


Number of nesting pairs of Christmas Shearwaters by year.

Christmas Shearwater adult sits at entrance to its nest burrow.

Wedge-tailed Shearwater – *Puffinus pacificus*

Nest mainly in burrows but sometimes under dense grasses. Lay one egg.



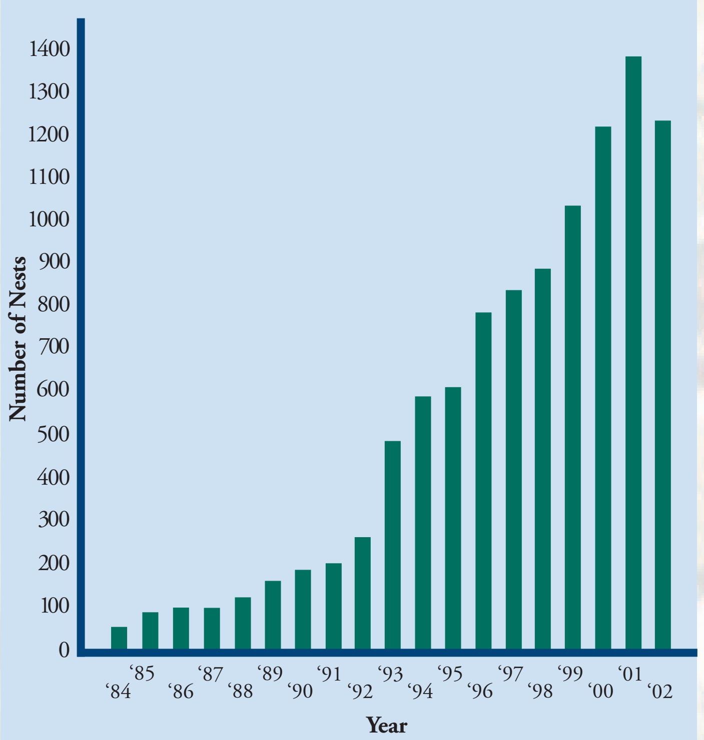
Number of nesting pairs of Wedge-tailed Shearwaters by year.

Wedge-tailed Shearwater chick about 25 days old.

Boobies, tropicbirds, frigatebirds (relatives of pelicans) – Order Pelecaniformes

Red-footed Booby – *Sula sula*

Nest in trees, but will nest on the ground and do so frequently on Johnston Atoll owing to lack of bushes. Build nest of twigs and vegetation. Lay one egg.

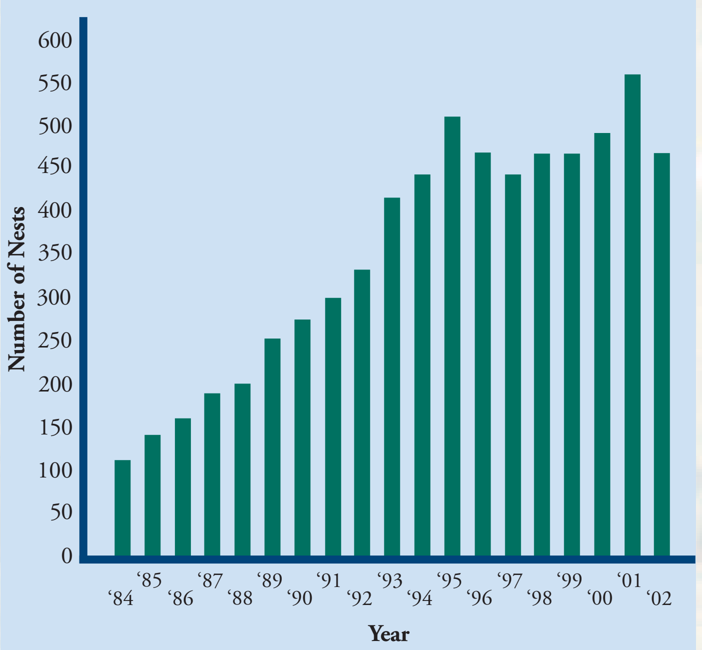


Number of nesting pairs of Red-footed Boobies by year.

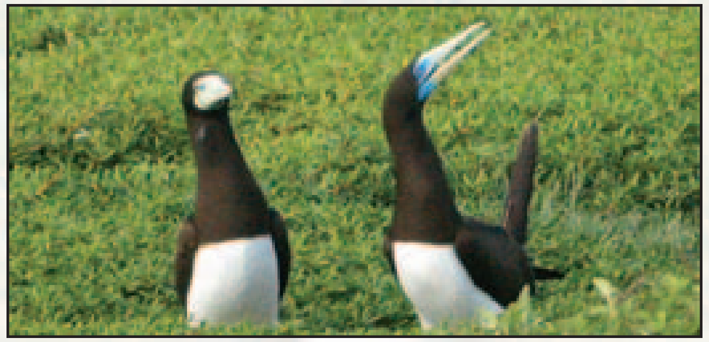
Red-footed Booby incubating its egg. Both sexes share nest duties in all seabirds.

Brown Booby – *Sula leucogaster*

Nest on the ground. Build a nest of twigs and grasses. Lay 2 eggs. In most areas of the world they only raise one chick. On Johnston Atoll about 0.5% of pairs raise two young (very unusual, indicates good feeding conditions locally). (See more extensive data on pages 19-21).



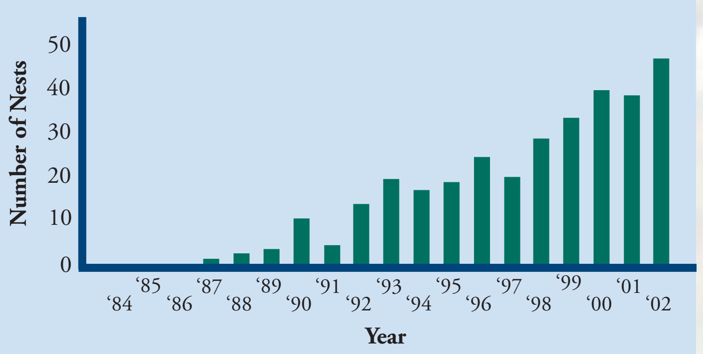
Number of nesting pairs of Brown Boobies by year.



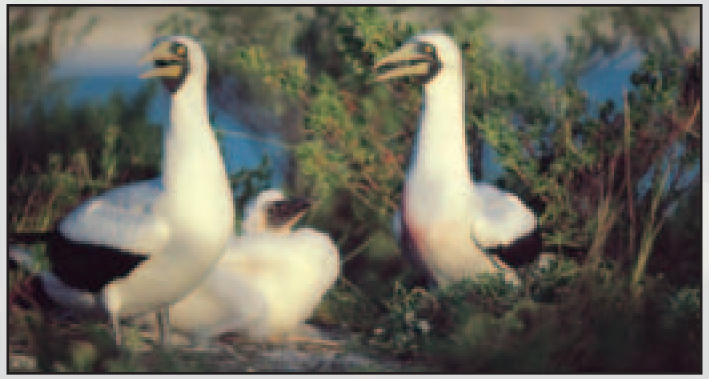
Brown Booby pair stands at their nest site. Male, on right, calls to bird flying over, indicating ownership of site.

Masked Booby – *Sula dactylatra*

Nest on ground. Build no nest. May lay out a few small pebbles around nest. Lay 2 eggs. Never known to raise more than one chick in a year. Second egg serves as an insurance policy in case first laid egg fails to hatch or the first chick dies early on.



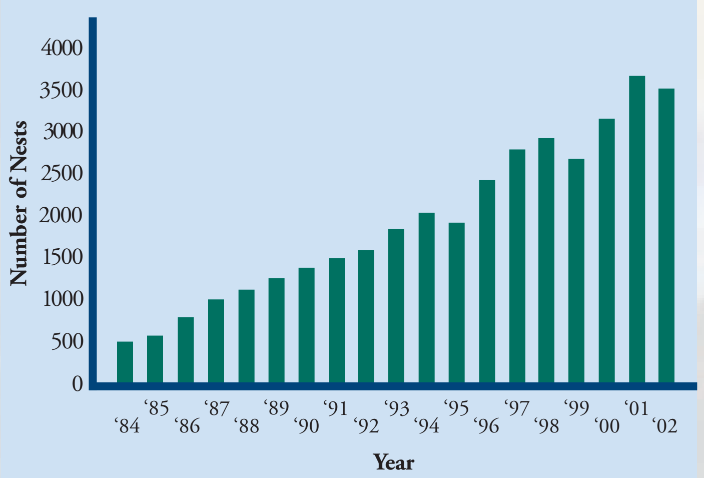
Number of nesting pairs of Masked Boobies by year.



Masked Booby pair with chick. Chicks get fed once or twice a day and eventually weigh about 25% more than their parents. Before they first fly, however, they lose this "baby fat."

Red-tailed Tropicbird – *Phaethon rubricauda*

Build no nest, but make a small scrape in sand or dirt and deposit the egg. We have the most extensive data on this species since they nest around the JACADS facility and are the most likely to have been affected by it. (See pages 16-19). (White-tailed Tropicbird *Phaethon lepturus* 0 to 2 pairs nest/year)

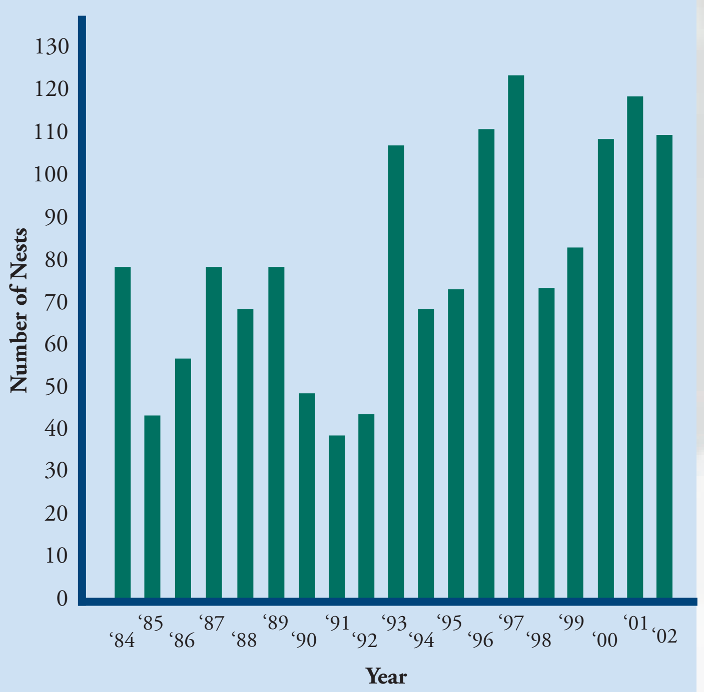


Number of nesting pairs of Red-tailed Tropicbirds by year.

Adult Red-tailed Tropicbird incubating its egg.

Great Frigatebird – *Fregata minor*

Nest in bushes or trees. Will nest on the ground as they do most often on Johnston Atoll where there are few bushes or trees. The only species that takes longer than a year to raise a chick. Lay one egg, which they incubate for 60 days. Adults spend 10-14 months feeding the chick before it is independent; one of the longest chick-care periods of any species.



Number of nesting pairs of Great Frigatebirds by year.

Great Frigatebird: two adults and their six-week-old chick.

Terns – Order Charadriiformes, Family Laridae:

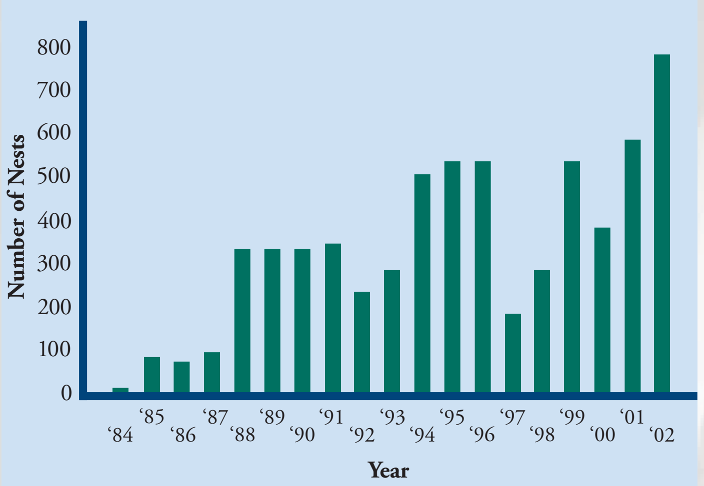
All the species on Johnston Atoll lay one egg. All incubate for about 30 days and take 8-10 weeks to raise young.

Sooty Tern – *Sterna fuscata*

Nest on the ground. Build no nest. May pull in a few very small pebbles around nest. They are strongly affected by El Niño events, when massive nesting failures occur. The number of nesting pairs varied widely from year to year: between 80,000 to 200,000 pairs.

Gray-backed Tern – *Sterna lunata*

Nest on ground. Build no nest.

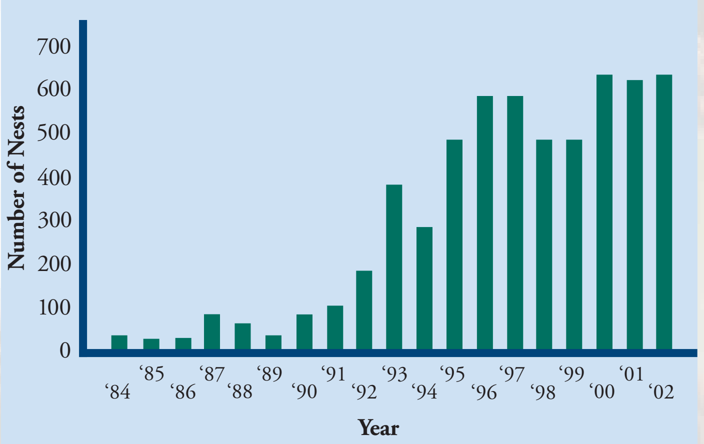


Number of nesting pairs of Gray-backed Terns by year.

Gray-backed Tern adult stands near nest site while mate incubates the egg.

White Tern – *Gygis alba*

Nest in trees or on any available structure, ledge, fence post. Build no nest, laying their one egg in a slight depression or crevice.



Number of nesting pairs of White Terns by year.

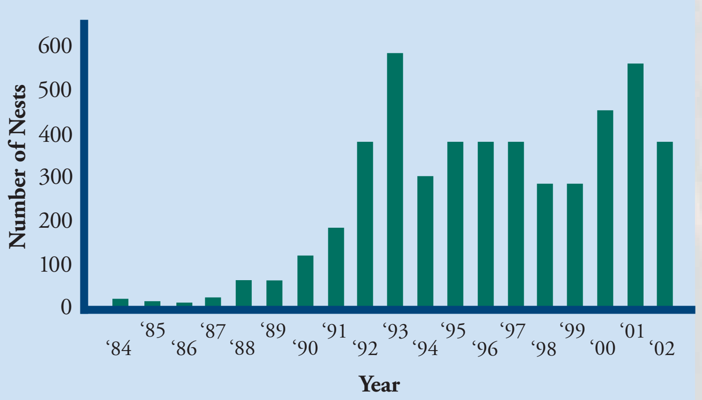
White Tern adult carries fish back to the nest for its chick.

