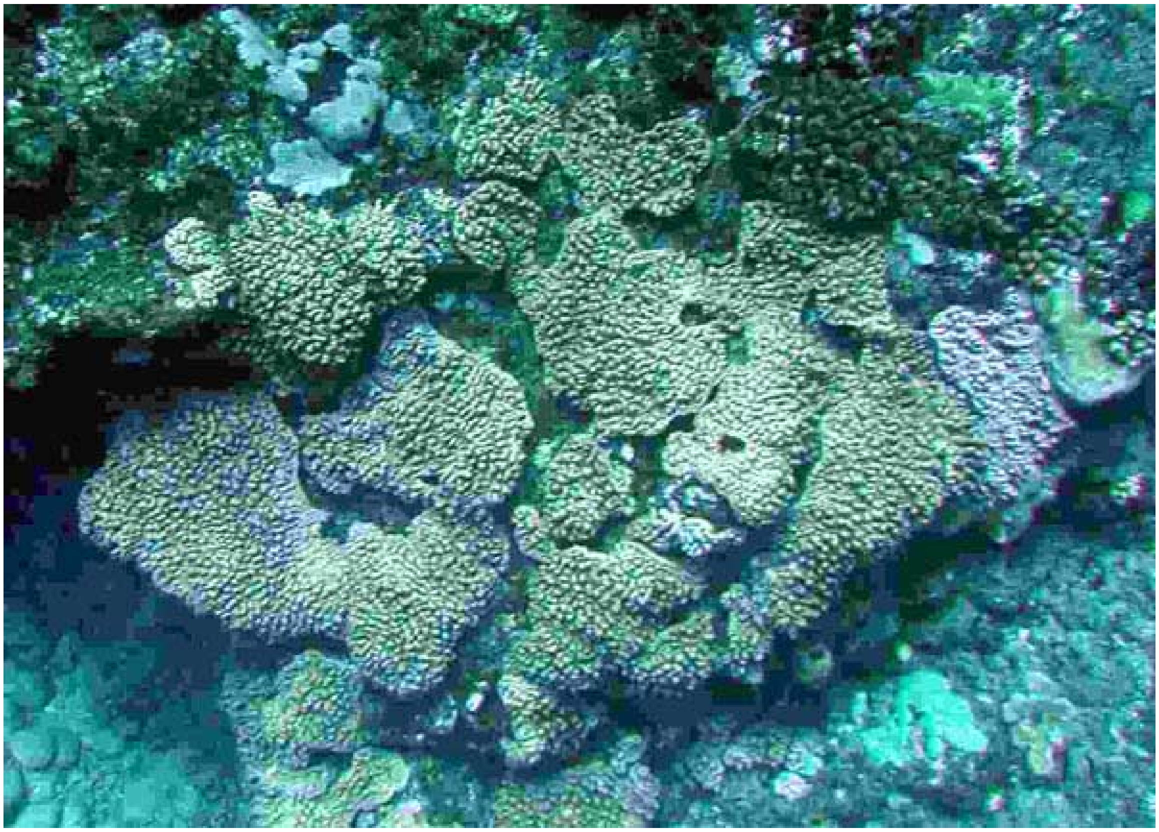
Final Report

A Mission to Acquire GPS-based Ground Control and Benthic Habitat Characterization Information in the Northwestern Hawaiian Islands



Coral Reef Mapping Team
National Ocean Service
NOAA

16 November 2001

Executive Summary

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A Mission to Acquire GPS-based Ground Control and Benthic Habitat Characterization Information in the Northwestern Hawaiian Islands.

The Northwestern Hawaiian Islands GPS and benthic characterization mission was a collaboration between the University of Hawaii, the private sector, the State of Hawaii, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the National Ocean Service. The information gathered during the mission is vital to a number of activities underway in the Northwestern Hawaiian Islands, including updating existing nautical charts, mapping shallow-water coral reef ecosystems, and providing information needed for developing comprehensive management plans for the area. The information also will provide a baseline for future characterizations.

The acquisition of data was performed during two consecutive mission legs. The first leg, launched on 5 August 2001, began at Midway Atoll, preceeded to Kure Atoll, returned to Midway Atoll, then went on to Pearl and Hermes Atoll, Lisianski Island, Laysan Island, and Maro Reef. The first leg then proceeded directly to Honolulu and ended on 25 August 2001. The second leg of the mission, launched on 26 August 2001, began at Honolulu and conducted surveys at Nihoa Island, Necker Island, French Frigate Shoals, Gardner Pinnacles, revisited Maro Reef, and ended at Midway Atoll. on 19 September 2001.

During the mission, land-based GPS ground control monuments were established, water-based benthic habitat characterizations were conducted, shallow-water bathymetric data gathering operations were conducted, feature photoidentification activities were conducted, and gravimetric measurements were gathered. These activites support the development of accurate, positional information for the Northwestern Hawaiian Islands. These operations also support the development of accurate detailed maps of the shallow-water benthic habitats of the Northwestern Hawaiian Islands.

Summary of Mission Accomplishments

1) GPS monument data were acquired at nine of the 10 locations visited by the mission. Of particular note is the GPS data obtained at Gardner Pinnacles. Obtaining these accurate GPS data involved establishing or reestablishing a GPS monument on each island. Once processed, the positional data gathered will enable these monuments to be placed to within five centimeters of their actual location on the earth. These GPS data will be vital for efforts to update and correct the locations of these islands and atolls on nautical charts. These data also will be vital for rectifying the positions of the islands and atolls seen in digital satellite imagery. This imagery will be used for mapping and characterizing the shallow-water coral reef ecosystems of the Northwestern Hawaiian Islands.

2) Benthic characterization data were obtained at all 10 locations visited by the mission. In total, 1,131 sites were visited at the 10 locations. Coral reef biologists observed and classified the seabed at each site using a classification scheme. Water depth and temperature also was measured at each site. Finally, digital camera photographs of the seabed were taken at each site, In total, hundreds of color digital camera images were taken at these locations. These data were gathered over as many of the types of habitat as possible and at varying water depths. The goal was to gather benthic habitat descriptive information at a large number of sites scattered throughout each location. These data are vital for characterizing the types of bottom habitats (e.g., coral, seagrass, algae) that can be identified in imagery of each location.

3) Photoidentification points were observed at eight of the 10 locations visited by the mission. Of particular note were the photoidentfication points gathered at three well-separated islands at Pearl and Hermes Atoll and French Frigate Shoals. This activity involved obtaining GPS data at several photoidentifiable sites on each island. When combined with the georeferenced monument data, these data help locate (geoposition) an entire atoll to within 30 centimeters of its actual location on the earth.

4) Gravimetric data were obtained at seven of the 10 locations visited by the mission. This activity involves obtaining gravimetric data at several sites on each island. Gravimetric data are used to determine to what extent the actual elevation of a particular location at sea level deviates from its predicted elevation. This hypothetical surface of the earth that coincides everywhere with mean sea level is called the earth geoid. The computed ellipsoidal shape of the Earth is called the earth ellipsoid. Because the earth is not a smooth sphere; deviations occur (due mostly to gravity and the varying densities of features on the earth) between the geoid and ellipsoid. The gravimetric data enable scientists to calculate those deviations. Associated with gathering gravimetric data is the need for accurate tidal range information so that an accurate computation of sea level can be made. Tide data were gathered at three of the 10 locales visited by the mission.

5) Bathymetric data were gathered at nine of the 10 locations visited. Water depth affects being able to correctly and accurately identify seabed habitats. The bathymetry team obtained 100 percent of the desired bathymetry information at five locations and nearly 100 percent at one other locale. In total, hundreds of nautical miles of trackline bathymetry data were obtained.

6) A. Wegmann conducted Hawaiian monk seal surveys at Nihoa Island and Necker Island. Mr. Wegmann representing the Fish and Wildlife Service and National Marine Fisheries Service to ensure all quarantine procedures were followed and no disturbance of island flora and fauna, in particular, the Hawaiian monk seals, occurred at most locations visited. No animals were collected, banded, or otherwise affected by this mission. While on Nihoa, Pritchardia remota seeds were collected for propogation and outplanting on Laysan Island.

Digital files of the processed GPS and photoidentification data and the benthic characterization data are provided on the included CD. The digital camera imagery also are included on CD.

Table 1. A summary of the GPS, bathymetry, and benthic characterization data gathered during the Northwestern Hawaiian Islands mission.

Location	NGS Monuments	Photoidentification Points	Gravity (Tide) Measurements	Bathymetry Measurements	Benthic Characterization Points
Midway Atoll	1	9	X (X)	X	183
Kure Atoll	1	14	X (X)	X	130
Pearl and Hermes Atoll	1	12	X	X	173
Lisianski Island	1	9	X (X)	X	136
Laysan Island	2	9	X	X	67
Maro Reef	0	0	--	X	151
Nihoa Island	10	2	--	X	28
Necker Island	5	12	X	X	63
French Frigate Shoals	3	13	X	X	158
Gardner Pinnacles	2	0	--	--	42

INTRODUCTION

The Northwestern Hawaiian Islands GPS and benthic characterization mission was a collaboration between the University of Hawaii, the private sector, the State of Hawaii, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the National Ocean Service. The information gathered during the mission is vital to a number of activities underway in the Northwestern Hawaiian Islands, including updating existing nautical charts, mapping shallow-water coral reef ecosystems, and providing information needed for developing comprehensive management plans for the area. The information also will provide a baseline for future characterizations.

The acquisition of data was performed during two consecutive mission legs. The first leg, launched on 5 August 2001, began at Midway Atoll, preceeded to Kure Atoll, returned to Midway Atoll, then went on to Pearl and Hermes Atoll, Lisianski Island, Laysan Island, and Maro Reef. The first leg then proceeded directly to Honolulu and ended on 25 August 2001. The second leg of the mission, launched on 26 August 2001, began at Honolulu and conducted surveys at Nihoa Island, Necker Island, French Frigate Shoals, Gardner Pinnacles, revisited Maro Reef, and ended at Midway Atoll on 19 September 2001.

During the mission, land-based GPS ground control monuments were established, water-based benthic habitat characterizations were conducted, shallow-water bathymetric data gathering operations were conducted, feature photoidentification activities were conducted, and gravimetric measurements were gathered. These activites support the development of accurate, positional information for the Northwestern Hawaiian Islands. These operations also support the development of accurate detailed maps of the shallow-water benthic habitats of the Northwestern Hawaiian Islands.

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1) GPS monument data were acquired at nine of the 10 locations visited by the mission. Of particular note is the GPS data obtained at Gardner Pinnacles. Obtaining these accurate GPS data involved establishing or reestablishing a GPS monument on each island. Once processed, the positional data gathered will enable these monuments to be placed to within five centimeters of their actual location on the earth. These GPS data will be vital for efforts to update and correct the locations of these islands and atolls on nautical charts. These data also will be vital for rectifying the positions of the islands and atolls seen in digital satellite imagery. This imagery will be used for mapping and characterizing the shallow-water coral reef ecosystems of the Northwestern Hawaiian Islands.

2) Benthic characterization data were obtained at all 10 locations visited by the mission. In total, 1,131 sites were visited at the 10 locations. Coral reef biologists observed and classified the seabed at each site using a classification scheme. Water depth and temperature also was measured at each site. Finally, digital camera photographs of the seabed were taken at each site, In total, hundreds of color digital camera images were taken at these locations. These data were gathered over as many of the types of habitat as possible and at varying water depths. The goal was to gather benthic habitat descriptive information at a large number of sites scattered throughout each location. These data are vital for characterizing the types of bottom habitats (e.g., coral, seagrass, algae) that can be identified in imagery of each location.

3) Photoidentification points were observed at eight of the 10 locations visited by the mission. Of particular note were the photoidentfication points gathered at three well-separated islands at Pearl and Hermes Atoll and French Frigate Shoals. This activity involved obtaining GPS data at several photoidentifiable sites on each island. When combined with the georeferenced monument data, these data help locate (geoposition) an entire atoll to within 30 centimeters of its actual location on the earth.

4) Gravimetric data were obtained at seven of the 10 locations visited by the mission. This activity involved obtaining gravimetric data at several sites on each island. Gravimetric data are used to determine to what extent the actual elevation of a particular location at sea level deviates from its predicted elevation. This hypothetical surface of the earth that coincides everywhere with mean sea level is called the earth geoid. The computed ellipsoidal shape of the Earth is called the earth ellipsoid. Because the earth is not a smooth sphere; deviations occur (due mostly to gravity and the varying densities of features on the earth) between the geoid and ellipsoid. The gravimetric data enable scientists to calculate those deviations. Associated with gathering gravimetric data is the need for accurate tidal range information so that an accurate computation of sea level can be made. Tide data were gathered at three of the 10 locales visited by the mission.

5) Bathymetric data were gathered at nine of the 10 locations visited. Water depth affects being able to correctly and accurately identify seabed habitats. The bathymetry team obtained 100 percent of the desired bathymetry information at five locations and nearly 100 percent at one other locale. In total, hundreds of nautical miles of trackline bathymetry data were obtained.

6) A. Wegmann conducted Hawaiian monk seal surveys at Nihoa Island and Necker Island by A. Wegmann. Mr. Wegmann representing the Fish and Wildlife Service and National Marine Fisheries Service to ensure all quarantine procedures were followed and no disturbance of island flora and fauna, in particular, the Hawaiian monk seals, occurred at most locations visited. No animals were collected, banded, or otherwise affected by this mission. While on Nihoa, Pritchardia remota seeds were collected by A. Wegmann for propogation and outplanting on Laysan Island.

Digital files of the processed GPS and photoidentification data and the benthic characterization data are provided on the included CD. The digital camera imagery also are included on CD.

Personnel Participating in Mission

The teams involved in the mission represented an interesting mix. The GPS, gravimetric, photoidentification, and bathymetry data gathering activities were performed by Cliff Middleton (the leg 1 Chief Scientist and GPS Team Leader), Dave Minkel (the leg 2 Chief Scientist and GPS Team Leader), Doug Adams, Dave Crump, Marti Ikehara, Joe Evjen, and Jim Harrington. They were all from NOS's National Geodetic Survey. Dave Crump participated in both legs of the mission.

The benthic characterization data gathering teams also were diverse. Evelyn Cox, Frank Stanton, Paul Jokiel, Eric Brown, Steve Kolinski, and Will Smith (the Benthic Teams Leader) were all from the University of Hawaii's Hawaii Institute of Marine Biology. Will Smith participated in both legss of the mission.

Kris Holderied from NOS’s Center for Coastal Monitoring and Assessment participated in leg 1 of the mission. Rick Stumpf, also from NOS's Center for Coastal Monitoring and Assessment, participated in the Kure Atoll and Midway Atoll portion of the mission. Both Kris and Rick participated in the benthic characterization data gathering activities.

Ruth Kelty from NOS’s Science Office participated in the benthic characterization data gathering activities during leg 2 of the mission.

Ben Richards from NOS’s Office of National Marine Sanctuaries participated in the benthic characterization data gathering activities during Phase 2 of the mission.

David Canny, a SeaGrant fellow from NOS's Special Projects Office, participated in the benthic characterization data gathering activities during leg 1 of the mission.

Miles Anderson, Principal Scientist and President of Analytical Laboratories of Hawaii, participated in the benthic characterization data gathering activities during leg 1 of the mission.

Wayne Sentman participated as a representative of the State of Hawaii's Department of Lands and Natural Resources to ensure there was no disturbance of flora and fauna occurred on Kure Atoll.

Alex Wegmann participated in the entire mission as the representative of both the Fish and Wildlife Service and National Marine Fisheries Service to ensure all quarantine procedures were followed and that there was no disturbance of flora and fauna, in particular, the Hawaiian monk seals, at most locations visited.

Bruce Casler, a monk seal researcher with NMFS on Midway, was involved in the mission on Midway to ensure no disturbance of monk seals on those islands.

Summary of Data Gathered during the Mission

At Midway Atoll:

- 50 hours of GPS data on monument on Sand Island;
- Gravity data at 10 sites on Sand Island plus Midway CORS station;
- GPS data for three (3) Photo ID locations on Eastern Island;
- GPS data at two tidal benchmarks on Sand Island;
- GPS data at six (6) Photo ID locations on Sand Island;
- GPS data for one (1) hour at 1959 Naval Hydrographic Office survey station on North Island;
- Completed bathymetry data gathering on all predetermined tracklines;
- Benthic habitat data at 183 water stations.

At Kure Atoll:

- Established and acquired 30 hours of GPS data at new station on Green Island;
- GPS data at five (12) Photo ID locations on Green Island;
- GPS data on two (2) North-South and two (2) East-West orientation lines;
- Completed bathymetry data gathering on all predetermined positions except those outside reef crest;
- Water level point occupied on Green Island;
- Gravity data at five (5) sites on Green Island;
- Benthic habitat data at 130 water stations.

At Pearl and Hermes Atoll:

- Established and acquired 48 hours plus of GPS data at new station on Southeast Island;
- GPS data at four (4) Photo ID locations on Southeast Island;
- GPS data at four (4) Photo ID locations on North Island;
- GPS data at four (4) Photo ID locations on Grass Island;
- Gravity readings acquired on Grass Island;
- Completed 50 miles of bathymetry data gathering on predetermined tracklines;
- Benthic habitat data at 173 water stations.

At Lisianski and Neva Shoals:

- Established and acquired 48 hours plus of GPS data at new monument on Lisianski;
- GPS data - multiple occupations - at nine (9) Photo ID locations on Lisianski;
- Water level data gathered at one (1) station on Lisianski;
- Gravity readings at 10 locations around Lisianski;
- Completed 50 miles of bathymetry data gathering on predetermined tracklines;
- Benthic habitat data at 136 water stations over Neva Shoals.

At Laysan Island:

- GPS data acquired at 1961 Astronomical Station on Laysan;
- GPS data acquired at USFWS monument on Laysan;

• GPS data - multiple occupations - at nine (9) Photo ID locations on Laysan;
• Gravity readings acquired at 12 locations around Laysan;
• Completed 100 percent of bathymetry data gathering on predetermined tracklines;
• Benthic habitat data at 67 water stations around Laysan.

At Maro Reef:

• no emergent land found ar Maro Reef;
• Completed 63 miles of bathymetry data gathering on predetermined tracklines around Maro Reef;
• Benthic habitat data at 151 water stations around Maro Reef.

At Nihoa Island:

• GPS data acquired at two 1961 Astronomical Stations on Nihoa;
• GPS data acquired at five existing and one new survey marks on Nihoa;
• GPS data acquired at three stations from the 1928 USC&GS survey on Nihoa;
• GPS data at two (2) Photo ID locations on Nihoa, but sites may not be valuable for ID;
• Completed 100 percent of bathymetry data gathering on predetermined tracklines;
• Benthic habitat data at 28 water stations around Nihoa;
• Alex Wegmann observed nine Hawaiian monk seals hauled out on Nihoa.