Brown Noddy – *Anous stolidus*

Nest on ground (in bushes in some places). Build a small nest of grasses, straw, shells, old bones, or other material. Often decorated with odd colorful bits. The number of nests ranged from 1,600 in 1984 to 17,000 in 2003.

Black Noddy – *Anous tenuirostris*

Nest in trees. Build a nest of leaves, grasses. Several hundred adults died of starvation during the 2002 El Niño.



Number of nesting pairs of Black Noddies by year.

A group of Black Noddies roost on the ground near their nesting trees.

Results of Research by Species

Red-tailed Tropicbirds

Red-tailed Tropicbirds were the main species of concern for scientists on Johnston Atoll. They nest all around the incinerator and could have been affected by any emissions or accidents. All the previously listed parameters (see page 9) were closely monitored each year over the 20 years of the study. Two groups of nests were set up once the incinerator began operation: 1) a group downwind of the JACADS incinerator that was susceptible to any emissions or leaks and 2) a group in a control site upwind of the plant and away from any potential effects. The six years of monitoring that took place before the plant became operational also serve as a control group.

In none of the parameters measured could scientists find any effect on the birds from the incinerator (Schreiber 2002, Schreiber et al. 2001). The results of some of these studies are presented here.

From 1984 through 2002, 32,000 tropicbirds were banded, and approximately 45% (0.02 SE) of nesting adults were recaptured each year to examine survival and movements of individuals. Within the atoll there was an average probability of movement of a bird from one island to another between consecutive breeding seasons equaling less than 1 in 100 (0.0079; 0.0002 SE). This illustrates their exceptional philopatry to their chosen nest site; birds return to the same site year after year. This also means that birds nesting downwind of the incinerator had long-term exposure to any emissions from the plant and had the potential to accumulate any released contaminants in body tissues.

Red-tailed Tropicbird wearing a radio transmitter (note antenna over lower hand holding bird). Data obtained from transmitters on adult birds allowed scientists to determine nest site attendance patterns and compare them between birds nesting upwind and those nesting downwind of the incinerator. No differences were found in the birds' activity patterns in the two sites. A specially wired digital watch on the birds' other leg records time in air (searching for food) versus time on the water (loafing) while the bird is at sea.

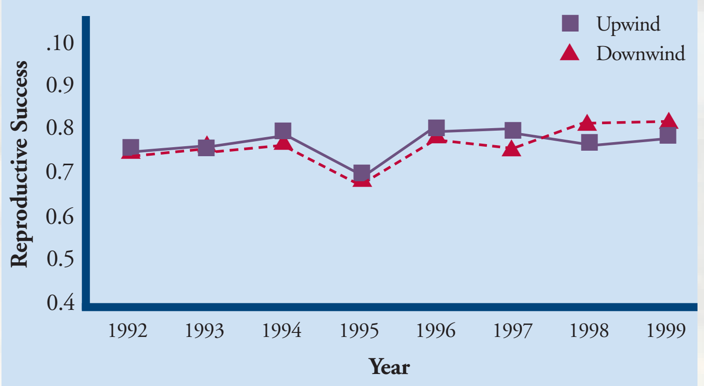
Red-tailed Tropicbird with 3 1/2-week-old chick. One parent stays with the chick all the time until it is at least 2 weeks old to protect it from heat and cold.

Population Size

The number of nesting pairs on Johnston Atoll increased steadily from 600 pairs in 1984 to about 3700 pairs in 2002 (see tropicbird graph page 14). The main affects on nesting numbers over the years were, 1) boobies and frigatebirds destroyed tropicbird nesting bushes and 2) the need to keep the perimeter of the runway clear of vegetation (which had been used by tropicbirds). An increasing population size is an excellent indicator of the health of a population.

Reproductive Success

There was no significant difference in reproductive success (chicks fledged from eggs laid) between birds nesting in downwind areas around the incinerator and those nesting upwind away from the incinerator (68 - 85% annually; see graph below). There was also little temporal variation in reproductive success, other than a small decrease in El Niño years (Schreiber and Schreiber 1993, Schreiber 2002). During El Niño events, hatching and fledging success decline in tropicbirds (about 5-12%). There have been no unexplained die-offs of tropicbirds on the atoll and the occurrence of El Niño events is the only factor that has lowered nesting success.



Mean reproductive success for nests upwind and downwind of the JACADS incinerator. No significant differences were found.

Johnston Atoll birds exhibit the highest reproductive success reported for tropicbirds (See table below), a good indicator of a healthy environment both on land and at sea.

	Johnston Atoll	Kure Atoll[1]	Midway Atoll[2]	Aldabra, Indian Ocean[3]
Reproductive Success	68-85%	17-38%	38-41%	44%

A comparison of annual reproductive success among colonies. (1 – data from Fleet 1974, 2 – data from Tyler 1991, 3 – data from Diamond 1971).

Red-tailed Tropicbird adult and chick. The nest site was destroyed by roosting Boobies and Great Frigatebirds. Adults attempting to nest in the sun generally abandon the nest, or the chick dies of heat exposure.

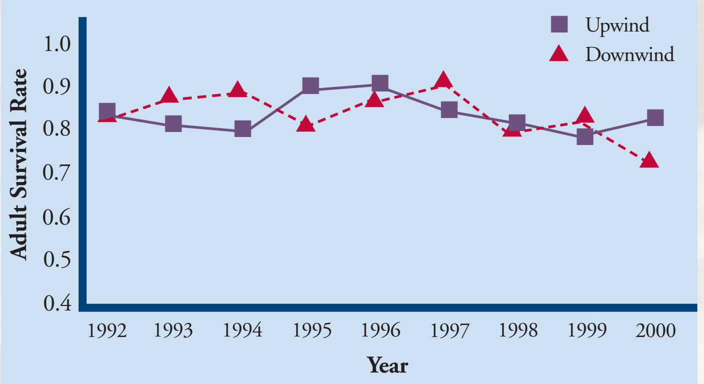
Survivorship

The research on Johnston Atoll has, for the first time, allowed scientists to examine survivorship in Red-tailed Tropicbirds (both of adults from year to year, and of juveniles to breeding age). Modern mark-recapture survivorship analysis techniques were used in this analysis (Arnason 1972, 1973, Clobert et al. 1994, White and Burnham 1999, Williams et al. 2002) to compare birds nesting in areas located both upwind and downwind of the JACADS incinerator (Schreiber et al. 2001).

Assumptions required by this model are similar to those required by Cormack-Jolly-Seber (CJS) models (Cormack, 1964, Jolly 1965, Seber 1965), (1) recapture probabilities are the same for all marked birds; (2) birds behave independently with respect to survival, recapture and transition probabilities; (3) bands are not lost; (4) all samples are instantaneous; and (5) state transition probabilities reflect a first order Markov process (Williams et al. 2002). Tropicbird data met these assumptions well.

Adult Survival Rate

Survival of adults from year to year was very high and there was no significant difference between sites in the annual survival rate of adults (downwind $\bar{x} = 0.85$ survival, $\hat{SE} = 0.02$; upwind $\bar{x} = 0.85$, $\hat{SE} = 0.02$; see following graph). There was some temporal variation in adult survival which is mainly an artifact of differences in recapture effort between the areas. (See Schreiber et al. 2001 for full details of the analysis.)



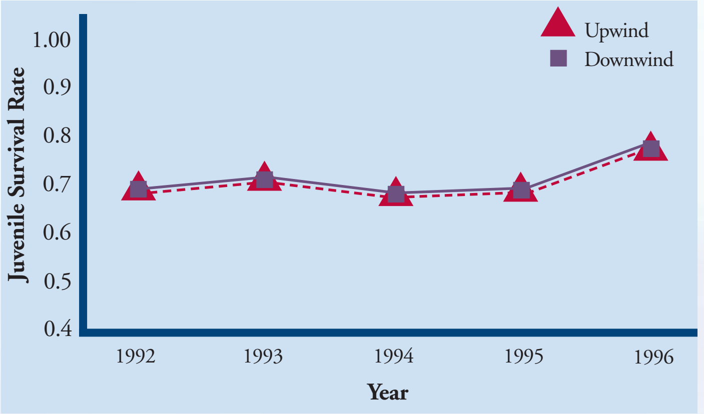
Adult survival rate for birds upwind and downwind of the JACADS plant from 1992 to 2000. There is no significant difference between the two areas.

There are no comparable data for Red-tailed Tropicbirds nesting in other areas of the world, but an annual rate of 85% is on the upper end of those reported for all four orders of seabirds (0.62-0.97, Schreiber and Burger 2001).

Juvenile Survival Rate

Scientists also examined the rate at which chicks that fledged from the atoll survived to return to breed. If chicks raised in the downwind areas had accumulated high concentrations of heavy metals, fewer of them might be expected to survive to breeding age. Since juveniles take 6-7 years to return to breed, juvenile survival was not estimated for the most recent 6 years (many birds of those chicks would not have returned yet). There were no differences in juvenile survival rate for tropicbird chicks fledged from upwind areas ($\bar{x} = 0.71$ survival, standard error [SE] = 0.03) as compared to downwind areas ($\bar{x} = 0.71$, SE = 0.03) of the JACADS facility (See following graph on page 18).

A one-week-old Red-tailed Tropicbird chick sleeping.

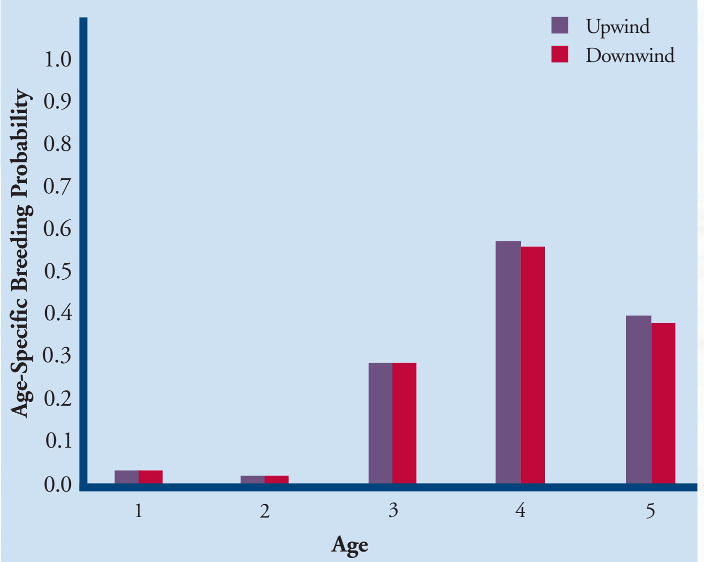


Average juvenile survival rate for birds upwind (triangles and dotted line) and downwind (squares and solid line) of the JACADS plant from 1992 to 1996.

A juvenile survival rate of 71% is exceptionally high, and the lack of a difference between rates in the two areas indicates that there was no effect of the incinerator on birds raised in the downwind area. There are almost no long-term studies of marked birds which provide data for comparison. In Roseate Terns juvenile survival to breeding is estimated at 20% (12 year study, Nisbet and Spendelow 1999).

Age at Which Birds First Breed

Seabirds in general do not begin breeding until they are 3-8 years old (Schreiber and Burger 2002). A delay in the return of birds raised in the downwind area could indicate some impairment of behavioral development that caused these birds to take longer to develop the mate-obtaining and breeding skills.



Mean age-specific breeding probabilities for tropicbirds, age 1-5, comparing upwind (purple bar) and downwind (red bar) sites.

No differences were found in the age at which chicks returned to breed (age-specific breeding probability; see graph above) between those raised upwind of the incinerator and those raised downwind, respectively: age 1 (Upwind mean 0.03, SE < 0.00; downwind mean 0.03, SE = 0.01), age 2 (mean 0.02, SE = 0.01; mean 0.02, SE = 0.01), age 3 (mean 0.29, SE = 0.02; mean 0.29, SE = 0.02), age 4 (mean 0.58, SE = 0.04; mean 0.58, SE = 0.05), or age 5 (mean 0.53, SE = 0.11; mean 0.52, SE = 0.12). This indicates that birds return to breed at the same age in both areas.

Adult Mass

Adult mass data were collected in an area downwind of the incinerator and in two control areas away from any effects of the incinerator. Decreased adult masses in a particular area of the atoll could indicate a perturbation occurring to the birds.

No significant differences were found between the downwind area and upwind (control) area (See table below; F = 0.49, P < 0.49).

Red-tailed Tropicbird chick getting weighed. Growth rates of tropicbird chicks were measured each year in the downwind sites around the incinerator, and in a control site upwind. No differences in chick growth rates were found between the two areas in any year.

Location	Mean Mass	Sample Size	Standard Error
Downwind of Plant	666 g	669	3.43
Upwind of Plant	662 g	466	5.96

Average mass of adults on Johnston Atoll, 1990-2002, downwind and upwind of the incinerator plant.

Egg Mass

A change in egg mass over time could be indicative of body concentrations of a contaminant that affect a females' ability to produce an egg. Data from a control site were needed to determine that any egg mass changes were not also occurring to birds in an area that was not subject to any incinerator affect. There were no significant differences in egg mass between areas around the incinerator and those in the control site away from any potential effects of the incinerator (See table below; F = 0.01, P = 0.99).

Location	Mean Mass	Sample Size	Standard Error
Downwind	66.14g	361	0.34
Upwind	66.17g	645	0.32

Egg mass on Johnston Atoll, 1990-2002, downwind and upwind of the incinerator plant.

Tropicbirds court in the air. Males and females fly around together, perhaps demonstrating their flying agility to each other, which could mean they are good at catching fish for chicks and would make a good mate.

Human disturbance

Tropicbirds appear to be able to tolerate a large amount of human disturbance as they chose to nest in close proximity to human activities all around Johnston Island. No areas of human activity discouraged tropicbirds from nesting there, and no areas were deserted by the birds in response to human activity. Essentially every area of bushes on Johnston Island has nesting tropicbirds.

Summary

As previously discussed (Schreiber et al. 2001), the main concerns for survival of birds nesting downwind of the JACADS plant were inhalation of heavy metals from the smoke stack and direct mortality from leaks of chemical agents. Ingestion of heavy metals from soil was not considered to be a problem since tropicbirds do not feed on land and do not tend to pick up objects with their bill while on land. No evidence was found of any negative effects of the JACADS plant on tropicbird population sizes, reproductive success, adult survival, juvenile survival, adult mass, or egg mass.

Brown Boobies

Brown Boobies do not nest in proximity to the incinerator so concerns for them and the potential for effects on them from the incinerator differed from those for tropicbirds (the only species nesting near the incinerator). Brown Boobies feed somewhat closer to the atoll than do the other species of seabirds (although there is extensive overlap) and their feeding areas may have had the potential to be affected by outfall from the incinerator or from increased dumping of waste in the local waters owing to the increased human population on the atoll. Satellite tracking data show that they most commonly feed from 5 to 30 miles offshore but do go out as far as 110 miles to feed (Schreiber 2002).

All the previously listed parameters were monitored over the 20 year period, as they were with tropicbirds. Data from before the plant operation began were compared to data collected after operations began and no differences could be found. Results of some of these studies are presented here.

Over 5,500 Brown Boobies were banded since this study began (at least 90% of chicks fledging every year were banded in cooperation with the US Fish and Wildlife Service) in order to 1) track survival of individuals and compare annual survival rates, 2) determine individual reproductive success, and 3) track temporal variation, if any, and determine the reason for it.

A female Brown Booby sits on the nest while her mate stands-by attentively. Periodically he will bring her a twig to weave into the nest.

Population Size

The number of nesting pairs on Johnston Atoll has increased from 120 nests in 1984 to 500 nests in 2000 (See Brown Booby graph on page 13). The number of nests varies somewhat in connection with the occurrence of El Niño events. During these events, fewer birds nest in response to decreased food supplies (Ainley et al. 1988, Schreiber and Schreiber 1989, Duffy 1990). The long-term population increase is indicative of a healthy population.

Satellite transmitters placed on the birds (here a Great Frigatebird) track where they go to feed at sea. Brown Boobies generally go from 5 to 30 miles out to sea to find flying fish for their chicks.

Reproductive Success

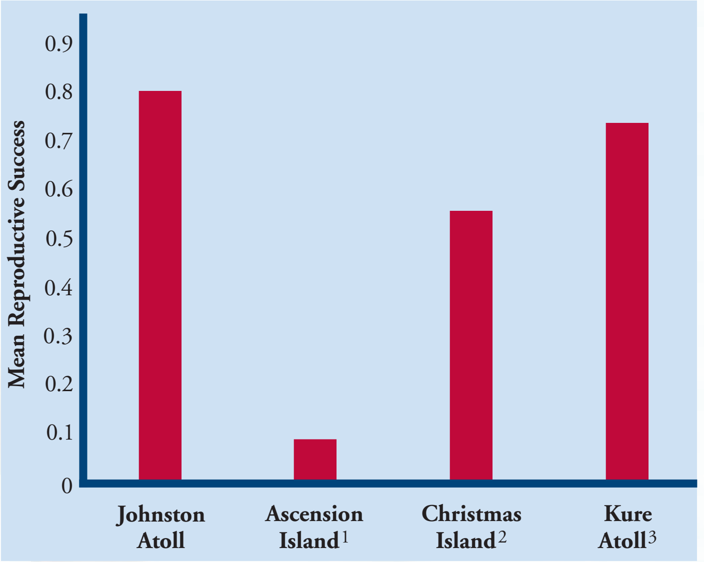
Johnston Atoll has provided a healthy environment for Brown Boobies to raise young: not only is the population growing, but reproductive success is high (approximately 82% of nests receiving an egg fledged a chick; see table below). Although over 95% of nests receive two eggs, only one chick is ever raised in most localities, thus reproductive success rates are reported as the percent of nests receiving eggs that raised a chick. Success rates on Johnston Atoll range from 75-87% each year and have remained high throughout the JACADS project. Scientists were not able to document any decrease in reproductive success due to the incineration process.

During some El Niño events fewer than expected numbers of birds nested. It may be that some birds that are less efficient fish catchers know they cannot catch enough to feed themselves and their young chicks in a poor year such as occurs during El Niño events.

	Before Incineration	During Incineration
Reproductive Success	81.7%	82.4%

Reproductive success in Brown Boobies before incineration operation and during operation.

The reproductive success rates of Brown Boobies are exceptionally high compared to that reported for most other colonies (See following graph). Additionally, Johnston Atoll is the only island where adults are regularly reported to raise two chicks in a year (about 0.5% of nests raise two chicks: Schreiber 2002), implying that resources are abundant in the area. Even with the constantly growing nesting population of all the species on the atoll, there are no data to indicate that birds are overeating the local fish resources.



Mean number of nests producing a fledged chick (reproductive success) compared among islands. 1 – Atlantic Ocean, data from Dorward 1962. 2 – Indian Ocean, data from Nelson 1978. 3 – N. Pacific Ocean, data from Woodward 1972.

Adult Mass

A change in adult mass can be an indication that a perturbation is occurring in the environment and causing stress to the birds. Adult masses did not vary significantly between 1984-1989 (before incineration began) and 1990-2002 (during incineration; see table below). To look more closely at the possible accumulative effects of any contaminants, data on adult masses from after the incinerator had been in operation for 4 years were analyzed. Again there was no decrease in mass associated with the incineration process.

There was no significant difference in male mass in the three time periods (t = 0.595, P = 0.552). Female mass became significantly heavier through time (t = -5.059, P = 0.0001). This could indicate a positive change in local food supplies that has allowed females to be in better condition in more recent years. This mass gain is also reflected in a gain in mass of eggs, which is to be expected (see table on page 21).

Sex	Before Incineration 1984-1989	During Incineration 1990-2002	Latest Incineration 1994-2002
Male	1178g (169, 8.2)	1171g (334, 6.9)	1188g (272, 7.8)
Female	1478g (168, 10.8)	1536g (304, 9.6)	1558g (240, 10.8)

Mean adult masses (in grams) compared among years: 1) before incineration operation began, 2) throughout incineration, and 3) after the incinerator had been operating for 4 years through the end of incineration. (mass, sample size, standard error).

Eight-week-old Brown Booby chick tries his wings while watched by female parent. Once a chick learns to fly, it continues to return to the nest and get fed by its parents while it works on perfecting its fish-catching abilities.

Egg mass

A decrease in egg mass over time could be indicative of body concentrations of a contaminant that affected the females' ability to produce an egg. Eggs became slightly heavier over time from 1984 to 2002 (t = -2.21, P = 0.03; see table below), coinciding with an increase in female mass (See table on page 20).

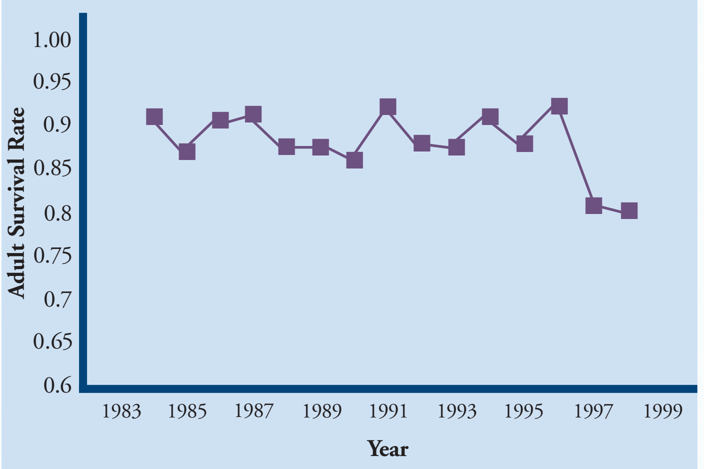
	Before Incineration 1984-1989	During Incineration 1990-2002	Latest Incineration 1994-2002
Egg Mass	57.9g (304, 0.42)	59.1g (310, 0.42)	59.1g (238, 0.46)

Mean egg masses (in grams) compared among years: 1) before incineration operation began, 2) throughout incineration, and 3) after the incinerator had been operating for 4 years through the end of incineration. (mass, sample size, standard error).

Adult survival

A lower annual survival rate of adults after the incinerator began operation could indicate an effect of the plant on the surrounding waters where Brown Boobies feed. However, survival of adults from year to year was very high: estimated to be 0.90 ± 0.01 (SÊ) overall (range 0.81-0.94; see following graph).

There was small annual variation in rates which sometimes corresponded with the occurrence of El Niño events and sometimes did not. The two years of lowest survival rates, 1997 and 1998 (adult survival of about 0.81) corresponded to a severe El Niño event, which is known to cause adult mortality (Duffy 1990, Chastel et al. 1993). During this event many adults of several species (Red-footed Boobies, Black Noddies and White Terns) were found starving to death. It is rare for adult seabirds to die during an El Niño event. Generally, they know if an event is going to be severe and do not nest, choosing to 'follow the food' to other areas of the ocean that year. By doing this, they survive to nest in future years.



Annual adult survival rates of Brown Boobies (squares) on Johnston Atoll. There is no significant difference among years.

Overall mean survival rate for adult Brown Boobies (.90) fall at the upper end of survival estimates spanning all four orders of seabirds (0.62-0.97, Schreiber and Burger 2001). There are no other good estimates for Brown Booby adult survival using modern estimation methods. One study on Kure Atoll over three years did estimate annual survival at 0.81 (Woodward 1972).

Summary

Research on the Brown Booby population of Johnston Atoll indicates that there were no effects of the chemical weapons incinerator on the birds. All parameters measured before the plant began operation were compared to the same parameters measured throughout operations and no differences could be found other than that female Brown Boobies got somewhat heavier and laid slightly heavier eggs. Once the military has closed down all operations and people are gone from Johnston Island itself, Brown Booby populations will probably increase more as the birds begin using this island also for nesting.

Large Brown Booby chick begs from male parent by wing flapping and giving a begging call. Parents often fly off a ways to get away from the aggressive begging. Booby adults recognize their own chick, even if it wanders from the nest site, and they will not feed a strange chick.

Other Nesting Species

Data for the other 11 nesting seabirds of Johnston Atoll are similar and owing to a lack of space, full details will not be presented here. In none of the species could scientists document any effect from the chemical weapons incinerator on the birds.

Migrating Shorebirds

Johnston Atoll is commonly used by shorebirds as a stopover during migration. These species do not nest here, but stop off to feed and are seen on all four islands of the atoll. The highest numbers occur during our winters, after the birds leave their nesting grounds. A few, perhaps younger birds, remain through the summer when the rest go back north to nest. Some limited banding data indicate that many of the same birds return to the atoll each year (Amerson and Shelton 1976).

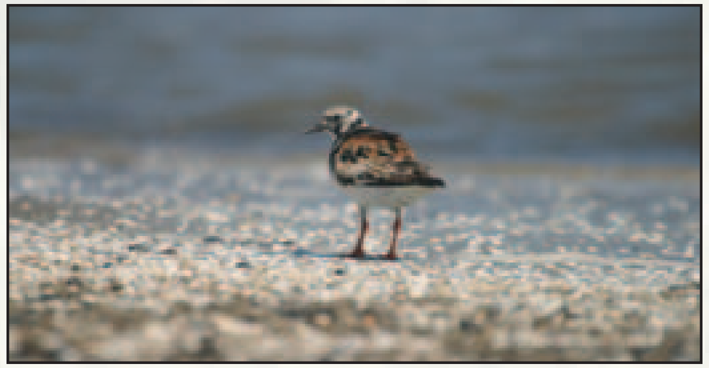
Bristle-thighed Curlew

The five species most commonly seen, in order of abundance, with the average wintering number present on Johnston Atoll:

Pacific Golden Plover, *Pluvialis fulva*	400 - 500
Ruddy Turnstone, *Arenaria interpres*	200 - 250
Bristle-thighed Curlew, *Numenius tahitiensis*	20
Sanderling, *Calidris alba*	10
Wandering Tattler, *Heteroscelus incanus*	10

The population sizes have remained consistent over the years. A few other species are seen much less commonly. For years people have fed the shorebirds, mostly bread scraps, and this food source may keep some of the shorebirds on the atoll longer than they would normally stay. Normally these species eat small insects, other invertebrate prey, and seeds. On Johnston Atoll they feed mostly in upland areas and not on the shoreline.

Bristle-thighed Curlews and Ruddy Turnstones lurk around tern nesting areas and steal eggs quite commonly. Scientists have counted as many as 200 eaten eggs in an area of 5,000 Sooty Tern eggs (4%). Bristle-thighs have also learned to take Red-tailed Tropicbird eggs in recent years. For instance, in an area of 40 nests, Bristle-thighs took 24 of them (60%) in 2003. Most areas are not that heavily predated, however.



Ruddy Turnstone *Brian Harrington*

Summary

Some shorebirds ingest grit to hold in the gizzard and help grind their food. If high levels of contaminants were present on the surface soil, shorebirds had the potential to ingest them. Additionally, by returning to the same wintering area each year, they increased the potential for concentration of contaminants. Shorebirds have not been part of the main avian monitoring program but mortality rates have been monitored. Over the past 20 years scientists have not documented any unusual mortality in the birds, or any decrease in numbers of wintering birds.

Dr. Betty Anne Schreiber (with a Masked Booby) has been studying tropical seabirds for 32 years and has worked on Johnston Atoll for 20 years. She is one of the world's authorities on boobies, tropicbirds and their relatives, and recently co-edited a textbook on seabirds, "Biology of Marine Birds".

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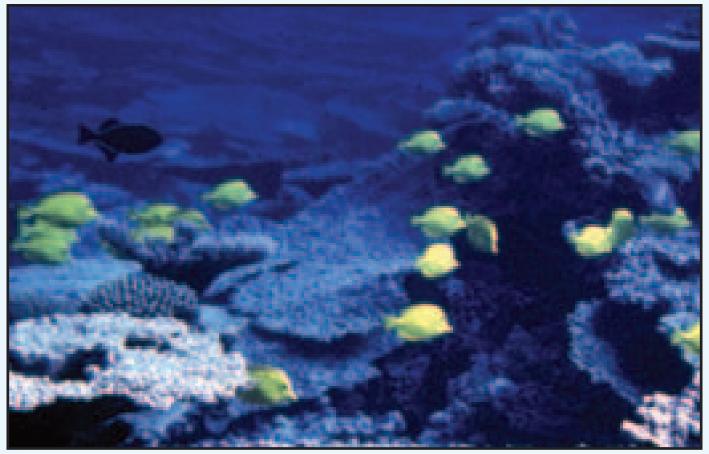
Biological Monitoring

The location of the JACADS facility was on a peninsula on the south side of Johnston Island next to the ocean.

The former herbicide orange storage site is located on the northwest corner of the island. Two independent scientific studies of the potential ecological risk concluded that the few grams of contaminant that remained in the soil did not pose measurable ecological risk.



On land Johnston Island is a military industrial complex, but just adjacent underwater it is a beautiful coral reef ecosystem.

Monitoring – What is it?

Overall, the objective is to document as completely as possible the status of biota on Johnston Atoll. This includes documentation of the history of contaminants that have entered the lagoon waters, in the days before ecological awareness and before environmental regulations.

This was accomplished by a series of field surveys and sampling key species and sediments for signs of the impacts that may result from contaminants. Rapid coral reef ecological impact surveys and assessments of the marine environment allow detection of warning signs of ‘biological ills’.

Prior impacts to Johnston Island and the atoll:

- Military base since 1930s
- Dredging of lagoon for ship channels and island construction - intermittent projects from late 1930s to mid 1960s
- Atmospheric nuclear bomb tests - 1960s
- Storage and offshore incineration of HO - 1970s
- JACADS construction, operation and closure from late 1980s until completion of clean-up (expected in 2004).

Vision of Department of Defense

The Department of Defense (DoD) voluntarily initiated their coral reef protection program in an effort to be sure that operations were conducted in the best way for the environment. Lessons learned from the JACADS monitoring program were developed into a guidance document for the DoD worldwide.