At Necker Island:

• GPS data acquired at three (3) 1961 Astronomical Stations on Necker;
• GPS data acquired at one (1) station from the 1928 USC&GS survey on Necker;
• GPS data acquired at one recovered 1928 survey mark on Necker;
• GPS data at twelve (12) Photo ID locations on Necker;
• Completed 100 percent of bathymetry data gathering on predetermined tracklines at Necker;
• Gravity readings acquired at five (5) locations around Necker;
• Benthic habitat data at 63 water stations around Necker;
• Alex Wegmann observed 22 Hawaiian monk seals, including one pup, hauled out on Necker.

At French Frigate Shoals:

• GPS data acquired at one (1) 1961 Astronomical Stations on Tern Island;
• GPS data acquired at GPS monument established by Mike Potterfield on Tern Island;
• GPS data acquired at new station (FRENCH 2001) on Tern Island;
• GPS data at six (6) Photo ID locations on Tern Island;
• GPS data at four (4) Photo ID locations on East Island;
• GPS data at three (3) Photo ID locations on Trig Island;
• Gravity readings acquired at eight (8) locations on Tern and East Islands;
• Completed 90 percent of bathymetry data gathering on predetermined tracklines at French Frigate Shoals;
• Benthic habitat data at 158 water stations around French Frigate Shoals;

At Gardner Pinnacles:

• GPS data acquired at two (2) 1961 Astronomical Stations on Gardner Pinnacle;
• Benthic habitat data at 42 water stations around Gardner Pinnacle.

For more information about the GPS data gathering activities, including CORS, GPS, photoidentification point, and gravimetric data, please contact Ed Carlson, NGS, NOS, 1315 East West Highway, Silver Spring, Maryland 20910, 301.713.3191; Ed.Carlson@noaa.gov.

For more information on the benthic characterization data, please contact Steve Rohmann, SPO, NOS, 1305 East West Highway, Silver Spring, Maryland 20910; 301.713.3000; Steve.Rohmann@noaa.gov.

Summary of the Mission Itinerary

Leg 1 of Mission:

4 August 2001 – Depart Honolulu and arrive Midway Atoll via Aloha Airlines.

5 – 7 August 2001 – Conduct GPS, photoidentification, gravimetric, tide, bathymetric, and benthic habitat data acquisition operations at Midway Atoll. Depart Midway for Kure Atoll.

8 – 9 August 2001 – Arrive Kure Atoll and conduct GPS, photoidentification, gravimetrric, tide, bathymetric, and benthic habitat survey operations. Depart Kure Atoll for Midway Atoll.

10 August 2001 – Arrive Midway Atoll. Develop detailed plans for the visiting and navigating the complex reef systems expected at the eight remaining NWHI locales. Depart Midway Atoll for Pearl and Hermes Atoll.

11 – 13 August 2001 – Arrive Pearl and Hermes Atoll and conduct three days of GPS, photoidentification, gravimetric, bathymetric, and benthic habitat data acquisition operations. Depart Pearl and Hermes Atoll for Lisianski Island.

14 August 2001 – Transit to Lisianski Island.

15 – 16 August 2001 – Arrive Lisianski Island and conduct GPS, photoidentification, gravimetric, tide, bathymetric, and benthic habitat data acquisition. Depart Lisianski Island for Laysan Island.

17 August 2001 – Arrive Laysan Island. Due to dangerous sea state, postpone deployment of survey teams until 18 August.

18 – 19 August 2001 – Conduct GPS, photoidentification, gravimetric, bathymetric, and benthic habitat data acquisition operations for two days. Depart Laysan Island for Maro Reef.

20 August 2001 – Arrive Maro Reef and conduct one full day of bathymetric and benthic habitat data acquisition operations. Depart from Maro Reef for Honolulu in the evening.

21 – 25 August 2001 – Transit back to Honolulu.

Leg 2 of Mission

26 August 2001 – Depart Honolulu Harbor to Nihoa.

30 – 31 August 2001 – Arrive Nihoa and conduct GPS, bathymetric, monk seal census survey, and benthic habitat data acquisition operations. Depart Nihoa for Necker.

1 – 2 September 2001 – Arrive Necker Island and conduct GPS, photoidentification, gravimetric, bathymetric, monk seal census survey, and benthic habitat data acquisition operations. Depart Necker for French Frigate Shoals.

3 – 6 September 2001 – Arrive French Frigate Shoals and conduct GPS, photoidentification, gravimetric, bathymetric, and benthic habitat data acquisition operations. Depart French Frigate Shoals for Gardner Pinnacles.

7 September – Arrive Gardner Pinnacles and conduct GPS and benthic habitat data acquisition operations. Depart Gardner for Maro Reef.

8 – 10 September 2001 –Arrive Maro Reef and conduct bathymetric and benthic habitat data acquisition operations. Depart Maro Reef for Pear and Hermes. Due to mechanical problem, visit to Pearl and Hermes is cancelled. Transit directly to Midway.

11 – 12 September 2001 – Transit to Midway Atoll.

12 September 2001 – Arrive Midway Atoll.

13 – 14 September 2001 – Conduct benthic habitat survey operations on Midway Atoll.

15 September 2001 – University of Hawaii benthic team members depart Midway via Aloha Airlines.

16 – 19 September 2001 – Conduct gravity measurements on Sand Island. Participate in beach clean-up effort on Sand Island. Visit and occupied for one (1) hour the 1959 Naval Hydrographic Office survey station set in 1959 on North Reef. Obtain three (3) photo ID points on Eastern Island. Shut down and disassemble CORS station on Sand Island. Assist on Dolphin surveys conducted by USFWS and Oceanic Society. NOS team departs Midway via Aloha Airlines.

Data Gathering Procedures

Establishing or reestablishing a National Geodetic Survey (NGS) monument required setting up special GPS equipment and letting the equipment continuously acquire GPS positional data for up to 48 hours. The GPS technician gathering these data worked with the Hawaii DLNR or FWS/NMFS representative during this activity to ensure no disturbances to island fauna and flora.

Gathering photoidentification points required a technician acquire GPS positional data at numerous sites scattered over an island. Using a portable GPS unit, the GPS technician walked to sites on the island. The sites were selected by perusing IKONOS satellite imagery for features that could both be seen in the imagery and found on the ground. At each location, the GPS technician acquired GPS position data for approximately 10 minutes. The GPS technician worked with the Hawaii DLNR or FWS/NMFS representative during this activity to ensure no disturbances to island fauna and flora.

Gathering gravity information required a technician acquire gravimetric data at numerous sites scattered over an island. Using a portable gravimeter, the GPS technician walked to sites scattered over the island and acquired gravimetric readings. Each occupation took approximately 20 minutes. The GPS technician gathering these data worked with the Hawaii DLNR or FWS/NMFS representative during this activity to ensure no disturbances to island fauna and flora.

Shallow-water bathymetric data were collected by traversing the open water areas of islands while regularly acquiring GPS position and water depth readings using a portable, survey-grade, recording fathometer. The GPS technician gathering the bathymetric data worked with the Hawaii DLNR or FWS/NMFS representative during this activity to ensure no disturbances to island fauna and flora.

Benthic habitat descriptive information was gathered at a large number of specific benthic habitat sites scattered throughout each locale. The procedure consisted of traveling by small boat to a predetermined longitude/latitude position. A handheld GPS unit was used to guide the boat to the location of interest. Two coral reef scientists entered the water to determine what features (e.g., coral, seagrass, algae) existed on the ocean bottom under the boat. The seabed characterization information, as well as water depth measured with a commercial pinger and the exact GPS position was recorded. The seabed information was gathered by either looking over the side of the boat or by snorkel. Digital camera photographs of the ocean bottom also were collected at each site visited. Typically, two separate benthic teams were on the water simultaneously. Most of the sites visited were pre-selected to ensure that a range of seabed habitats and water depths were represented. The methods implemented in this survey were modeled after those previously developed for assessing the accuracy of habitat maps prepared from remotely sensed imagery. The methods were adapted to apply to using high-resolution satellite imagery to generate maps of NWHI benthic habitats. Georeferenced IKONOS satellite imagery was used as the basis for initially locating the benthic characterization sites at each locale.

A benthic habitats classification scheme for the NWHI was developed using information gathered at a series of meetings and workshops. The draft scheme was reviewed and feedback from coral reef biologists and management specialists from Hawaii. The draft classification scheme can be downloaded from <http://biogeo.nos.noaa.gov>

Table 1. Universal Transverse Mercator zone designations for each locale visited.

Reef Area	UTM Zone
Kure Atoll	1
Midway Atoll	1
Pearl and Hermes Atoll	1
Lisianski Island	2
Laysan Island	2
Maro Reef	2
Gardner Pinnacles	2
French Frigate Shoals	3
Necker Island	3
Nihoa Island	4

After navigating by GPS to the site, or waypoint, the position of the site was obtained using a Trimble GeoExplorer 3 GPS data logger. The GPS unit also contained a data dictionary designed to prompt the operator for the information to be recorded at each site. The data dictionary included, but was not limited to, the information from the coral reef habitat classification scheme.

Upon arriving at the waypoint, a weighted line was dropped to the bottom and a buoy was fastened to the line. A GPS position for the site was established by collecting 100 GPS readings at the buoy. These 100 readings were averaged to generate a single GPS position. Next, two types of benthic habitat assessments were conducted. The first involved assessing the benthic habitat visible in a seven-meter radius around the buoy weight. This assessment was performed either using a glass bottom look box, by snorkeling, or by observing the seabed from the boat. For these assessments, the most common habitat type was identified, based on the classification scheme. Long hand notes were kept for each site where descriptive information including dominant seabed species and estimations of live benthic cover. Rugosity and other noteworthy observations also were recorded. The depth and water temperature at the site was recorded using a handheld depth sounder and thermometer. In areas where waves and sea conditions precluded reaching the site by boat, the GPS was placed in a watertight container and a swimmer carried the GPS unit to the seabed characterization site. At each site, photographs were taken of characteristic benthic habitat using a digital camera in an watertight housing.

The second site assessment involved determining the seabed habitats within a 20-meter radius of the area. The goal of this assessment was to determine the association of the dominant benthic habitat, as described in the classification scheme, with nearby benthic habitats.

Each day, all of the GPS, photoidentification, benthic characterization, and other data were downloaded, archived, and evaluated. The plans for the next day's work was developed using the previous day's results. Also, annotations from each day's field work were added to that day's computer data files.

IKONOS satellite imagery purchased from Space Imaging LLC was used to produce the figures in this report. The IKONOS satellite imagery is covered by a licensing agreement and is used with permission of Space Imaging. The imagery was processed by the NOS Coral Reef Mapping Team. For more information, please contact Dr. Steve Rohmann, SPO/NOS, 1305 East West Highway, Silver Spring, Maryland 20910; 301/713-3000; Steve.Rohmann@noaa.gov.

Table 2. A summary of the of GPS, bathymetry, tide, gravity, and benthic characterization data gathered in the Northwestern Hawaiian Islands during the mission.

Location	NGS Monuments	Photoidentification Points	Gravity (Tide) Measurements	Bathymetry Measurements	Benthic Characterization Points
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Gardner Pinnacles	2	0	--	--	42
Total	22	80			1,131

Description of Activities at Each Location – Leg one of the Mission.

Midway Atoll (see Figure 1):

5 – 7 August 2001 – First visit to Midway Atoll National Wildlefe Refuge.

First visit Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; R. Stumpf; F. Stanton; E. Cox; and A. Wegmann (FWS/NMFS representative).

During the first visit to this locale, all operations were based from the SS Midway, which was docked at the Midway Harbor pier.

During the visits and working with the FWS/NMFS representative, the GPS team established a GPS base station at the CORS (Continuously Operating Reference Station). The GPS team established a GPS monument station and acquired data for over 50 hours. The GPS team acquired gravity measurements at 11 stations on Sand Island, including the CORS. The GPS team completed 100 percent of predetermined bathymetry tracklines. The GPS team acquired tide data at two tidal benchmarks on Sand Island. The GPS team obtained GPS data at six photoidentification points on Sand Island and three photoidentification points on Eastern Island. Finally, the team acquired GPS data for one (1) hour at 1959 Naval Hydrographic Office survey station on North Island.

During the visits, the benthic characterization teams acquired data at 183 sites scattered throughout Midway Atoll, except in restricted areas.

General Observations: Of all the Northwestern Hawaiian Islands, Laysan and Midway are the islands that have seen the most extensive alterations to their ecosystems as a result of human habitation. Midway's island ecology has been extensively modified starting around 1903. After many years of occupation, the Navy officially turned the island over to the Fish and Wildlife Service on 20 May 1996. Now, the island is home to hundreds of thousands of birds and other animals.

7 August 2001 – The SS Midway departed for Kure Atoll about 18:00:00.

10 August 2001 – Second visit to Midway Atoll. The SS Midway arrived at Midway Atoll by 7:00 am local time 10 August.

Second visit Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; R. Stumpf; F. Stanton; E. Cox; A. Wegmann

(FWS/NMFS representative), and Wayne Sentman (Hawaii Department of Land and Natural Resources representative). R. Stumpf and W. Sentman left the mission after this stop at Midway Atoll.

During the second visit, the GPS team took down and disassembled the GPS base station after over 50 hours of continuous operation.

During the second visit, the benthic characterization teams carefully planned routes to predetermined waypoints at upcoming locales. Some reefs are very shallow and traversing locales will be challenging due to currents, waves, and trade winds. The GPS team reviewed imagery and routes for acquiring trackline bathymetry.

Second visit General Observations: Last night, there was brilliant blue-green bioluminescence off the bow as we made the run east to Midway. Seas were relatively calm and the SS Midway made port at Midway Atoll before dawn.

10 August 2001 – The SS Midway departed from Midway Atoll for Pearl and Hermes Atoll at about 17:30:00.

11-12 September 2001 – The third visit to Midway Atoll was, in part, due to a mechanical problem with the SS Midway. After leaving Maro Reef, the SS Midway was scheduled to stop at Pearl and Hermes Atoll. That destination was, however, aborted, and the SS Midway traveled directly to Midway. The SS Midway arrived at Midway Atoll at approximately 17:00:00 local time. The GPS and benthic characterization teams moved off of the SS Midway and lived in shore facilities on the night of the 12 September.

Third visit Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

13 September 2001 – Benthic characterization operations were conducted in the central lagoon area of Midway Atoll. Duration was 7:15:00 and 55 stations were characterized.

The GPS team off-loaded all equipment from the SS Midway and began packing the equipment for shipment.

14 September 2001 – Benthic characterization operations continued in the northeastern part of Midway Atoll. The last field day was ended earlier than usual so both teams could process all data.

15 September 2001 –. Field data were processed, copied to several sets of CDs were distributed to each group of researchers. The University of Hawaii benthic team members departed Midway Atoll at 18:00:00 in route to Honolulu on Aloha Airlines.

The GPS team participated in a nation-wide clean up the beach campaign.

16 September 2001 – The GPS team disassembled and packed the CORS equipment on Sand Island. Other non-essential equipment was similarly packed for shipment.

17 September 2001 – On Monday, the GPS team conducted a gravity survey on Sand Island. The GPS team participated in dolphin surveys conducted by USFWS and Oceanic Society and in another beach clean up.

18 September 2001 –. On Tuesday, the GPS team interviewed the Midway Atoll Harbormaster regarding changes to the Coast Pilot. The GPS team packed equipment for transport via Aloha Airlines to Honolulu.

19 September 2001 – On Wednesday, the remaining NOS personnel (the GPS team) departed Midway Atoll. The NWHI GPS and benthic characterization mission in the NWHI concluded.

<u>Kure Atoll</u> (see Figure 2):

8 – 9 August 2001 – The SS Midway arrived at Kure Atoll about 7:00 am local time.

Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; R. Stumpf; F. Stanton; E. Cox; A. Wegmann (FWS/NMFS representative), and Wayne Sentman (Hawaii Department of Land and Natural Resources representative).

Working with the Hawaii Department of Land and Natural Resources representative, the GPS team was unable to locate the 1961 astronomic station on Green Island. The GPS team established a new GPS station - KURE, 2001 - near the former US Coast Guard facility and acquired 30 hours of GPS data. The GPS team acquired gravity measurements at five stations on Green Island. The GPS team completed 100 percent of predetermined bathymetry tracklines. The GPS team acquired tide data at one tidal benchmark on Green Island. The GPS team obtained GPS data at seven photoidentification points on Green Island.

The benthic characterization teams acquired data at 130 sites scattered throughout Kure Atoll.

General Observations: One of the benthic characterization teams started their day with a grey reef shark escort. This team also saw a vivid 360 degree sunbow. This team captured a pretty good photo of a spectacular parrotfish, and saw some nice patch reef with good fish populations. The reefs leading up to the reef flat have large communities of healthy coral. An old encrusted anchor was found in the lagoon and a photo of it was taken. The NGS team spotted a 10 foot tiger shark near the shore. Spinner dolphins were ubiquitous and a pair of Alua (a large jack) also were present.

9 August 2001 – The SS Midway departed back to Midway Atoll about 18:00:00.

<u>Pearl and Hermes Atoll</u> (see Figure 3):

11 – 13 August 2001 – The SS Midway arrived at Pearl and Hermes Atoll about 06:00 am local time on 11 August. While establishing anchorage, the nylon line above the chain broke and the anchor was lost.

Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; F. Stanton; E. Cox; and A. Wegmann (FWS/NMFS representative).

Working with the FWS/NMFS representative, the GPS team was unable to locate the 1961 astronomic station on Southeast Island. The GPS team located a reference mark for the 1961 astronomic station, occupied that site, and acquired 48 hours of GPS data. The GPS team acquired gravity measurements on Grass Island. The GPS team completed 100 percent (approximately 50 nautical miles) of predetermined bathymetry tracklines. The GPS team obtained GPS data at four photoidentification points on Southeast Island, four photoidentification points on North Island, and four photoidentification points on Grass Island.

The benthic characterization teams acquired data at 173 sites scattered throughout Pearl and Hermes Atoll.

General Observations: The SS Midway arrived at Pearl and Hermes to a southeast wind and swell, which built during the day. After loosing its anchor, a crew member of the SS Midway attempted to locate it. This proved fruitless. However, the diver did see a giant alua, a small tiger shark, a hammerhead shark, several grey reef sharks and a ray. An accurate GPS reading on the ship's original anchor position was obtained. One benthic team saw two six foot white tip sharks at one of their way points and another five footer at the next station. Both teams have seen quite a bit of marine debris here, the site of the highest per kilometer marine debris in the northwestern chain. Today one team swam up to a tangle of net and took some photographs of the organisms living in and around the net and buoy. Multiple tiger sharks were spotted in the water by the GPS team, the largest about nine feet. Alua are everywhere.