The main home site for access to Legacy program reports:
http://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Legacy/natural_water.html

The below websites on the DoD web “DENIX” refer to The Coral Reef Conservation Guide for the Military.
http://osiris.cso.uiuc.edu/denix/Public/ES-Programs/Conservation/Legacy/Coral/coral.html
or
https://denix.cecer.army.mil/denix/Public/ES-Programs/Conservation/Legacy/Coral/coral.html
and
The site for the DoD Coral Reef Protection Implementation Plan is
https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Legacy/Coral-Reef/Plan/coralreef.html

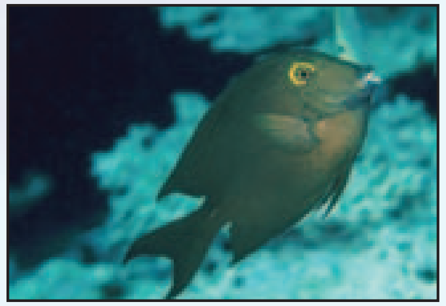
https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Legacy/Coral-Reef/Plan/implementation.html

Selection of Species

The purpose of biomonitoring is to determine if contaminants that may have been spilled in the lagoon have entered the food chain. Contaminants found in fish not only impacts fish health but also the health of humans who eat the fish. Since we cannot sample all fishes, we select certain key indicator species and use these to estimate levels of bioaccumulation of contaminants. A few of the key species that were sampled are shown here.

Convict Surgeonfish, *Acanthurus triostegus sandvicensis*, Manini Distribution: Hawaii and Johnston Atoll endemic subspecies. *Acanthurus triostegus* is found throughout the Indo-Pacific and tropical eastern Pacific.

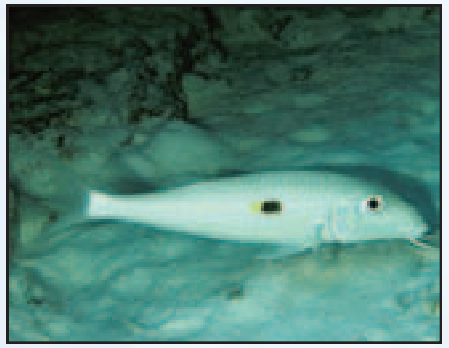
The Convict Surgeonfish (maximum size is 11 inches) is an herbivore browser feeding mainly on fine filamentous algae while avoiding ingestion of carbonate sand particles. It digests alga food mainly by acid lysis in a thin-walled and distensible stomach. This species is abundant in the lagoon and is one of the top ten fishery species consumed by residents of Johnston Atoll.



Goldring Surgeonfish *Ctenochaetus strigosus.* Kole Distribution: Hawaii and Johnston Atoll

The Goldring Surgeonfish (maximum size is 7 inches) is the most abundant species overall in the lagoon. All surgeonfishes are herbivores but differ in whether they also ingest sand. Species with thick-wall stomachs that ingest fine grain sand with algae are called grazers. Species that avoid sand ingestion and have thin-wall acidic stomachs are browsers. Since many contaminants adhere to sediments and are not dissolved in the water, grazers are predicted to show more bioaccumulation than browsers.

Goatfish are predators on very small fish, crustaceans and other animals that are usually found buried in sand. They use their specialized chin-barbels, which are covered with taste-buds to detect prey hidden in sand. There are a total of 7 species (2 genera) of goatfish at Johnston Atoll. These fish are a popular fishery species. Since these fish are predators on small critters that live and feed in sand, they should show effects of contaminant bioaccumulation. Also, since these fish are eaten by people, the presence of contaminants is a human health concern.

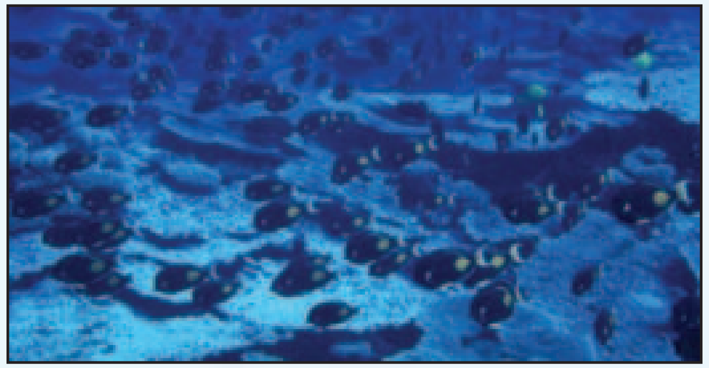


Yellowstripe goatfish, *Mulloidichthys flavolineatus*. Weke’a

Note - chin barbels extended as searching in sand for invertebrate prey. This species usually displays a black spot on its side, below the first dorsal fin.

Manybar goatfish, *Parupeneus multifasciatus Moano.* This species is one of the 10 most common species at Johnston Atoll.

Goatfish are predators on tiny shrimps, worms and crabs that dwell in the sand. These tiny invertebrates are exposed to any contaminants present. Thus, goatfish would show the effects of bioaccumulation, if such contaminants are present.



The coral reefs of Johnston Atoll have dense populations of fishes and corals.

Marine Ecological Studies

Johnston Atoll (JA) became a prime test site and staging area during the nuclear test era of the 1960s. The military counterpart of the Atomic Energy Commission, Joint Task Force Eight, conducted a series of atomic tests at JA starting in 1962. The test series, code-named DOMINIC, included four high altitude and five low altitude successful tests and three THOR missile misfires. Radioactive contamination of soil and sediments resulted from fallout (Wolf et al. 1997). The Defense Threat Reduction Agency (formerly the Defense Nuclear Agency) is currently conducting radiological studies of the islands and lagoon areas.

In 1971, the US Army began using 41 acres of Johnston Island for chemical weapons storage. These weapons included rockets, artillery shells, bombs and ton containers containing nerve and blister agents. Beginning in 1985, the mission of the US Army's Johnston Atoll Chemical Agent Disposal System (JACADS) has been the destruction of these chemical weapons, which comprised 6.6% of the United States' stockpile. JACADS completed destruction of all chemical weapons stored on the atoll in November 2000.

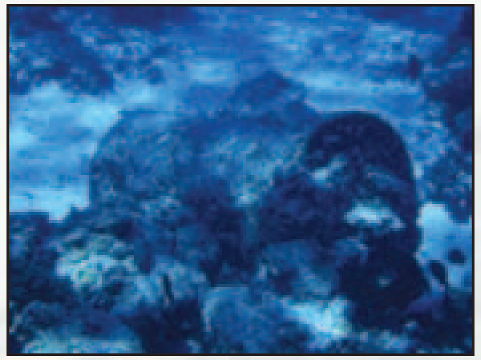
In 1972, the US Air Force (USAF) brought approximately 5.18 million liters of unused Herbicide Orange (HO or "agent orange"), from Vietnam to JA for storage. During redrumming operations an estimated 113,400 kg accidentally leaked onto the soil of the former storage site on the northwest corner of Johnston Island (VERSAR 1991). The HO stored at JA contained two active ingredients, the n-butyl ester of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), as well as the contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). This stock of HO was incinerated at sea in 1977 aboard the Dutch ship Vulcanus. Dioxin contamination of marine sediments was presumably caused by soil transport (wind or surface water runoff) and liquid seepage into the adjacent reef area. A newly constructed seawall (1995) surrounds the former HO storage site and was designed to prevent further transport from the soil to the lagoon.

The US Coast Guard (USCG) maintained a LORAN navigation station on Sand Island from the late 1950s until 1992. This operation contributed mainly PCBs and some heavy metals released from transformers and other electrical equipment, which were disposed in reef areas adjacent to Sand Island. The USCG has since removed all potential sources for hazardous materials.

Other military operations have contributed to the presence of contaminants in the lagoon, however, to a lesser extent. These include activities associated with the burning of refuse, fire training operations and storage of fuels. The solid waste burn pit (SWBP), located on the northwestern end of Johnston Island near the HO site, was used to burn combustible refuse generated from daily operations. Lead-acid batteries, paints and organic solvents were also disposed of at the SWBP. Lead-contaminated ash at this site was stabilized, removed and placed into an underground storage cell in 1995. JP5 fuel and other burnable liquids were dispersed at a fire training area located next to the SWBP and the HO areas.

Fuel storage tanks (above and below ground) located near the power plant in the mid-section of Johnston Island have been a source of petroleum hydrocarbons released into soil, groundwater and the lagoon. PCBs associated with this seepage were also detected in lagoon fishes. Active measures have been taken to control transport of these compounds into the lagoon.

Because of the public's concern for potential dioxin contamination resulting from certain types of incinerators, the US Army initiated an exploratory study of JA to determine ambient concentrations of dioxins in the marine environment. The concern was that dioxins and furans in stack emissions from the JACADS facility would eventually enter the lagoon. However, JACADS has an extensive pollution abatement system to avoid the formation of these emissions. Particular areas of concern were reefs located downwind of stack emissions from JACADS which are also adjacent to the USAF's former HO storage site. A few random samples collected in 1991 (13 sediment samples and 13 fish samples) revealed the presence of measurable quantities of various dioxins and furans (Lobel unpublished). Soon after, a debris field containing transformers was located off the north side of Sand Island. The USAF coordinated an interagency advisory panel to develop a sampling and analysis plan to map the distribution and concentrations of contaminants throughout JA. Because the former HO site was an obvious area of concern and overlaps with the Army's concern over the attribution to downrange stack emissions, the initial focus of the investigation was the evaluation of dioxin in reefs off Johnston Island's west end. Subsequent efforts have included the evaluation of metals, PCBs and PAHs in the marine environment.


This transformer is an example of some old military debris. All hazardous materials have been removed but some sediment contamination remains in a few limited areas.

Marine monitoring program - Introduction

Oceanographic and marine biological studies of Johnston Atoll were initiated in 1983 in order to specifically examine issues pertaining to the building and operation of the JACADS facility. The first studies were faunal inventories and overall assessment of the coral reef habitat. Oceanographic studies originally began to explore possible ocean dumping options, which were soon abandoned. In 1990, comprehensive studies of the fishes and coral reef community became the focus of the marine monitoring program.

One of the early tasks for the marine monitoring project was to document the status of the coral reef environment prior to JACADS operations.

Contaminants of concern include:

- Dioxin - only found in the nearshore area of former HO storage site.
- PCBs - found mainly in the nearshore areas of Sand Island and in main harbor.
- Metals – mainly found off the west end near old dumps.
- Plutonium – scattered in lagoon but mainly near the north shore of JA.

Some of the more interesting aspects and results of the marine monitoring projects that have been conducted over the years are highlighted in the following sections; however, this listing is by no means all inclusive. The marine monitoring program has mainly involved scientists and students from the Boston University Marine Program (BUMP) in Woods Hole, MA under the leadership of Professor Phillip Lobel. The research projects have been varied and with diverse scientific perspectives. The emphasis has been on quantitative documentation of contaminants in sediments and biota and an assessment of whether this has adversely impacted the coral reef ecosystem. As part of this overall project, many specific marine biological studies were conducted as means to best understand the ecology of JA's species. Periodic surveys were routinely conducted to monitor the marine environment for any warning signs of 'biological ills' (such as decreased reproduction or deformities in marine life). The main objective was to document as completely as possible the biological status of biota on JA. The following sections describe some of these studies.

Long-term Monitoring and Surveys of Johnston Atoll's Coral Reef Ecosystem

Although Johnston Atoll had been occupied by the DoD since the 1930s, no comprehensive survey of marine resources had been conducted until the JACADS project was planned. The purpose of the detailed resource inventory and survey was to document an ecological baseline and establish long-term monitoring sites within JA.

The first stage of this study was to determine the biodiversity of reef fish. The initial survey of reef fish populations was conducted in 1983 by John Randall (Bishop Museum, HI), Phillip Lobel (BUMP) and Edith Chave (University of Hawaii), and recorded 88 new species records to add to a total of 301 species.

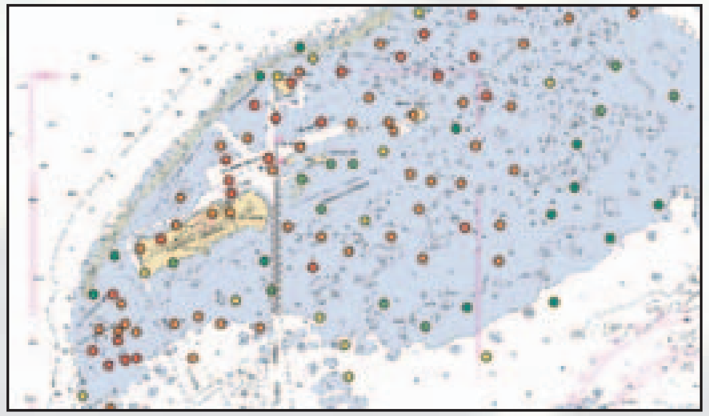
The second stage established a long-term monitoring program to detect fluctuations in fish populations. In 1984, prior to the construction and operation of JACADS, CMA sponsored an atoll-wide resource assessment conducted by members of the US Fish and Wildlife Cooperative Fishery Research Unit at the University of Hawaii. The purpose of this study was to characterize and describe the shallow-water ecosystem in an attempt to better assess its environment and resources. Dr. James Parrish (University of Hawaii) and his students conducted fish, invertebrate, and algal censuses at 113 sites across the atoll. These results serve as the ecological baseline of JA's marine environment prior to the commencement of JACADS activities.

In 2003, BUMP conducted comprehensive follow-up surveys of several sites from the 1984 study. The results from this study will be compared to the 1984 baseline study to determine possible changes to the marine environment since JACADS operations began. All surveys were conducted using underwater video equipment and will be archived into a video library. This will allow for future reef conditions to be directly compared with reef conditions in 2003. This study is being conducted by Jason Philibotte as part of his Ph.D. research at BUMP.


Green sea turtles are common in waters south of Johnston Island, where there is abundant macroalgae for them to eat.

Transect line used to conduct fish and invertebrate surveys. The beginning of the transect line is marked by the orange handle. Transect lines are used to standardize the amount of area surveyed. This allows scientists to estimate fish densities and compare these densities among sites.

Diver conducting an underwater video survey at Johnston Atoll. The video is then analyzed in the laboratory to determine reef fish population density and percentage of live coral cover.



Map of Johnston Atoll: Each dot represents a 1984/2003 survey site. Color of dot represents percent of coral coverage at that site. The highest percentage of coral cover (80-90%) is represented by the color red, and green represents the lowest percentage (10-20%) of coral cover.

Monitoring JACADS Using the Coral Reef fish, *Dascyllus albisella*

Research by Steven J. Oliver and Phillip S. Lobel

This is the domino damselfish, *Dascyllus albisella* (Pomacentridae). This species is one of the coral reef fish whose populations were monitored to assess possible adverse affects from military activities on Johnston Atoll.

Size, weight, and age distributions of a population can be used to indicate differences in the relative health of populations, reveal differences in habitat, and detect anthropogenic impacts on a population. Because of the nature of the military's mission at Johnston Island, there was concern over the ecological impact of JACADS. One method to monitor reef fish health is to measure the growth and health of individual fish (belonging to the same species) at the potential impact area and compared to control sites.

Two populations of domino damselfish, *Dascyllus albisella*, were tagged and measured to determine the size distribution of the fish uprange and downrange from the JACADS facility. The same individual fish were subsequently collected for final weight and length measurements to assess growth, age, and to assess any abnormalities (i.e., lesions, etc.).

Methods

During initial tagging, only standard length was measured. After fish were sacrificed at the end of the study, we measured standard length, greatest body depth, body width and weight prior to viscera removal, gonad examination and otolith extraction. A length to weight regression was calculated for all fish collected. Separate regressions were used to compare weight-length relationships between the downrange fish and those collected uprange. A difference in the regression slopes would suggest differences in the growth patterns of fish at these sites. Length distributions between males and females were compared to determine sex-based size differences.