Grass Island now exists as two islands. One of the benthic teams saw several white tip sharks, three green turtles, including one large inquisitive one, and a school of about 25 large alua. The other team found a large patch of approximately 50 different-sized (aged) <u>Porites evermanni</u> colonies, suggesting these might be a brooder colony.

The deep mini-atoll lagoon areas at Pearl and Hermes are consistently 75-80 feet deep and rise up steeply to within one foot of the surface. The "micro-atolls" in the middle are quite spectacular from the surface, and are primarily Porites compressa, with only occasional colonies of other species. A benthic team caught sight of a tombo (small tuna with pretty maze design on the tail) and a turtle swimming away quickly. Bioluminescence was observed off the bow of the SS Midway again last night.

13 August 2001 – The SS Midway departed from Pearl and Hermes about 17:30:00 for Lisianski Island.

Lisianski and Neva Shoal (see Figure 4):

14 August 2001 – Transit to Lisianski Island through rough seas. The trip from Pearl and Hermes to to Lisianski Island took 24 hours due to 6-8 foot swells, with 10-12 foot swells at times. Reached Lisianski at approximately 17:00:00 Midway time.

Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; F. Stanton; E. Cox; and A. Wegmann (FWS/NMFS representative).

Working with the FWS/NMFS representative, the GPS team was unable to locate the 1961 astronomic station or any of its reference points. Starting about 6:00 pm local time, the GPS team established and acquired 48 hours plus of GPS data at a new monument on Lisianski.

15 – 16 August 2001 – Working with the FWS/NMFS representative, the GPS team acquired multiple occupations at nine photoidentification points on Lisianski. The GPS team acquired gravity readings at 10 locations on Lisianski. The GPS team also acquired water level data at one station on Lisianski. The GPS team was able to acquire 100 percent (approximately 50 nautical miles) of bathymetry data for predetermined tracklines around Lisianski.

The benthic characterization teams acquired data at 136 sites scattered throughout Lisianski and Neva Shoal.

General Observations: Neva Shoal is a large shallow-water area that surrounds Lisianski Island, and extends over 100 square miles SSE of the island. It is named after the Russian ship Neva - captained by Urey Lisianski - that ran aground on the reef in 1805. The waters surrounding Lisianski Island are turbid and there is little in the way of a sheltered lee.

Sea state was challenging. The water also was murky. Much of the shallows to the southeast and south of Lisianski were very turbid and murky. Numerous birds, boobies, shearwaters, and terns visited the GPS and benthic teams. The boobies seemed to be curious about the boats and snorkelers and kept biting the buoy line.

One benthic team found a 35-foot section of end of a boat bobbing on the reef at the south end of Lisianski Island. Because there was little fouling, the piece of hull looked like part of a fairly new wreck. It had a bulb on the keel, suggesting it may have been the bow section. The water was murky and there were lines and ropes in the water, so attempts to identify a name or numbers on the wreck were not attempted. Photos were taken and coordinates of the site were noted, though the wreck was still moving. The other benthic team was chased from the water by a shark of unknown size, species, and disposition in murky water with visibility of about five feet.

16 August 2001 – The SS Midway departed from Lisianski about 17:30 pm local time for Laysan Island.

Laysan Island (see Figure 5):

17 August 2001 – The transit to Laysan Island was completed by 12:00 noon local time on 17 August.

Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; F. Stanton; E. Cox; and A. Wegmann (FWS/NMFS representative).

Working with the FWS/NMFS representative, the GPS team located the 1961 astronomic station "Lays 1961" and occupied this station. The GPS team also occupied the U.S. Fish and Wildlife Service monument. Working with the FWS/NMFS representative, the GPS team acquired multiple occupations at nine photoidentification points on Laysan. They also acquired 12 gravity points around the island. The GPS team was able to acquire 100 percent of bathymetry data for predetermined tracklines around Laysan Island.

General Observations: Of all the Northwestern Hawaiian Islands, Laysan and Midway are the islands that have seen the most extensive alterations to their ecosystems as a result of human habitation. The ecology of Laysan has been extensively modified as a result of human habitation and exploitation. First discovered in 1828, it was not until the 1890s that Laysan began to suffer. Guano mining, the introduction of rabbits, and the harvesting of bird feathers and wings devastated the island and its fauna. By 1923, Laysan was essentially a wasteland. After 1923, conditions on Laysan slowly improved. Laysan finches and ducks survived the destruction. Plants slowly began to return. Visitors introduced others. In 1961, it is believed that, while establishing an astronomical monument (mentioned below), the military introduced sandbur, an invasive plant from Central America, to Laysan. By the end of the 1980s, sandbur had expanded considerably. Sandbur does not provide a stable habitat for the thousands of burrowing seabirds that nest on Laysan. Starting in 1991, the FWS began a sandbur eradication effort that has successfully removed the weed from the island. However, constant vigilance is required as is a strict quarantine procedure for any visitors. Before stepping foot on Laysan, every visitor must put on brand new clothes that have been held in a freezer for at least 48 hours. Special quarantine procedures exist for every island in the NWHI.

Due to poor sea state, even to the lee of the island, the benthic teams did not launch on 17 August. Rather, the benthic teams received a tour of Laysan by the FWS staff. The benthic teams saw the hypersaline lake, numerous boobies, frigatebirds, terns, shearwaters, noddies, albatross, both alive and dead, as well as the Laysan Duck. In addition they observed from a distance numerous monk seals and walked back via the scalloped leeward beaches.

The Laysan Ducks shed their normal shy demeanor and posed admirably for photos. Laysan has a beautiful shelly leeward shore. There were significantly fewer flies at Laysan that at Lisianski, but we were informed it was a "low fly day." A small pod of what appeared to be bottlenose dolphins accompanied the Midway for a little while on the way into Laysan until they bored of the pace of the ship.

18 – 19 August 2001 – Continue work at Laysan Island.

The GPS team completed 100 percent of bathymetry data gathering on predetermined tracklines.

The benthic characterization teams acquired data at 67 sites scattered throughout Laysan Island.

General Observations: The weather was relatively foul when operations were launched on 18 August. The weather, which appeared to be breaking when benthic team one and the bathymetry team left the SS Midway, quickly deteriorated to blowing rain and lightning, reducing visibility to 100 feet. Both boats managed to get into shore and shelter, and the SS Midway held position off shore to await a break in the weather.

Monk seal #921 (emblazoned on the both sides of the animal) visited and snorted at one benthic team boat while the boat was at anchor. Visibility was better here than at Lisianski. The bathymetry and benthic habitats on the leeward side of the island was quite varied. In waters shallower than 25 feet, crustose coralline algae covers high relief globular rock formations with deep sand channels running between. There is a slight shelf to about 50 feet, where there is another drop to 60 plus feet and, at least near shore, sand with occasional rubble. An algal ridge may encircle the island, with long stretches of flat pavement with plate-form coral on the outside, and sand channels and some coral on the inside.

19 August 2001 – The SS Midway departed Laysan Island about 18:00 for Maro Reef.

Maro Reef (see Figure 6):

20 August 2001 – The first visit to Maro Reef (25 22'N X 170 35'W).

First visit Personnel: C. Middleton, Chief Scientist; D. Adams; Ms. M. Ikehara; D. Crump; W. Smith, Lead, Habitat Team; M. Anderson; D. Canny; K. Holderied; F. Stanton; E. Cox; and A. Wegmann (FWS/NMFS representative).

Because little or no emergent land exists at this locale, the GPS team did not establish any GPS stations at Maro Reef.

During the two visits, the GPS team was able to acquire 100 percent (approximately 70 nautical miles) of bathymetry data on predetermined tracklines around Maro Reef.

During the two visits to Maro Reef, the benthic characterization teams acquired data at 151 sites.

General Observations (first visit): Maro Reef is a shallow water reef ecosystem approximately 50 kilometers long and 30 kilometers wide. It is considered to be one of the most ecologically rich locales in the Northwestern Hawaiian Islands. Only one small rock outcrop of this former island reportedly extends above the ocean surface, and then only at very low tide. The 637 square kilometers of high-resolution IKONOS satellite imagery of Maro Reef indicates a series of intricate "articulated" reef crests and surrounding lagoons over much of the area.

Many areas of Maro Reef appear quite similar to Pearl and Hermes, including a few small micro atolls. This reef seemed to have the most diverse coral in small areas, and the most coral cover of the sites visited. Both benthic teams saw one small shark each.

The benthic characterization teams successfully collected data on the northwestern end of the reef system. Conducting the benthic characterizations was challenging because the reef is particularly rugged with strong current and limited visibility in many areas. Extreme caution was used at all times while navigating this area.

20 August 2001 – The SS Midway departed from Maro Reef about 18:00 for Honolulu.

21 – 25 August 2001 – Transit back to Honolulu.

8 September 2001 – The second visit to Maro Reef (25 22'N X 170 35'W).

Second visit Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

General Observations (second visit): Benthic characterization operations began at Maro Reef on 8 September. The benthic teams started work in the center of the reef system and worked to the southwest. Working in this direction was considered the best plan for this part of Maro as the boats were able to stay together and were working both downwind and down current. The SS Midway moved to the southwest part of the reef during the day and retrieved the small boats at the end of their surveys. The SS Midway then steamed to the northern section of Maro Reef so that the same pattern can be followed the next day. During surveying, the teams found a combination of sand, reticulated reef structure, and colonized and uncolonized hardbottom. In many of the sand areas, the sand was covered with an algal mat composed of blue-green type algae. In some areas the bottom was covered with an accreted crustose coralline algal framework forming accreted mounds. Areas that did contain coral were primarily colonized with P. lobata, P. meandrina, P. duerdeni, and P. damicornis. Visibility was poor (<30 ft) at most sites.

The GPS team attempted to locate the historic 1928 survey station “FISH.” A likely reef was found. It is a large, somewhat circular reef approximately 100 m in diameter, with 5 isolated features that protrude above the "table top" of the reef. Positions for these features were taken with a handheld GPS receiver. It is unclear if the features occupied were the remnants of a tower structure erected by the 1930 survey party or if they were natural features. The coral in this area could grow fast enough to disguise a man-made feature. It is unclear whether or not this sample will prove useful for assessing the geographic position of Maro Reef.

The benthic habitat teams did not collect additional data in the northeastern portion of the reef system. Treacherous conditions, resulting from the interaction of NE Trade Wind Swell and North Pacific Swell from the NW, were encountered. Wave fronts moving through the topographically complex reef areas along the north edge of Maro Reef created difficult working conditions.

The SS Midway departed Maro Reef earier that scheduled, in part due to poor weather and sea state. The SS Midway began transit to Pearl and Hermes Atoll at 11:45:00. En route, a mechanical problem required that the scheduled visit to Pearl and Hermes Atoll be aborted. The SS Midway transited directly to Midway Atoll, arriving about approximately 17:00:00 local time. Please see summary of activities at Midway Atoll above.

A total of 151 stations were sampled at Maro Reef. Of all the stations sampled, 134 were classified and 17 were too deep to be classified. Eighty percent of the stations sampled were at a depth of 50 feet or less, while the remaining 20 percent ranged from 50 to 103 feet in depth. Of the 134 classified stations, about 37 percent had coral cover of 10 percent or greater, 34 percent were unconsolidated sand or rubble, 7 percent were fleshy macroalgae, 13 percent were uncolonized hardbottom, and 10 percent were crustose coralline algae habitats. Deep water, dangerous waves, high turbidity, and aggressive Galapagos sharks hampered observations at many sites.

Maro Reef is the emergent portion of a large shelf area that is about 31 miles long in a NW direction and about 18 miles wide. The shallow reef complex consists of carbonate formations and is an about 12 miles long on a NW axis and 5 miles wide. The shallow reef areas consist of numerous patch reefs, submerged pinnacles and elongate reticulate reef complexes. Channels of deep water with highly irregular bottom topography lie between the shallow reef structures. Only one very small area about 2 feet high shows above high water on the N side of the reef complex. A wide shelf with depths from 12 to 20 fathoms surrounds the shallow reef area.

Maro Reef is essentially an open atoll that lacks the typical protective outer ring of islands and ocean reefs that enclose a typical atoll lagoon. The outermost reefs of Maro Reef function as a broken fore reef–reef crest complex, and absorb the energy of ocean swells that travel toward the inner “lagoon” region. Areas experiencing long-period ocean swell with breaking waves are functionally fore-reef environments. Habitats on this functional fore reef–reef crest are similar to those found on the reef crests of closed and partially closed atolls in the remainder of the NWHI. Crustose coralline algae dominate these zones at depths of less than 20 feet, based on the few points the benthic teams were able to sample due to the large swells impacting this region of the complex. The innermost area of the reef complex lies within boundaries of reticulated reefs and aggregated patch reefs and has all the characteristics of a true lagoon, with little or no influence from large ocean swell.

Topography is characterized by high vertical relief and discontinuous broken reef structures. Benthic communities are very heterogeneous and very patchy if viewed in the horizontal plane. Heterogeneity is less if viewed in the vertical plane. Shallow reef crests are encrusted with calcareous crustose algae. The deeper sloping portions of these structures are generally colonized by reef corals, but many areas are uncolonized. Deeper areas varied between coral, carbonate mounds, or sand and rubble. Boundaries between zones exist as diffuse gradients. The dominant habitat type is colonized pavement grading into uncolonized pavement, with unconsolidated sand in deeper areas of the “lagoon.” Colonized hardbottom is interspersed with areas of uncolonized hardbottom and unconsolidated sediment. The major reef forming corals in wave-exposed areas are Porites compressa and Pocillopora meandrina. Within the lagoon, the same species dominate with a larger proportion of other “lagoon” species such as Porites compressa, Montipora spp., Pocillopora damicornis, and Cyphastrea ocellina. The genus Acropora was not observed at any of the sites.

Attached Picture: Colonized high-relief carbonate structures are a common habitat at Maro Reef, as shown at site Ma013 on the central leeward side of the reef complex (see the 9/10/01 Sit Report).

The attached image is provided by NOAA with the permission of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and the State of Hawaii's Department of Land and Natural Resources.

Description of Activities at Each Location – Leg two of the Mission

28 August 2001 – On Tuesday at about 22:00 hours, the SS Midway left Pier 13 in Honolulu for the island of Nihoa. The second leg of the GPS and benthic characterization mission to the Northwestern Hawaiian Islands was underway.

Second leg Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

29 August 2001 –. The SS Midway was in transit to Nihoa all day.

Nihoa Island (see Figure 7):

30 August 2001 – The SS Midway arrived at Nihoa (23 03' N X 161 56' W) about 07:00:00.

Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

Working with the FWS/NMFS representative, the GPS team acquired GPS observations on five existent survey marks and set a new station. Two 1961 astronomic survey stations and three USC&GS 1928 stations were occupied. Since one of the 1928 stations was marked with a Hydrographic station disk, it is believed these stations were the basis of the original hydrographic survey of the island. The GPS team acquired two photoidentification points, but the locations may not be identified on the satellite imagery. The GPS team established and occupied for at least 24 hours a new GPS station. This station was located to maximize access and minimize human impact to the island.

The GPS team acquired 100 percent (9000 points) of bathymetry data on predetermined tracklines around Nihoa Island. Water up to a maximum depth 183 ft. was sampled.

The benthic characterization teams acquired 28 samples at Nihoa Island. The maximum depth sampled was 125 feet.

General Observations: Nihoa, is estimated to be 7.2 million years old. Erosion has left only about 150 acres of what was once a large island. The sheer cliffs of the island jut up to as high as 700 feet.

Nihoa Island is the emergent portion of a large basaltic shelf that measures about 18 miles long in a NE-SW direction 10 miles wide and has depths of 14 to 36 fathoms. Shallow areas of 10 fathoms or less occur only close to the island, except for a reported depth of 6.5 fathoms located at the west end of the platform.

Landing on Nihoa can be extremely difficult. Great care must be taken and prior experience can be invaluable. The GPS team had favorable conditions the day they landed on Nihoa.

Nihoa is considered to provide the best example of a nearly undisturbed coastal ecosystem in the entire Hawaiian archipelago. As a result, an estimated 500,000 birds of 17 species regularly breed on the island. The Nihoa Finch and the Nihoa Millerbird that breed on Nihoa are found nowhere else on earth.

Starting about 1980, Sheila Conant, an ornithologist at the University of Hawaii, began studies of the Nihoa Finch and the Laysan Finch. Her research revealed that food type and availability has influenced the evolution of the size and shape of the beaks of these birds. Dr. Conant's findings confirm that these birds can adapt rapidly (produce offspring with more appropriate beaks) to changes in food type and availability. For may years, similar research was conducted on the Galapagos by Peter and Rosemary Grant of Princton University.

The shallowest areas close to the island (depths of <30 ft.) are dominated by high relief, eroded basalt features and boulder habitats. Many areas exceeded 10 percent coverage by reef corals and colonial anemones (zoanthids). Noteworthy assemblages of the soft coral Sinularia abrupta occur on shallow wave-exposed areas on the windward side of the island.

The most common coral in shallow water is Pocillopora meandrina. Coverage by the soft coral Palythoa caesia (formerly Palythoa tuberculosa) reaches 10-20 percent in the shallow areas. Depth increases rapidly with increasing distance from the island, with some areas showing carbonate accretion as a thin veneer over basalt. Thus, many areas classify as carbonate pavement. At greater depths (30-100 ft.), areas of uncolonized hardbottom with low relief are characteristic. A thin sand veneer is found overlying much of the area, with thicker areas of sand forming in low spots or depressions. The alga Halimeda dominates is found in many of these sandy areas.

All shallow water communities reflect the extreme wave energy that impacts Nihoa throughout the year. Northeasterly Trade Wind-generated waves occur throughout the year with major impact from North Pacific swell during the winter. In deeper water, the sand moving about on the flat shelf appears to inhibit coral settlement and growth.

Due to the inexperience of everyone aboard the SS Midway regarding landing on Nihoa, two members of the Midway crew reconnoitered the candidate landing areas before deciding which small boat to use and deploying the GPS team onto Nihoa. Based on the weather forecast for the area, it was decided to leave the GPS on the base station for retrieval the next day. However, an increase in sea state of a few feet would have made equipment retrieval impossible.

While on Nihoa, A. Wegmann observed nine Hawaiian Monk seals hauled out on the beach.

A. Wegmann and J. Evjen collected Pritchardia remota seeds on Nihoa for propagation and outplanting on Laysan Island.

31 August 2001 – The GPS team recovered the GPS equipment from Nihoa. The SS Midway departed Nihoa about 11:15:00 for Necker Island.

Necker Island (see Figure 8):

1 – 2 September 2001 – The SS Midway arrived at Necker (23 34'N X 164 41'W) at 07:15:00 on 1 September.

Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

Working with the FWS/NMFS representative, the GPS team acquired GPS data at three 1961 Astronomical stations and one 1928 USC&GS survey station on Necker. The GPS team acquired GPS data at twelve (12) photoidentification locations on Necker. The GPS team acquired gravity data at five sites on Necker Island.