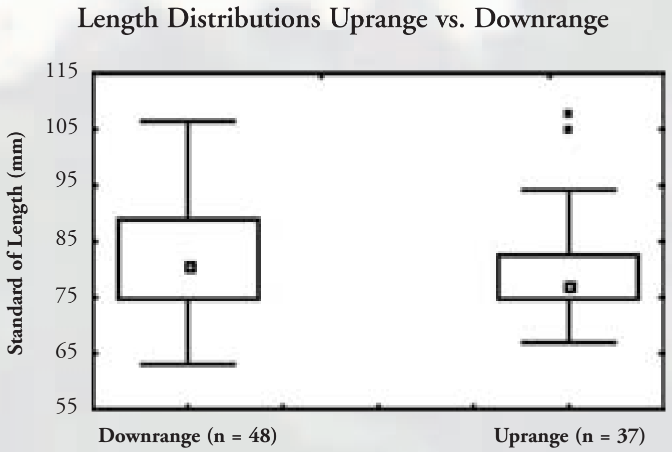
Otoliths (the fish's inner ear bones) were examined to determine the age of fish. Otoliths were extracted from both males and females at each of the study sites. Correlations of age versus length and age versus weight were calculated to determine if there was a significant relationship.

Fish used in the study were measured at the time of tagging and re-measured when they were collected at the end of the study. Fish that were measured over intervals of greater than 200 days were used to estimate adult growth rates. Fish measured over shorter intervals were excluded because the estimation of yearly growth rate from short growth intervals tends to overestimate rates.

A population of the domino damselfish, *Dascyllus albisella* at Johnston Atoll. This species is often found in colonies that use giant corals as their home. Adult domino damselfish are about 4 to 5 inches in length. The coral shown here is the antler coral, *Pocillopora eydouxi.* Its dimensions are approximately 30 inches tall and 48 inches diameter. A domino damselfish colony usually contains more females than males. This fish is distinctive due to its conspicuous behavior of producing loud sounds while males swim in a courtship "dance". These sounds were monitored as a method for measuring the male's reproductive activity patterns.

Preliminary Results

There was no difference between uprange and downrange sites for length of males (t-test for independent samples: t-val. = 0.71, p=0.49, d.f.=29; see graph below) or females (t-val. = 0.297, p=0.767, d.f.=36). There was likewise no difference between uprange and downrange for weight of males (t-val. = 0.935, p=0.34, d.f.=22) or females (t-val. = 0.259, p=0.71, d.f.=20). Males were significantly larger than females (mean ± SD = 88.0±8.75 mm SL versus 77.5±8.98 mm SL; t-test for difference of means - t-val = 4.84, d.f. = 66, p<0.001).



Distributions of fish standard lengths from uprange and downrange sites. There was no significant difference between the two groups (t-test for independent samples: t-val. = 1.94, p=0.055, d.f.=83).

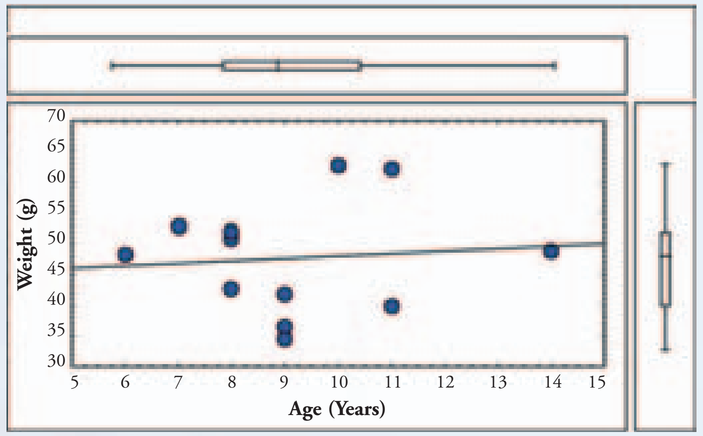
Feeding behavior showed no differences between uprange and downrange sites in total proportion of time spent feeding (t-test; p=0.401 d.f.=56). There were no significant differences in courtship rates, the timing of spawning, the sex ratio, the size of clutches laid by females, egg survival, or territorial behavior. In all categories, populations located uprange vs. downrange were the same.

Gross histological study showed no tumors, abnormalities, or growths (inside or outside) in any of the fish from any of the sites.

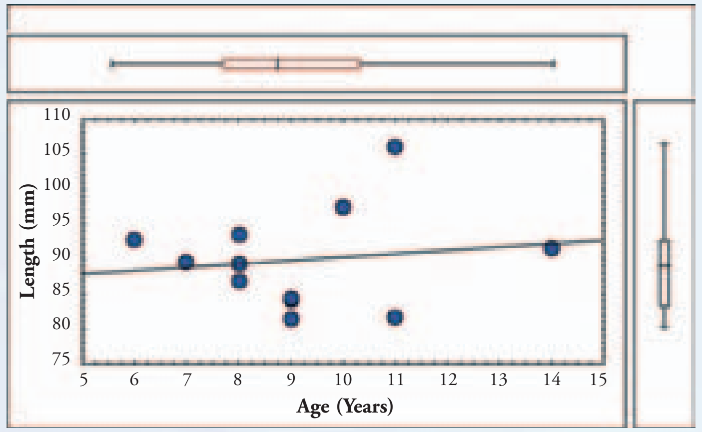
There is a significant relationship of length to weight for all fish (r^2=0.899, p<0.001, n=86; see plots on page 30). The relationship holds for males (r^2=0.895, P< 0.001, n= 23) and females (r^2=0.87, p < 0.001, n = 22), and there are no significant differences between the r-values for males and females (p=0.465). Boxplots for weight and length show a few large males as outliers, which suggests that very large males are rare.

There was no difference between the regression coefficients for fishes from the downrange site and the uprange sites. There was no relationship between age and weight (r2= 0.009, p= 0.772, n=12; see plot A on page 30) or age and length (r= 0.021, p =0.656, n=12; see plot B below). While age and size (both in terms of weight and length) are related during the early stages of life (from recruitment to juvenile stages), the trend does not seem to continue through the adult phase of life. Our sample sizes are small, but they suggest little direct relationship between age and size among adult male *D. albisella*.

Scatterplot A. Age vs. Weight



Scatterplot B. Age vs. Length



Scatterplot of size versus age for the males at the down range site. Boxplots show distributions of the data. A. Age versus Weight. B. Age versus Length

Conclusion

There are a number of anthropogenic pollution sources on JA that could adversely impact reef fish populations. When populations are under different ecological regimes, their population size structure can reflect this exposure. Anthropogenic impacts can drastically alter both growth patterns and the weight-length relationship of an exposed population. The distribution of sizes in a population reflects the pattern of growth and mortality for that particular species. Based on this study of *D. albisella*, there is no evidence of such effects. For every phenotypic, behavioral, and reproductive trait measured, there was no difference between that seen at the downrange site compared to the uprange site. There were no significant differences in the slope of weight-length regressions for uprange versus downrange. No fish displayed any evidence of lesions, tumors, or other abnormalities. Males were generally larger than females at both sites. The largest males at the uprange sites were relatively larger than average compared to the males at the downrange site. This may reflect monopolization of food resources (i.e. plankton) by larger males at the upcurrent end of the atoll where food is more plentiful.

Ciguatera Ecology of Johnston Atoll

Research by Mindy Richlen and Phillip S. Lobel

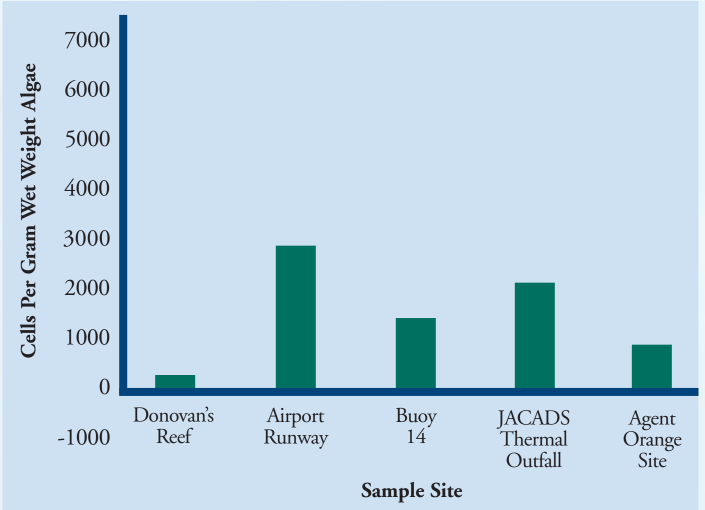
Ciguatera is the most common type of marine food poisoning, affecting as many as 50,000 individuals annually. The toxins that cause the disease are produced by benthic dinoflagellates that live on the surface of macroalgae and areas of dead coral. Herbivorous fishes that feed on macroalgae accumulate the toxins produced by the dinoflagellates in their tissues. As predators consume the herbivorous fishes, the toxin levels are concentrated, making these fishes much more toxic. Poisoning is caused by the consumption of certain coral reef fishes, particularly those from higher trophic levels, such as jacks and snappers. The disease causes gastrointestinal, neurological and cardiovascular disturbances and is occasionally fatal.

Gambierdiscus toxicus, the most significant toxic dinoflagellate in ciguatera ecology, from macroalgae sample collected at Johnston Atoll in 2003.

Much is still unknown about the environmental conditions that precipitate outbreaks or why fishes from some reefs are highly toxic, while others are not. One of the most interesting and consistently observed factors associated with outbreaks are physical disturbances of reef systems by natural events such as hurricanes or by human events such as construction, dredging, and explosions. As such human impacts are commonly associated with military activities, installations such as JA are particularly relevant to the study of ciguatera ecology.

Research into ciguatera poisoning on JA commenced in 1951 with a reef fish survey by Halstead and Bunker to investigate frequent poisonings of the civilian workers. They found that near half of the fishes at Johnston Atoll were toxic. In the years following, the Johnston Atoll clinic reported cases of ciguatera poisoning by island residents after eating fishes caught in the lagoon. In May 1990, a random sampling of 13 algal samples collected by Dr. Phillip Lobel from shallow water near the JACADS plant and near the JOC building found numerous ciguatera dinoflagellates. To further evaluate the abundance and distribution of ciguatera dinoflagellates at JA, macroalgae was collected as part of a comprehensive marine monitoring program to assess populations of key toxic dinoflagellates. Several sampling sites throughout the atoll were selected and dinoflagellate populations were monitored from 1990-1992.

An example of the data collected is provided in the table below. As evidenced by this particular summary, although high numbers of dinoflagellates were found in some areas, no significant difference was found among the sampling sites.



Number of ciguatoxic dinoflagellates on macroalgae (1990 Survey).

Because of the threat ciguatera poses to human health, the DoD coral reef assessment program is sampling ciguatera dinoflagellates as part of a comprehensive ecological evaluation to obtain a better understanding of the population ecology and broad distribution of ciguatera across DoD sites. The ecology of ciguatera on JA is currently under study by Mindy Richlen from Boston University as part of her PhD thesis. In addition to examining the population distribution of ciguatera dinoflagellates, she is investigating abundances in areas of heavy wave action, focusing on regions on or near the reef crest.

Sampling macroalgae *Caulerpa serrulata* at Johnston Atoll.

Biogeography of Johnston Atoll

The biogeography of certain coastal marine animals supports the hypothesis that Johnston Atoll is included with the Hawaiian Islands in a definable ocean circulation system. These data are by no means conclusive but they emphasize the probability of a regular current pattern system connecting Hawaii to Johnston Atoll. The close connection between JA and Hawaii is evident in the biogeography of shore fishes and reef corals. The majority of JA species are Hawaiian although some Line Islands species occur at Johnston Atoll but not elsewhere in Hawaii. When one examines the distribution of Hawaiian endemic fish species and subspecies with their closest relatives from the Line Island (N=11 sibling species pairs), with only one exception, the result is that the Hawaiian form has colonized JA, not the Line Islands form. Only 10 non-Hawaiian fish species compared to 48 endemic Hawaiian species occur at JA.

One intriguing aspect of fish spawning patterns in Hawaiian waters is in its potential relationship to ocean current patterns. The fact that 29% of Hawaiian shore fishes (approximately 460 spp.) are taxonomically recognized as endemic species emphasizes their restricted biogeographic distributions. Given that many of these species have planktonic larval phases lasting to three months, it is enigmatic how these fishes remain restricted to Hawaiian waters. Furthermore, not all islands around which endemics are found are near each other. JA's coral species are also predominantly Hawaiian. Johnston Atoll is situated about 800 miles southwest of the nearest reefs in Hawaii and over 900 miles from other reefs to the south and west. It is one of the most isolated atolls in the world. It does, however, sit within the domain of an Archipelago-sized gyre feature during March-April.

Two pieces of additional evidence suggests a path of current drift between the Hawaiian Islands and Johnston Atoll. Flow from the main islands to the atoll was suggested by finding kukui nuts on JA beaches. These nuts had clearly been adrift at sea before being washed ashore (samples have been preserved). Kukui nuts were found during each of three field trips in 1983-84. The only known sources in the North Pacific are the main Hawaiian Islands. Biogeographical data suggesting current flow from JA to the northwest Hawaiian Islands is supported by populations of an Acropora coral living at French Frigate Shoals and nearby reefs. These coral populations did not appear to be sexually reproductive, probably deriving from larvae spawned at JA. The key point is that for such close faunal affinities to occur between JA and Hawaii, currents must exist which transport pelagic larvae from one location to the other. Prevailing currents from other directions could have connected JA to several other island groups each with their own distinct fauna, but apparently this has not happened.

Endemics

There are certain fishes which have populations restricted to Johnston Atoll. These are called “endemics”. These fish are of special interest because any adverse ecological impacts would affect their species survival.

The flame angelfish, *Centropyge loricula*, is a species with a broad distribution in the Pacific but the Johnston Atoll population appears to be distinctive in coloration. Scientists once considered it a separate species and named it *C. flammeus*. BUMP scientists are using new molecular DNA techniques to determine if this species is in fact unique to Johnston Atoll.

The rainbow angelfish, *Centropyge nahackyi*, is a species found only on Johnston Atoll, and is the atoll’s most unique species. Any impacts to the marine environment would directly affect this species survival.

This fish is a very special case - it is in fact a hybrid between a species found only in Hawaii (i.e., a Hawaiian endemic) and its sister species found elsewhere in the Pacific. At Johnston Atoll, both parent species’ co-occur and the populations hybridized. This species’ ecology is being studied as a unique example of a rare evolutionary situation whereby a new species may originate by hybridization and subsequent population isolation. This study is by P. Lobel and J. Randall (Bishop Museum) and students.

A test of the question “Are Johnston Atoll fish populations isolated?” using damselfish larvae from Hawaii and Johnston Atoll.

The majority of reef fishes have a planktonic larval phase with durations in the pelagic ocean habitat ranging from a few weeks to months. The pelagic larval duration (PLD) is an important factor associated with biogeographic distributions of reef fish populations. The key question is: to what degree are larvae passively carried and distributed by ocean currents or are larvae somehow retained near natal habitats? The importance of determining population distributions is to assess the degree of risk to a population that may be impacted by local adverse ecological impacts. In other words, estimating ecological risk depends in part on determining what percentage of a population is likely to be exposed? Thus, if a population is restricted to just JA, it is at greater risk from local sources of pollution or other impacts than if fish larvae are regularly derived from adult populations living in Hawaii or elsewhere.