The GPS team acquired 100 percent of bathymetry data on predetermined tracklines at Necker.

The benthic characterization teams acquired 63 samples at Necker Island. On 1 September, 38 priority points and 7 ancillary points were sampled. On day two, 18 additional benthic characterization points were sampled.

General Observations: Necker Island is all that remains of an estimated 10 million year old shield volcano. Geologists believe that the portion of the volcano above water was once as large as the current size of Oahu. Now, the highest point on Necker is about 277 feet above sea level. Wave erosion has reduced the volcano to a submerged shelf about 40 miles long in a NW-SE direction and about 15 miles wide. The shelf lies at depths of 8 to 23 fathoms. Necker Island, itself, is about 0.7 miles long and less than 0.2 miles wide, with steep sea cliffs on all sides.

Water depth increases rapidly with distance from the island. All shallow benthic environments at Necker are subjected to severe wave action throughout the year. The winter North Pacific Swell, summer South Pacific Swell and the prevailing Northeast Trade Wind Swell continue to erode the cliffs at their base throughout the year. It appears that intense wave energy at Necker directly impacts the bottom and continually moves sand across the shelf areas. Abrasion and burial inhibit coral reef development, so coral coverage is low. The submerged shelf forms the major benthic zone. The major habitats are uncolonized hard bottom and unconsolidated sediments (sand). In some areas a thin veneer of carbonate sand has accreted in spite of wave erosion. Areas at depths up to 30 feet are characterized by high relief volcanic rock habitats that generally have coral coverage of less than 10 percent. In a few areas, coverage by reef corals reaches 20-30 percent. In general, the high-wave resistant coral Pocillopora meandrina dominates the shallows with coverage by Porites lobata as depth increases. At greater depths, the shelf generally shows low relief and low slope. Thin veneers of carbonate sand cover the underlying basalt in many areas. A thin layer of cabonate sediments is typically present and fills low areas or depressions on the shelf. Extensive areas of sand occur in some regions off Necker.

At least 52 archaeological sites have been identified on Necker. Many of these sites are Tahitian. Artifacts from some of Necker's archeological sites are on display at the Bishop Museum in Honolulu.

Necker was "rediscovered" and named in 1786 by Jean Francois de Galaup. He reported that, due to the terrain and the strong waves and currents, landing on the island was not possible.

Necker is essentially a barren island, having only six species of plants present. Despite this, each year, at least 60,000 birds of 16 species rest and nest there.

As is the case on all the NWHI, strict quarantine procedures must be followed by all personnel going ashore. New cloths, including shoes, that have been frozen for at least 48 hours, are required in order to step foot on Necker.

While on Necker Island, A. Wegmann conducted Hawaiian Monk Seal counts operations to provide an anecdotal count of population numbers. In total, there were 22 sightings, including one pup, of Monk seals hauled out on Necker.

Seas off the windward side of Necker Island were 8-10 ft with a 4-6 swell on the leeward side. Trade winds were moderate to strong. Benthic characterization using snorkel on the southwest side of the island was inhibited by a school of gray reef sharks that persisted in following the survey boats and schooling directly beneath them. As a result, the sites were classified from the boats using the underwater viewer instead of snorkel. In general, the benthic habitats surrounding Necker Island can be classified as uncolonized hard-bottom with sand patches and infrequent coral cover. Most habitats were gently sloping offshore with low relief (1-2 out of a possible 5). Several Monk seals were seen underwater in addition to the aforementioned gray reef sharks and a number of Uku (snapper).

Gyres in the lee of Necker Island caused erratic swinging of the SS Midway and started to draw her closer to the rocks. The captain elected to recall the small boats and reposition and re-anchor the SS Midway farther offshore. This repositioning was conducted without incident.

The benthic characterization teams noted abundant large herbivorous fishes and ecosystem dominance by apex predators. Sharks, jacks (Ulua and Kahala), snappers (Uku), Monk seals, and other large carnivores were conspicuously present at every benthic characterization site. The scarcity of well developed coral habitat as refugia for fishes is offset by high relief volcanic outcrops along the shoreline.

Figure Below (attached): White-tip shark, abundant large herbivorous fish, low coral cover and basalt features with high relief typify shallow areas off Necker Island (photo by Paul Jokiel). Macroalgae such as the Caulerpa sp. shown here are conspicuous features of many shallow areas.

Photo taken by Paul Jokiel of the University of Hawaii, Hawaii Institute of Marine Boilogy and provided by NOAA. Photo provided with permission of the U.S. Fish and Wildlefe Service, National Marine Fisheries Service, and the State of Hawaii's Department of Land and Natural Resources.

2 September 2001 – Operations on Necker Island were completed at approximately 15:30 and transit from Necker Island to French Frigate Shoals began at 18:00:00.

French Frigate Shoals (see Figure 9):

3 – 6 September 2001 – The SS Midway arrived at French Frigate Shoals (23 50'N X 166 17'W) about 06:00 on 3 September 2001.

Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

Working with the FWS/NMFS representative, the GPS team acquired GPS data at the 1961 Astronomic station, the GPS monument established by Mike Potterfield of Trimble, and established and occupied a new station “FRENCH 2001” on Tern Island. The GPS team acquired GPS data at six photoidentification points on Tern Island, four photoidentification points on East Island, and three photoidentification points on Trig Island. The GPS team acquired gravity data at six sites on Tern Island and two sites on East Island.

The GPS team acquired 90 percent (approximately 110 nautical miles) of bathymetry data on predetermined tracklines at Necker.

The benthic characterization teams acquired 158 samples at French Frigate Shoals. On 3 September, 45 sites were sampled. On 4 September, 51 sites were sampled. On 5 September, 27 sites were sampled. On 6 September, 35 sites were sampled.

General Observations: A triangulation station on East Island, SOUTHEAST BASE, from the 1926 USC&GS survey was searched for, but not found. US Fish and Wildlife Service and National Marine Fisheries Service personnel accompanied the NGS crew at all times, due to the presence of nesting birds and Hawaiian Monk Seals. Photoidentification work was not be possible on some of the islands due to the presence of Monk seals with pups.

General Observations: French Frigate Shoals is an extensive shallow-water, semi-enclosed atoll. The shallow water portion of the atoll covers at least 700 square kilometers. Tern Island, in the northern portion of the atoll, is permanently inhabited. Tern Island also has one of two landing strips in the NWHI. The second is on Midway.

French Frigate Shoals lies essentially halfway between Midway Atoll and the big island of Hawaii. It was formed approximately 13.8 million years ago as the Pacific Plate crossed over a "hotspot" in the Earth's mantle. The Pacific Plate continues to move WNW at about 9 cm. each year.

French Frigate Shoals appears to be the remnant NE portion of an atoll. The crescent-shaped windward reef is 17 miles long in a NNW direction that protects an extensive shallow lagoon that is bounded on the south by a series of elongated and broken reticulated reefs. The lagoon is from 1 to 6 miles wide. La Perouse Pinnacle, located near the middle of the south edge of the lagoon, is the major visual landmark in the area. La Perouse Pinnacle is a very dense volcanic “rock” remnant about 180 feet long, 60 wide, and 122 feet high. It indicates the center of the shield volcano that formed French Frigate Shoals. Numerous sand islets dot the lagoon area of French Frigate Shoals. East Island, 3 miles ENE of La Perouse Pinnacle, is a low sand bar 1800 feet long in a NW direction and about 300 feet wide. These sandy islets are constantly changing size and shape with changes in waves and currents. It also provides a roosting area for numerous seabirds.

Circulation in the reef areas is dominated by the North Pacific Swell, Trade Wind Swell, by the Trade Winds and, to a lesser extent, by tide. Waves constantly break over the crest of the ocean reef, creating a current that flushes the lagoon to the SW. Along the south margin of the lagoon, the elongate reticulated reefs are subjected simultaneously to current and small waves from the lagoon side and to small refracted ocean swell from the south. A SW current of 2 knots was encountered on the fore-reef channel northwest of Tern Island. Strong currents are generated by waves along the entire shallow windward reef area. Current decreases in the back-reef, as water depth increases in the lagoon. The NE trades prevail throughout the year and drive lagoon circulation. The average wind velocity is 12 knots, with monthly averages of about 16 knots in December.

French Frigate Shoals presents a contrast in benthic habitats. Vast areas of many square miles are devoid of reef coral development, while other areas are among the richest reefs observed in Hawaii. Sand, rubble, uncolonized hardbottom and crustose coralline algae dominate the lagoon and the windward reef. It appears that severe North Pacific Swell and NW Trade Wind Swell suppresses reef coral development in major areas of the atoll. Large amounts of sand constantly move with shifting wave patterns and currents along the lagoon floor, periodically burying and uncovering large areas. Sand islands constantly change size and shape. The lagoon is strewn with small patch reefs, all of which consist of a dead Porites compressa framework and rubble with little live coral. No evidence was found of former reef formation by Acropora cytheria in these regions. Porites compressa apparently was the major reef framework coral when the lagoon was deeper, although it is no longer a major reef-forming coral anywhere in the atoll. However, several areas of the atoll have immense stands of reef corals dominated by the table corals Acropora cytheria and Porites lobata. The southeastern portion of the atoll has several large coral mounds similar to those surveyed in previous days and several spectacular areas of aggregated coral heads. The mounds rose 30-40 feet from the surrounding area, contained numerous archways and canyons, and exhibited extensive live coral cover, mainly of Acropora cytheria, Porites lobata and Pavona duerdeni. Live coral cover on these features at times reached 70-80 percent. All of the coral-rich areas are characterized by the following:

1. Shelter from direct impact of the North Pacific Swell and NE Trade Wind Swell;
2. Sloping bottom topography that transports sand away from the area and prevents accumulation;
3. High local topographic relief; and
4. Good water circulation (current) no damaging storm surge.