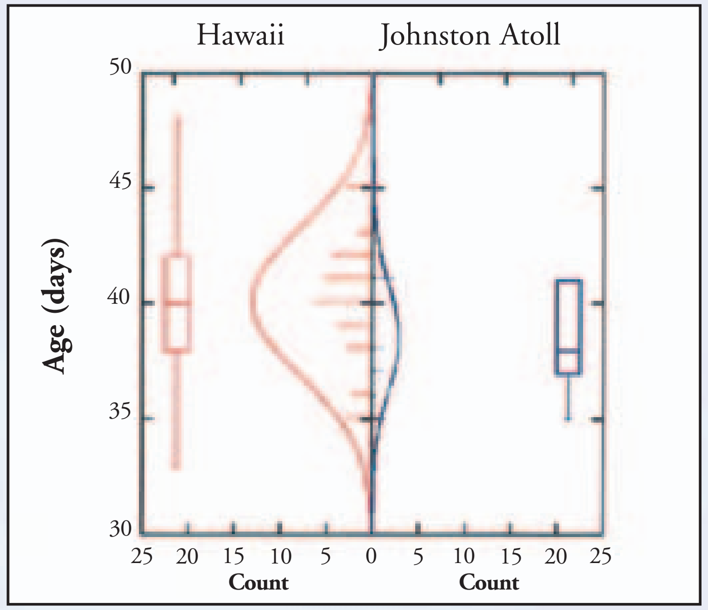
In this study, the ages of settlement stage larvae of the bright-eye damselfish, *Plectroglyphidodon imparipennis* (Pomacentridae) collected near JA and Hawaii were compared. If the source of recruitment of fishes to JA is from the Hawaiian Islands, then the pelagic larval durations of those larvae collected from JA should be longer than those collected near their point of origin in Hawaii. If larvae spawned locally on JA and Hawaii are retained near their natal habitats and recruitment is from the local population, then the PLD’s from both locations should be very similar. Both Hawaii and Johnston Atoll have mesoscale eddies and other current patterns that may enhance local retention of ichthyoplankton.

Plectroglyphidodon imparipennis is a small omnivore common on shallow reefs. The species has a very broad tropical distribution from Eastern Africa to Hawaii, the Line, Marquesan and Pitcairn Islands; north to the Ryuku and Bonin Islands; south to New Caledonia and Rapa; throughout Micronesia and the Indonesian archipelago. The color pattern of this species varies geographically.

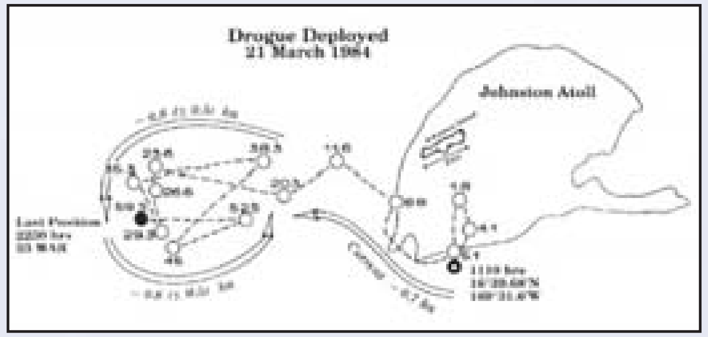
Settlement stage larvae were collected by “nightlighting”; a bright light was suspended in the water near the surface. Larvae attracted to the light were caught in a handnet and then preserved in 90% ethanol. Hawaiian larvae were collected from 20 February 1982 to 30 June 1982 within 5 miles of the coastline from Kailua-Kona to Keahou Bay, Hawaii. JA larvae were collected on 5 September 1983 also within 5 miles. Larval age was determined from otolith ring counts using the sagittae and/or lapillae. The highest ring count from a fish’s otoliths was used as its age value (days).

The drift time for a passive larva to be transported from Hawaii to JA may range from 74 to 104 days (average 92 days). During the later developmental stages of post flexion and settlement stage, fish can swim actively. Assuming active swimming accelerates the trek; larvae arriving on JA from Hawaii would still be expected to be at least a few weeks older than the local Hawaiian population. This assumes that there is a minimum developmental time until the larva reaches the settlement stage and that these fish are motivated to swim to the reef habitat at their earliest opportunity.

The pelagic larval duration was estimated from otolith ring counts which are assumed to be daily growth increments as found in other pomacentrids. The average age of larvae collected from Hawaii (N = 62) was 40 days ± 3 sd (range 33 to 48) and from JA (N = 10) was 39 days ± 2 sd (range 35 to 41). The maximum age for larvae collected from Hawaii was compared to larvae from JA using a two-sample t-test (SYSTAT 6.0). Two tests were computed for comparing group means: the pooled variance t-test ($t = 1.528$, $df = 70$, $p = 0.131$) and the separate variance t-test ($t = 1.908$, $df = 15$, $p = 0.076$). The difference between the means was 1.597. The pooled test assumes population variances are equal whereas the separate variance test does not make this assumption. Results of both tests p indicate no significant difference in the age of settlement stage larvae collected from Hawaii and JA.



Comparative Otolith ring counts = age (days). Age distribution of settlement stage larvae collected from Hawaii (N = 62) and Johnston Atoll (N = 10). A dual plot showing each datum; normal curve calculated using the sample mean and standard deviation is shown on the center vertical axis and a box plot displays sample median, quartiles and outliers.



Surface current drogue offshore Johnston Atoll. A current drogue track, deployed March 1984, showing circulation in a cyclonic ocean eddy. Position numbers are elapsed hours since deployment. A drogue is a drifting buoy and its trajectory illustrates what path a floating fish larvae may take when dispersed from the atoll. In this example, it shows that a larva may be entrained in an eddy current keeping the larva in deep ocean but near the atoll. This would make it easier for a fish larva to eventually migrate back to the lagoon.

Conclusion

The conclusion is that the settlement stage *P. imparipennis* collected offshore JA were probably originally spawned there. Research into this question using new genetic methods is being continued by Lobel and BUMP graduate student, Jason Philibotte and BUMP Assistant Professor, Paul Barber.

This research was published in
Lobel, P.S. 1997. Comparative settlement age of damselfish larvae (*Plectroglyphidodon imparipennis*, Pomacentridae) from Hawaii and Johnston Atoll. *Biological Bulletin* 193: 281-283.

An adult *Plectroglyphidodon imparipennis*, adult approximately 2 inch length.

Plectroglyphidodon imparipennis, settlement stage lava, approximately half inch length.

Monitoring Johnston Atoll top predator – the Grey Reef Shark

Research by P. S. Lobel & Lisa Kerr Lobel

This study was part of the environmental risk assessment investigation that was conducted to evaluate the possible environmental impacts potentially resulting from 1) the runoff of dioxins and other contaminants from the former HO storage site and 2) from the operations of the JACADS facility. Shark tissues were analyzed for the presence and concentrations of a variety of contaminants. Contaminants were previously found present in fishes that are common shark prey including parrotfishes and surgeonfishes. A tracking project was conducted to document the movement patterns of some individual sharks to determine their exposure to the HO site and downrange of the JACADS plant.

Preliminary analysis of contaminants in sharks at Johnston Atoll.

Samples from the grey reef shark, *Carcharhinus amblyrhyncos*, were analyzed for PCBs, dioxins, and furans to examine the extent of bioaccumulation in this top predator at JA. Four females were collected from an aggregation that occurs annually off of Sand Island. All four sharks were pregnant, ranging in size from 154 to 173 cm TL. Liver samples were analyzed for the presence of 25 specific PCB congeners and 17 dioxin or furan congeners. Total PCBs in liver ranged from 131.0 to 946.0 ng/g. PCB concentrations in Johnston Atoll shark tissues are lower than found in sharks from other studies (San Francisco Bay, New York). Toxic equivalents (TEQ) for 2,3,7,8 tetrachlorodibenzo-p-dioxin in shark liver ranged from less than 0.001 to 77.910 pg/g. Bioaccumulation of dioxin in Johnston shark muscle tissue is higher than dioxin in muscles of sharks reported in other studies (San Francisco). The sharks and their prey are attracted to the food disposal site near a dioxin contaminated area. Sharks may be spending more time in this area and therefore feed on more contaminated fish than would be expected, possibly explaining the high dioxin tissue concentrations. Contaminants were also measured in muscle tissue and embryos of two sharks that had developmental defects. One adult shark was missing a gill arch on one side while another shark contained an embryo with a deformed vertebral column. A third shark contained an embryo that had ceased developing at the four-cell stage. The extent to which these abnormalities normally occur is unknown.

Behavioral ecology of sharks at Johnston Atoll

The work on JA provides a unique understanding on the behavioral dynamics of *C. amblyrhynchos* migrating to and from the female's aggregation site along with interactions among other shark species on an atoll.

Female Gray Reefs, *C. amblyrhynchos*, aggregate in shallow water off of Sand Island during late February – March, April and May. The sharks arrive at the shallow reef site in late morning and depart in late afternoon (See table below). Very little is really known about the reasons for this behavior but it is generally suspected to be associated with a phase in their reproductive cycle.

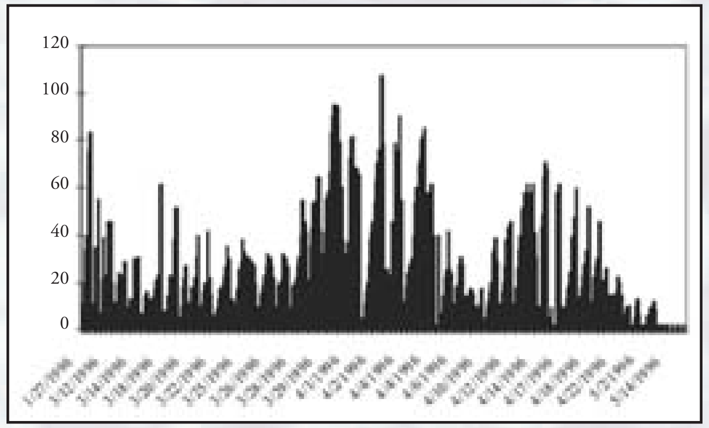
Prior study has revealed that for grey reef sharks on JA:

1. Only females aggregate at the Sand Island site.
2. Aggregations occur starting from mid February to mid-late March and continue until late May or early June.
3. Individual females return to the aggregation daily, at least over a several day period.
4. Females return individually or in pairs, trios and rarely in larger sub groups of more than four individuals.
5. It appears that some females in the aggregation are relatively small size and without swollen abdomens while others are larger and full bodied, possibly indicating internal embryo development (but this needs to be ascertained by sampling).

This research is aimed at understanding the basic reproductive and social biology of the grey reef shark. The following questions are of special interest:

- Are all sharks at the aggregation site female?
- What is their reproductive status?
- Where do they go when not at the aggregation site?
- Do the same individuals return daily and annually?
- Is the same pattern of aggregation repeated annually?
- Why do they aggregate when and where they do?

Maximum daily number of female grey reef sharks at the aggregation site January 27 – May 14, 1996



The pattern of daily numbers of individual female grey reef sharks at the aggregation site off Sand Island. Some days there are in excess of 100 sharks at the site, other days there are only a few. Our research is trying to determine why.

The results of this research are to be applied to understanding the behavior and ecology of a top-level predator as part of an ecological monitoring and environmental impact assessment study. The key question is "What is the biological and ecological impact of contaminants in the atoll?"

A male grey reef shark.

Female grey reef sharks at the aggregation site.

Biomonitoring Using a Coral Reef fish

Research by Lisa Kerr Lobel and P. S. Lobel

One of the most innovative results from the JACADS sponsored marine ecological research of JA is the development of a biomonitoring tool using reef fish development to detect anthropogenic impacts. This method involves monitoring populations of damselfish, spawning in the field, in areas that are potentially "impacted" by chemical contamination as compared to "non-impacted" areas. This method measures both reproductive and developmental parameters which are among the most sensitive to chemical pollution.

The blackspot sergeant major damselfish (*Abudefduf sordidus*), a common fish found on reefs throughout the Indo-Pacific is used as the “indicator” organism for two reasons: 1) it has a high potential for exposure to contaminants through its diet, and 2) it lays eggs in a conspicuous nest that is easy for divers to monitor and sample. This species seems to “prefer” artificial structures for its nesting sites and can befound spawning on pier pilings, cement blocks, and even in old 55 gallon drums. Samples of fertilized eggs (embryos) are collected from the field and quantitatively examined for developmental defects. The level of developmental effects is correlated with the level of environmental contamination.

The method of examining fish embryos for developmental defects and relating the level of effects observed to contamination has been used extensively in temperate habitats. However, this is the first application of this technique in tropical environments. Most importantly, this monitoring method is relatively “low tech” and only requires a good quality microscope. This particular damselfish has close relatives on reefs in the Caribbean so similar monitoring could be conducted there as well. Current work includes expanding the embryo monitoring to other reef fish species.

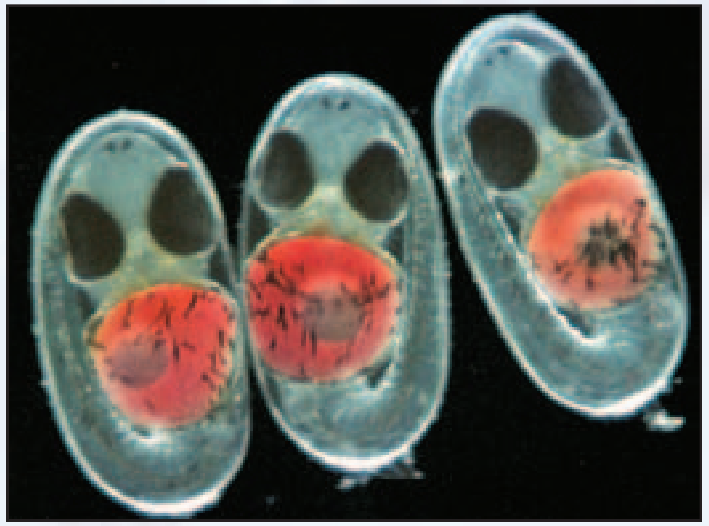
The ongoing study at JA is specifically examining PCB accumulation and the occurrence of embryonic abnormalities in the damselfish, *Abudefduf sordidus*, from PCB contaminated and uncontaminated sites within the atoll. This PCB contamination was derived from old transformers and other electrical equipment which were dropped in the lagoon long before environmental awareness and laws were in effect. This research was conducted to determine just how much PCB pollution there is at JA and whether it causes lasting damage to the coral reef ecosystem. This research also established the necessary baseline and establishment of environmental conditions that could have otherwise have been confused with JACADS affects. No adverse marine ecological impacts have been detected that have been directly linked to JACADS operations.

Damselfish developmental anomalies were assessed using embryos collected in the field during four natural spawning seasons (1996, 1998, 1999, and 2001). Laboratory incubations of abnormal embryos demonstrated that the abnormalities observed were lethal. PCBs were measured in fish collected in three years. Mean whole body concentrations of total PCBs ranged from 364.6 to 138,032.5 ng/g lipid. A significant residue-effect relationship was found between total PCB concentration and embryo abnormalities. The occurrence of embryo abnormalities was positively related to fish PCB concentration. This study provides baseline monitoring criteria and evaluates sediment quality benchmarks used for ecological risk assessments on coral reefs.

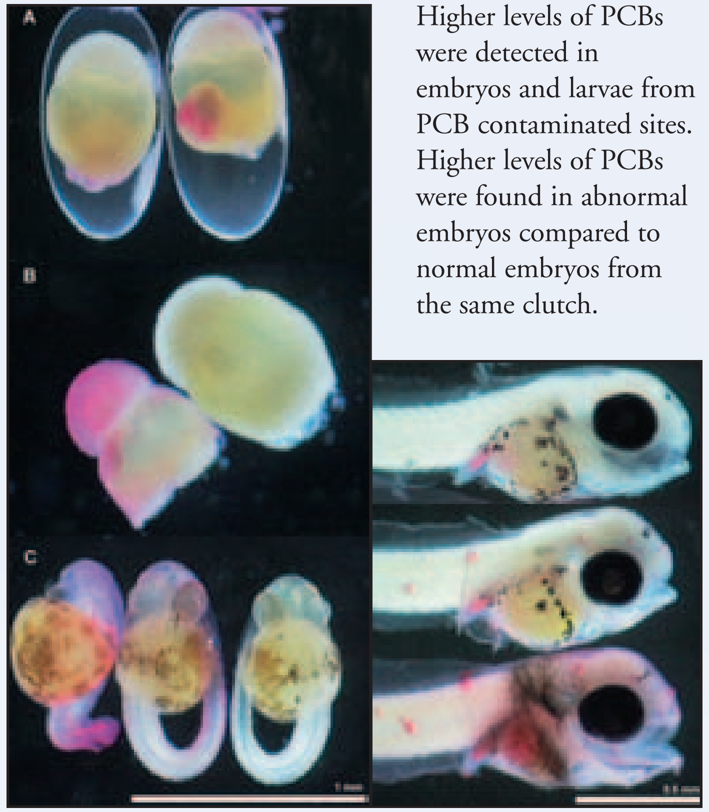
This method which was developed primarily by Lisa Kerr Lobel with support from CMA, USAF and USCG has been listed as one of the newest innovations in the development of diagnostic monitoring/biocriteria tools for coral reefs, see: www.epa.gov/owow/oceans/coral.

Adult male blackspot sergeant major damselfish, *Abudefduf sordidus*.

Most coral reef fishes have a larval stage where they develop in the open ocean before returning to the reef as juveniles. Once these embryos hatch, the 3 mm long larvae will spend at least 20 days in the open ocean. The early life stages of coral reef animals (embryos and larvae) are extremely sensitive to environmental changes including chemical pollution.

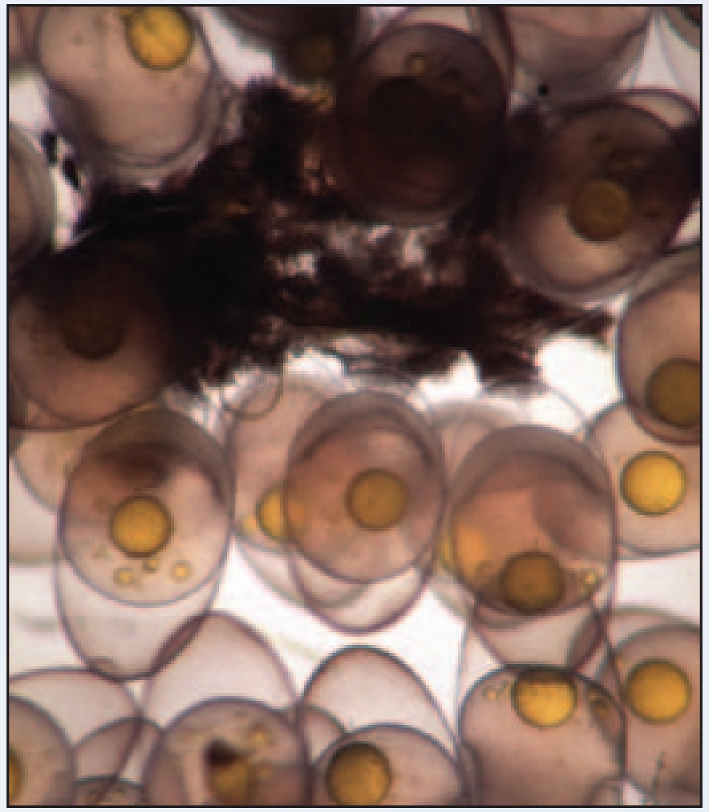


Five day old damselfish embryos.

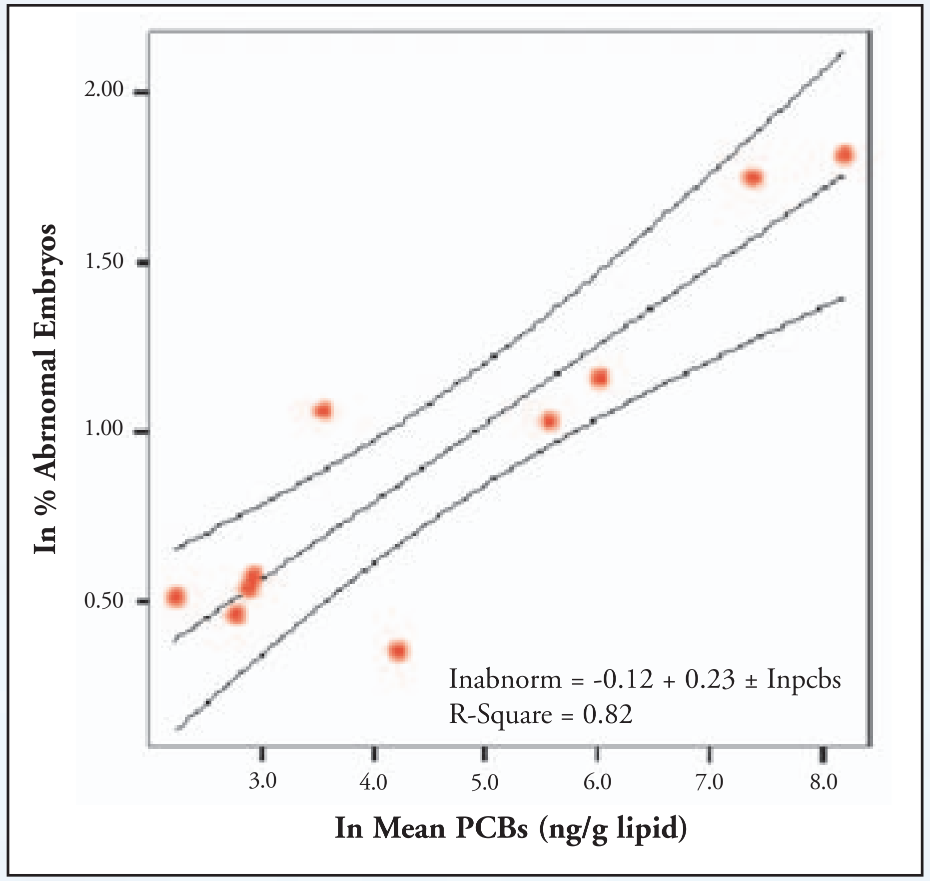


Higher levels of PCBs were detected in embryos and larvae from PCB contaminated sites. Higher levels of PCBs were found in abnormal embryos compared to normal embryos from the same clutch.

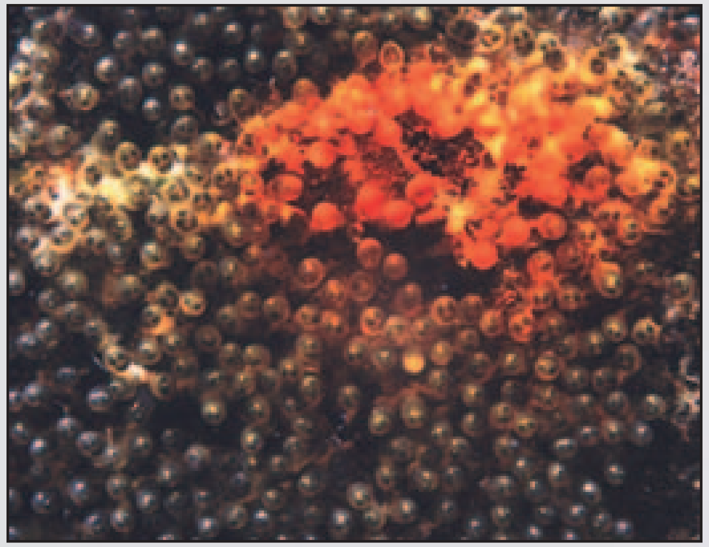
Anti-PCB immunohistochemical staining in damselfish embryos and newly hatched larvae. Pink color shows PCB location and relative concentration. Methodological staining occurred in the gut of all larvae.



Eggs of the damselfish, *Abudefduf sordidus*.



A significant residue-effects relationship was found between fish PCB concentrations and the level of observed embryonic abnormalities.



Damselfish embryos. The orange coloration shows the effects of rust on these eggs laid on old metal debris in the lagoon.

For published details of this research see

Kerr, L. M. 1996. Developmental defects in damselfish (*Abudefduf sordidus*, Pomacentridae) embryos from metal artificial reefs. Biological Bulletin 191: 306-307.

Kerr, L.M., K.L. Lang and P.S. Lobel. 1997. PCB contamination relative to age for a Pacific damselfish, *Abudefduf sordidus* (Pomacentridae) *Biological Bulletin* 193: 279-281.

Kerr, L.M., P.S. Lobel and J.M. Ingoglia. 1999. Evaluation of a reporter gene system biomarker for detecting contamination in tropical marine sediments. *Biological Bulletin* 197: 303-306.

Kerr Lobel, L.M. and E.A. Davis. 2002. Immunohistochemical detection of polychlorinated biphenyls in field collected damselfish (*Abudefduf sordidus*; Pomacentridae) embryos and larvae. *Environmental Pollution* 120(3): 529-532.

Lobel, P.S. and L.M. Kerr. 1999. Courtship sounds of the Pacific damselfish, *Abudefduf sordidus* (Pomacentridae). *Biological Bulletin* 197: 242-244.

Lobel, P.S. and L.M. Kerr. 2002. Status of contaminants in Johnston Atoll lagoon sediments after 70 years of US military activity. Proceedings of the 9th International Coral Reef Symposium. Bali, Indonesia 23-27 October 2000. Vol 2. pp. 861-866.

Results of the Atoll Wide Survey to Assess Contaminants in Marine Sediments

A total of 216 samples were collected at 13 locations during 1994 and 1995 within Johnston Atoll (See map on page 39). Analyses for each sample were selected based upon the potential for a particular contaminant to occur at a particular site and specific concerns of the military party responsible for that site. For example, the herbicides found in HO were only expected to be found near the area where HO had been stored. However, reference sites at other atoll locations were also chosen for these compounds for comparison. Therefore each sample at each site did not have every analysis performed.

Concentrations of metals were generally low with antimony, arsenic, cadmium, chromium and mercury concentrations all falling below screening levels for marine sediments (See table on page 40). Lead and zinc were each found in one sample exceeding the screening guidelines. Copper exceeded its screening guideline in two samples. Barium was found in 99% of sediment samples and exceeded the screening guideline (AET of 48 µg/g) in 53 samples (50%). Cadmium was not detected in any of the samples. PCBs were detected in most of the samples analyzed, but concentrations were generally low except for eight samples (14.5%) collected from Sand Island (sites 6,7) that exceeded screening guidelines. PAHs were detected in 30% of the samples with two (2%) of these detections exceeding the screening guideline for total PAHs. Herbicides were only detected in one sample. Dioxins and furans were detected in 80% of the samples although the majority of the detections were at fairly low concentrations. Dioxin/furan concentrations, expressed as TEQ, exceeded the screening guideline of 3.6 pg/g (AET) in nine (9%) samples. The most toxic dioxin isomer, 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) was detected in 28% of the samples. Contaminant distribution varied by site across the atoll (See tables on page 41 and 42). In general, sites with no known sources of contamination had low levels of metals and organics (sites 1,2,3,8,9). Metals at these sites usually included barium, chromium and zinc. However, lead or arsenic was sometimes detected. Organic contaminants at sites with no known contaminant history included low levels of PCBs, and PCDDs/PCDFs in some samples. TCDD was not detected at any of these sites. PAHs were only measured at two sites with no known contaminant history (sites 1,8). No PAHs were detected at site 1 while PAHs were detected but below quantification limits at site 8.

Collecting fish samples in tidepools.

Schematic map of Johnston Atoll sediment sampling sites. Atoll is outlined at the 10 fathom contour. Islands are shaded gray with sample sites in black.
Sample sites are:
1) Donovan's Reef
2) East Island
3) Tug Boat
4) Tall Aid to Navigation
5) Short Aid to Navigation
6) West Sand Island
7) East Sand Island
8) Buoy 14
9) Buoy 22
10) Herbicide Orange Site
11) Site 4
12) Site 3
13) West Camera Stand

A shipwreck from past military activities.

In comparison, metal and organic detections at sites with known or potential contaminant sources (sites 4,5,6,7,10) were higher. Additional metals including antimony, copper and mercury, as well as higher concentrations of barium, lead, zinc, chromium, and arsenic were detected at sites with known contaminant sources. High concentrations of PAHs were detected at the HO site along with high levels of TCDD. Reef sites along the west end (sites 11,12,13) were potentially impacted by contaminants from JACADS fallout. However, metal and organic contaminant concentrations in sediments from these sites were comparable to sites with no known contaminant history.

The interagency research team for sampling sediments and biota to test for contaminants, February 2003. From left to right standing Mindy Richlen (BUMP), Mark Ingoglia (USAF), Jason Philibotte (BUMP), Phillip Lobel (BUMP), Lisa Lobel (BUMP), Maya Rose Lobel (baby). From left to right sitting Gary McCloskey (CMA), Janelle Morano (BUMP) and Ray Saracino (EPA).

Summary of analyses completed on Johnston Atoll marine sediments showing average, minimum and maximum contaminant concentrations as well as the number of samples exceeding screening guidelines across the atoll. Average, minimum and maximum concentrations were calculated using only those samples with detectable concentrations. Screening guidelines are from the NOAA SQuirTs website.

Analyte	Total # Samples	% Detections	Average Conc.	Minimum Conc.	Maximum Conc.	Screening Guideline	# Samples Guidelines
Organics (ng/g)*							
PCBs	85	87	39.8	0.4	389.0	22.7	8
PAHs	105	30	589.6	9.2	7243.0	4022.0	2
2,4-D	87	1	–	6.5	6.5	NA	–
2,4,5-T	87	1	–	24.0	24.0	NA	–
TEQs (pg/g)	105	80	11.849	0.001	901.286	3.6	9
TCDD (pg/g)	105	28	25.210	0.615	901.000	3.6	9
Metals (µg/g)							
Antimony	100	16	0.7	0.2	1.8	9.3	0
Arsenic	205	47	0.6	0.2	2.3	8.2	0
Barium	105	99	76.8	3.2	294.7	48.0	53
Cadmium	205	0	ND	–	–	1.2	0
Chromium	105	81	8.9	3.5	60.1	81.0	0
Copper	205	21	11.5	1.1	171	34.0	2
Lead	205	24	19.6	1.6	82.6	46.7	1
Mercury	205	8	0.02	0.005	0.078	0.15	0
Zinc	205	82	14.9	1.2	163.3	150.0	1

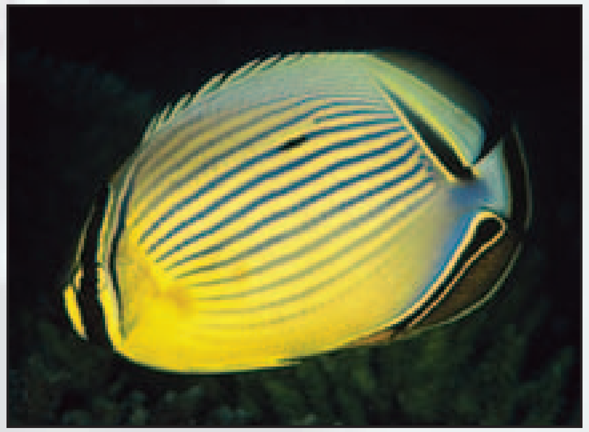
ND – none detected NA – not analyzed * note that units for TEQ and TCDD are pg/g

Belted Wrasse, *Stethojulis balteata.*

Distribution and concentration of organic constituents (A; mean ng/g (range)) including total organic carbon (TOC) and metals (B; mean µg/g (range)) in Johnston Atoll lagoon sediments by site. Mean and range are calculated only for samples with detectable concentrations. Sample sizes (N) for metal analyses are the same as for the organic analyses. Sample sites are shown in map on page 39. For details see Lobel and Kerr Lobel 2002.

A - Organics

Site	N	PCBs	PAHs	TCDD (pg/g)	TCDD TEQ (pg/g)	2,4-D	2,4,5-T	TOC (%)
1	5	NA	ND	ND	0.003 (0.0022 – 0.0034)	ND	ND	0.18 (0.12 – 0.22)
2	2	0.7 (0.4 – 1.0)	NA	NA	NA	NA	NA	NA
3	2	0.6 (0.4 – 0.7)	NA	NA	NA	NA	NA	NA
4	5	1.3** (1.0 – 1.7)	NA	NA	NA	NA	NA	0.14 (0.12 – 0.15)
5	4	1.2** (0.9 – 1.5)	NA	NA	NA	NA	NA	0.17 (0.13 – 0.21)
6	55	35.7 (0.6 – 389.0)	NA	NA	NA	NA	NA	0.10 (0.06 – 0.16)
7	14	0.4 (0.2 – 0.8)	NA	NA	NA	NA	NA	46.4 (2.2 – 171.0)
8	2	0.45 (0.4 – 0.5)	J	ND	0 – 0.001	NA	NA	NA
9	5	NA	ND	ND	0.004 (0.003 – 0.005)	ND	ND	0.23 (0.18 – 0.38)
10	72	2.39 (1.0 – 7.2)*	589.6 (9.2 – 7243.0)	25.21 (6.47 – 901.0)	16.917 (0.002 – 901.285)	6.5	24.0	5.1 (1.4 – 12.1)
11	6	NA	J	0.546	0.092 (0 – 0.546)	NA	NA	NA
12	5	NA	1 ND 4 J	ND	0.0005 (0.0008 – 0.0005)	NA	NA	NA
13	10	NA	5 ND 5 J	ND	0.003 (0 – 0.012)	5 ND 5 NA	5 ND 5 NA	0.22 (0.16 – 0.32)



Oval Butterflyfish, *Chaetodon lunulatus.*

B - Metals

Site	Antimony	Arsenic	Barium	Chromium	Copper	Lead	Mercury	Zinc
1	NA	ND	15.7 (3.2 – 27.4)	5.4 (4.5 – 6.2)	ND	ND	ND	18.5 (2.9 – 54.5)
4	ND	ND	NA	NA	ND	ND	ND	25.0 (11.3 – 39.5)
5	0.5 (0.5 – 0.5)	ND	NA	NA	2.1 (1.9 – 2.3)	ND (5.8 – 21.7)	0.009	14.5
6	0.81 (0.3 – 1.8)	2.3 (0.2 – 0.6)	NA (1.1 – 55.3)	NA	8.1 (7.3 – 82.6)	31.0 (0.005 – 0.078)	.022 (1.2 – 103.9)	12.9
7	0.4 (0.2 – 0.8)	0.6 (0.2 – 1.1)	NA	NA	46.4 (2.2 – 171.0)	ND	0.03	31.9 (2.7 – 135.7)
8	NA	0.4	174.2 (152.6 – 195.8)	10.4 (9.9 – 10.9)	38.2 – 40.3	ND	ND	ND
9	NA	ND	19.4 (13.4 – 23.6)	6.2 (5.7 – 6.6)	ND	ND	ND	19.0 (4.3 – 48.5)
10	NA	0.6 (0.2 – 1.6)	76.3 (4.5 – 294.9)	10.2 (3.6 – 60.1)	5.1 (1.4 – 12.1)	10.1 (1.6 – 40.1)	0.014 (0.011 – 0.016)	12.9 (1.6 – 163.3)
11	NA	0.5	119.7 (89.4 – 180.2)	4.7 (3.6 – 6.2)	ND	31.8 (29.7 – 34.3)	ND	ND
12	NA	0.4	110.3 (73.6 – 144.4)	5.4 (3.5 – 7.7)	ND	30.0 (28.4 – 31.2)	ND	ND
13	NA	0.7 (0.6 – 0.8)	77.3 (9.4 – 179.0)	5.4 (4.5 – 6.7)	ND	32.9 (30.6 – 35.2)	ND	4.1 (2.4 – 5.3)

NA – Not analyzed ND – None Detected * – PCBs were only analyzed in eight samples from the herbicide orange site
** – PCBs were only analyzed in two samples from the short and two samples from the Tall Aid to Navigation
J – Detected but below quantifiable limits

Short-nose Wrasse, *Macropharyngodon geoffroy*

Global Climate Event causes Coral Bleaching

Research by Anne L. Cohen, P. S. Lobel, and Gabrielle L. Tomasky
For scientific details see -
http://www.whoi.edu/GG/science/people/acohen/research/bleaching.html

Published 1997, Cohen, A., P. S. Lobel, and G. L. Tomasky. An unusual event of Coral bleaching on Johnston Atoll, Central Pacific Ocean. *Biological Bulletin* 193:276-279.

On 10 September 1996, extensive coral bleaching was noted on Johnston Atoll. Between September 1996 and March 1997 the nature and extent of the bleaching, as well as the anomalous conditions of ocean temperature, were monitored.

Coral "bleaching," or the loss of zooxanthellae (i.e. symbiotic microalgae) and their photosynthetic pigments, is one of the first visible signs of thermal stress. The association between mass reef bleaching, and subsequent coral mortality, with elevated ocean temperatures is of concern in light of predicted global temperature increases over the next century. Mass bleaching is most often associated with anomalous ocean temperatures during the warmest month of the year. A temperature increase of 1°-2°C above the historical mean summer maximum is considered necessary to induce coral bleaching in tropical and subtropical environments.

The 1996 JA bleaching event did not occur in isolation but appears to have been part of a global-scale bleaching episode that began in the western Caribbean and Gulf of Mexico in the summer of 1995 and was observed at several sites in the western and central Pacific the following year. Satellite images indicate a basin-wide sea surface temperature anomaly (SSTA) of between 0.5°C and 1.5°C in September 1996, coincident with reports of coral bleaching on the Hawaiian Island and on JA.

On JA, six lagoon and reef-edge sites were examined to depths of 5 meters during three field excursions: October and November 1996, and March 1997. Affected corals were tagged and photographed at one lagoon site to monitor recovery rates. Colonies that were fully bleached were distinguished from those that showed partial bleaching, i.e., bleaching confined to localized regions on a single colony. Observations were as follows:

1. Bleaching was confined to corals in lagoon sites. No bleaching occurred along the emergent reef with the exception of one bleached colony (*Pocillopora meandrina*) noted on the inside of the eastern reef edge.
2. Bleaching was species specific. All *Montipora spp.* and *Pocillopora spp.* were affected, although the degree of bleaching of individual colonies varied from completely unaffected to partially bleached to complete loss of skeletal pigment. Beaching was not observed in Acropora cytherea, the dominant coral species on JA.
3. Tissue loss from affected colonies did not occur during the first 3 weeks after the bleaching was noted, ie, 10 September-4 October 1996. Tissue loss was noted for several bleached Pocillopora colonies in late October. On the contrary, bleached Montipora colonies maintained living polyps for the duration of the bleaching event.
4. Aerial extent of the bleaching in lagoon sites was estimated to be from 15% to 20% between 0 to 5 m depth. Bleached corals were observed to a depth of 5 m.
5. By March 1997, 50% of the affected, tagged colonies had made a full recovery and regained pigment. Recovery was unrelated to the degree of bleaching experienced by individual colonies but was to some degree species-specific in that Pocillopora colonies without tissue were eventually overgrown by algae.

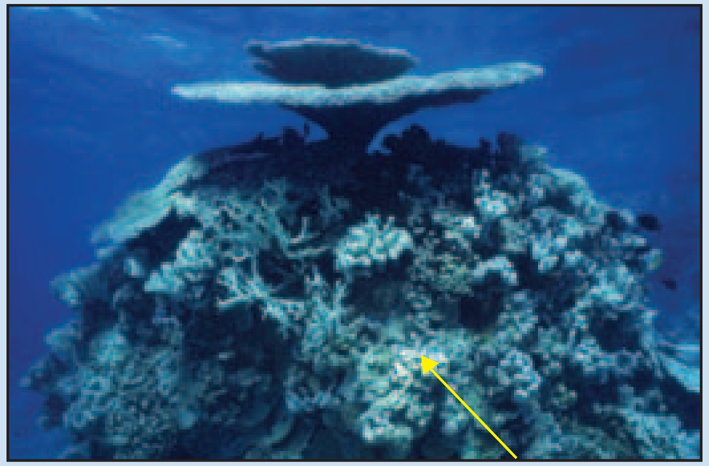
Daily temperatures at two lagoon sites and one reef-edge site were recorded using temperature loggers. The reef-edge site is a 6-m-deep channel (referred to as Mustins Gap) in the emergent reef structure. Temperatures recorded at this site were regarded to be representative of open-ocean mixed layer temperatures. In-situ temperature records in combination with IGOSS NMC satellite-derived SSTs allowed the following observations to be made:

1. Temperature loggers recorded a maximum summer lagoon temperature of 31.1°C on 25 August 1996, compared with a maximum summer temperature of 29.7°C in the previous year (14 September 1995).
2. Average daily temperatures at the reef edge were 0.2°C lower than those recorded in the lagoon between 3 July and 21 October 1996. The maximum recorded SST at Mustins Gap was 29.8°C, and the maximum recorded difference between reef-edge and lagoon sites was 0.4°C in late August 1996.
3. Satellite-derived summer (JAS) SSTAs for a 1°x 1°C grid square centered on 16.5°N, 169.5°W indicate an anomaly of 0.6 °C in 1996 (compared with the historical mean since 1982).

In timing, nature, and extent-including the species affected, tissue loss, and rate of recovery, the bleaching episode on JA was very similar to the one that was observed on the Hawaiian Islands in the same year and that was predicted on the basis of laboratory manipulations of temperature. However, whereas temperatures between 28°C and 29°C are sufficient to induce bleaching of *Montipora spp.* and

Pocillopora spp. on Hawaii, congenerics on JA appear tolerant of temperatures up to 29.8°C. Although the exact date when bleaching first occurred was not documented, the distribution of bleaching across the atoll, the timing of SST maxima in the lagoon, and the timing of the first observation of extensive bleaching lead to the conclusion that the most sensitive coral species on JA have an upper thermal limit of about 30°C. This apparent difference in coral thermal tolerances between Hawaii and JA corresponds to differences in the maximum summer temperatures between these two sites.

Although in situ temperature data enable estimates of the upper thermal limit of the affected JA coral species, the time series are too short to determine how high this limit is above normal summer SST maxima. The longer satellite-derived temperature record shows an anomaly of 0.6°C during the summer of 1996; according to field and laboratory observations, this anomaly is not high enough to induce coral bleaching by temperature alone. However, in assessing whether temperature was the sole cause of the JA coral bleaching event or whether other factors were involved, it is important to recognize the spatial resolution over which satellite-derived SSTs are averaged (1° X 1°). Satellite temperatures are therefore representative of relatively large-scale open-ocean conditions and do not distinguish fine-scale temperature variability across the atoll. The logger data indicate that small but important differences in SST occurred between sites on JA. SSTs in the lagoon, where bleaching occurred, were up to 0.4°C higher than those at the reef edge, where bleaching did not occur. Thus, lagoon temperatures were at least 1°C higher than the long-term ambient summer SST, which is in good agreement with that predicted to induce coral bleaching.



A typical Johnston Atoll coral reef. The bright white coral colony in the foreground appears "bleached".

Publications from the Marine Monitoring Program

The following list is of scientific publications, theses and reports from the Lobel lab's marine ecological studies at Johnston Atoll.

The Johnston Atoll Project has supported six PhDs and five MAs theses based upon field research at Johnston Atoll.

1995 Economakis A. Aggregations of gray Reef Sharks and Water temperature at Johnston Atoll. Masters thesis 83pp.

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In prep Richlen, Mindy. Ecology of Ciguatera on Johnston Atoll. PhD thesis in prep Boston University.

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Yellowfin Goatfish, *Mulloidichthys vanicolensis.*

Future of Johnston Atoll

The future for wildlife and marine life on Johnston Atoll appears healthy and productive. There has been no documentable effect on the birds or marine ecosystem from the JACADS project through 20 years of extensive monitoring. Due to careful planning and research design ahead of time, the researchers were able to ensure that they had the data needed to quickly determine if the JACADS project was affecting the ecosystem. Throughout the project, no ill effects could be found in any of the many parameters measured. Johnston Atoll provides an excellent example of how military operations can be compatible with the ecosystem and both can thrive together sucessfully.

The future plan for Johnston Atoll is for the US Air Force, the current landowner, to close the facility and return the property to the US General Services Administration. The atoll would remain a National Wildlife Refuge as established in 1926 under the US Fish and Wildlife Service.

It is expected, with the abandonment by man, that many more seabirds will find Johnston Island itself (the one human inhabited island on the atoll) a good place to visit, and even nest. Over the years, as birds get used to this new undisturbed habitat, the nesting populations may grow. This is more good news for seabirds since current estimates suggest that Pacific populations of seabirds are 1-10% of what they used to be before human inhabitation of the islands. They badly need undisturbed habitat to keep from going extinct. While the growth in nesting numbers of some species may crowd out others, this has to be considered part of a natural system, to which the birds are adapted.

The marine ecosystem of Johnston Atoll should thrive as well; however, there is some concern that the continued growth of long-line fisheries around the world will affect fish populations, and consequently the bird populations as well. But this is no reflection on the condition in which the US Army is leaving Johnston Atoll – a healthy, natural ecosystem.

Nesting Red-footed Boobies. The populations of most of the nesting seabird species on Johnston Atoll are expected to increase once the military activities and cleanup of the atoll are complete (2004). Research conducted by Dr. Schreiber on the seabirds nesting here indicates that this is one of the healthiest and most productive colonies in the world.

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