The above conditions, favorable to reef coral development, are found on the extreme SE, NW, and S areas of the atoll platform. In these areas, stunning coral formations occur at depths of from 20 to 70 feet with the best development at depths of approximately 40- 50 feet. Acropora cytheria and Porites lobata now the dominant reef forming coral species. Coraline algae, mollusks, echinoderms, and foraminifera are presently the major reef forming organisms in the lagoon.

The satellite images showed the presence of large dark patches along the north reef slope of the atoll. These patches were considered to be priority sites for benthic characterization. These features turned out to be immense, almost exclusive patches of the soft coral Zoanthus sp. The soft coral covered areas up to several acres in size. Adjacent areas along the fore-reef were free of Zoanthus. Zoanthus is common in nutrient enriched bays in the main eight islands, but patches never reach the size and densities observed here. Dominance by soft coral was unexpected in an open-ocean, high wave energy location. Lighter areas surrounding the dark patches seen in the imagery were crustose coaline algae interlaced with sand patches and channels. Dark areas in the lagoon were dead Porites compressa reefs or rubble; light areas were sand. Dark areas on the southwest end of the lagoon were extensive living reef complexes; light areas were sand or uncolonized hardbottom with a thin veneer of sand.

One of the most striking features of the French Frigate Shoals reef ecosystem is the dominance by large predators. This has been emphasized in reports from previous surveys. Any observer familiar with the reef fauna of the main eight Hawaiian Islands would certainly be startled at the abundance of large Ulua (Caranx ignobilis), Omilu (Caranx melampygus), Uku (Aprion virescens), Grey Reef Sharks (Carcharhinus amblyrhynchos), Hawaiian Monk Seals, and other large predators.

French Frigate Shoals is the most important breeding and nesting for the Hawaiian green sea turtle in the entire Hawaiian archipelago. The numerous shoals and sand bars offer perfect habitat for these ancient creatures to reproduce.

French Frigate Shoals also the home to millions of birds. On Tern Island alone, an estimated 1.5 million Sooty Terns nest and breed.

La Perouse Pinnacle is believed to provide an underground sanctuary for Hawaiian monk seals and other marine creatures that would otherwise end up as food for resident and visiting sharks. The presence of an underground lava tube certainly could provide safe haven for seals and turtles being chased by sharks.

The GPS team scouted La Perouse Pinnacle to see if it was possible to reach the top to locate a previous control point from the 1928 survey of French Frigate Shoals. Research indicated that the pinnacle was the primary location for the astronomic control work done on the atoll for hydrography. The GPS team determined that it was too difficult to land on and climb the pinnacle.

The areas surrounding La Perouse, while technically within the lagoon area, were more typical of open bank/shelf areas with extensive areas of volcanic rock and boulders. On this substrate were found extensive coverage of P. lobata as well as numerous colonies of Acropora cytheria, A. valida, and A. humilus. There was also a large tunnel that extended from one side of the pinnacle to the other, approximately 30 feet under water. The total length of this tunnel was not more than 30 ft. This tunnel possibly acts as a sanctuary to protect smaller fish and Monk seals from predators.

Also found in the deeper areas of the lagoon near La Perouse Pinnacle were a number of pinnacles or mound composed of dead P. compressa framework, dead and live P. lobata; rose 30-40 feet above the surrounding sand and rubble areas and were several hundred feet in diameter.

The benthic team also recovered Fish Aggregation Device Buoy (FAD) "T" which recently broke loose from between Kailua Bay and Makapuu Point Bay, Oahu.

Due the size and remoteness of French Frigate Shoals, the small boats will stayed within radio contact of both the SS Midway and each other.

The benthic team experienced slight trouble with the GPS units due to poor satellite geometry. With signals from only 4 satellites aligned in a row, triangulation was an issue and we had to spend some extra time allowing the GPS units to stabilize on our positions. Despite this inconvenience, all sites were surveyed accurately.

Image of the soft coral Zoanthus sp. at French Frigate Shoals. Photo provided by NOAA with the permission of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and the State of Hawaii's Department of Land and Natural Resources.

The attached image from French Frigate Shoals is provided by NOAA with the permission of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and the State of Hawaii's Department of Land and Natural Resources.

The attached image from French Frigate Shoals is provided by NOAA with the permission of the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and the State of Hawaii's Department of Land and Natural Resources.

image. of a stand of the coral Acropora cytherea taken near La Perouse Pinnacle at French Friagte Shoals. (see 9/8/01 Situation Report)

6 September 2001 – The SS Midway departed French Frigate Shoals about 17:30 hours and transited to Gardner Pinnacles.

Gardner Pinnacles (see Figure 10):

7 September 2001 – The SS Midway arrived at Gardner Pinnacles (24 59'N X 168 00'W) about 7:45:00.

Personnel: D. Minkle (Chief Scientist), D. Crump, J. Evjen, J. Harrington, A. Wegmann (FWS/NMFS representative), E. Brown, P. Jokiel, R. Kelty, S. Kolinski, B. Richards, and W. Smith.

Working with the FWS/NMFS representative, the GPS team acquired GPS data at two 1961 Astronomical Stations on Gardner Pinnacles. No photoidentification points or gravity data were acquired.

Because of mechanical problems with the small boats, no bathymetry data was gathering at Gardner Pinnacles.

The benthic characterization teams acquired 42 samples at Gardner Pinnacles.

General Observations: Gardner Pinnacles - all three acres of it - is what remains of a shield volcanic island that, 14 million years ago, may have been over 80 square miles in size.

The astronomical GPS stations on Gardner Pinnacles were established during a reconnaissance during the early 1960s. It has been reported that, in order to establish a monument on Gardner Pinnacle, the top of the pinnacle was actually dynamited so that helicopters could land.

Any approach to Gardner Pinnacles can be dangerous, and actually landing on the island can be very treacherous. The island has very sheer rock walls that also are slippery from seabird guano. On the day the GPS team attempted to land on Gardner Pinnacles, sea state was calm. Rather than leave the GPS equipment on the island overnight and risk not being able to retrieve it, the GPS team acquired data for approximately six hours, disassembled the equipment, and departed the island.

Ships report that charts depicting Gardner Pinnacles are as much as two kilometers from its actual position. The GPS data gathered during the mission will enable the position Gardner Pinnacles to be accurate to within 0.5 meters of its actual location on the earth.

The seabed surrounding Gardner Pinnacles was mostly covered by uncolonized hardbottom areas and volcanic rock. There were, however, several areas colonized with P. meandrina, Palythoa, Sinularia, and a few Acroporids. Near the pinnacle, the bottom was composed of large volcanic boulders, which was home to a variety of reef fish, Ulua, and Uku.

Photoidentification points could not be identified on Gardner Pinnacle due to the nature of the island and the amount of bird guano on the island.

Gardner Pinnacles includes a vertical island wall habitat, the only occurrence of this habitat type in our sampling in the NWHI system.

Gardner Pinnacles are two volcanic islets. These islets are the remnant emergent portions of a large shield volcano that has been eroded to produce an extensive bank or shelf. The larger pinnacle is 190 feet high and about 600 ft. in diameter. The smaller pinnacle is located about 300 ft. from the NW side of the larger. Gardner Pinnacles lie near the NE side of the extensive bank, which is about 50 miles long and about 20 miles wide near the N end. The bank has depths ranging from 60 ft. to 150 ft. depth. Benthic habitats at the base of the pinnacles consist of vertical basalt walls and boulder habitats. Depth increases rapidly to a basalt platform lying at a depth of approximately 40 ft. near the islets. The platform slopes steeply away from the pinnacles, leveling off near the 60 ft. depth. The shallowest (10 ft. ‹30 ft.) portions of this sloping habitat show some areas with coral coverage of 10 percent to 30 percent dominated by the reef corals

Pocillopora meandrina and Porites lobata. Acropora spp. is present, in very small amounts. The soft corals Palythoa caesia and Sarcophyton sp. are abundant in localized areas. However, the dominant habitat type to depths of 60 feet is uncolonized volcanic rock. From depths of 60 to over 100 feet, unconsolidated rubble and sand habitats are common and dominate areas of uncolonized basalt. The volcanic shelf surrounding the Pinnacles shows low relief with areas of shifting unconsolidated substratum, which presumably prevents coral settlement and reef development in spite of excellent water clarity. The platform is remarkably flat and featureless for great distances.

7 September 2001 – The SS Midway departed from Gardner Pinnacles about 19:00:00 for Maro Reef.

8 – 10 September 2001 – Second visit to Maro Reef. Please see information provided above related to activities performed during the visit to the second visit to Maro Reef.

10 September 2001 – Begin transit to Pearl and Hermes Atoll. En route, mechanical problem with SS Midway required the trip to Pearl and Hermes to be aborted. The SS Midway transited directly to Midway Atoll.

11 – 12 September 2001 – Transit to Midway Atoll. The SS Midway arrived at Midway Atoll about 17:00:00 on 12 September 2001.

13 – 19 September 2001 – Third visit to Midway Island. Please see information provide above related to activities performed during the third visit to Midway Atoll.

19 September 2001 – All remaining NWHI misison personnel leave Midway Atoll. The mission officially ends.

Figure 1 - Midway Atoll

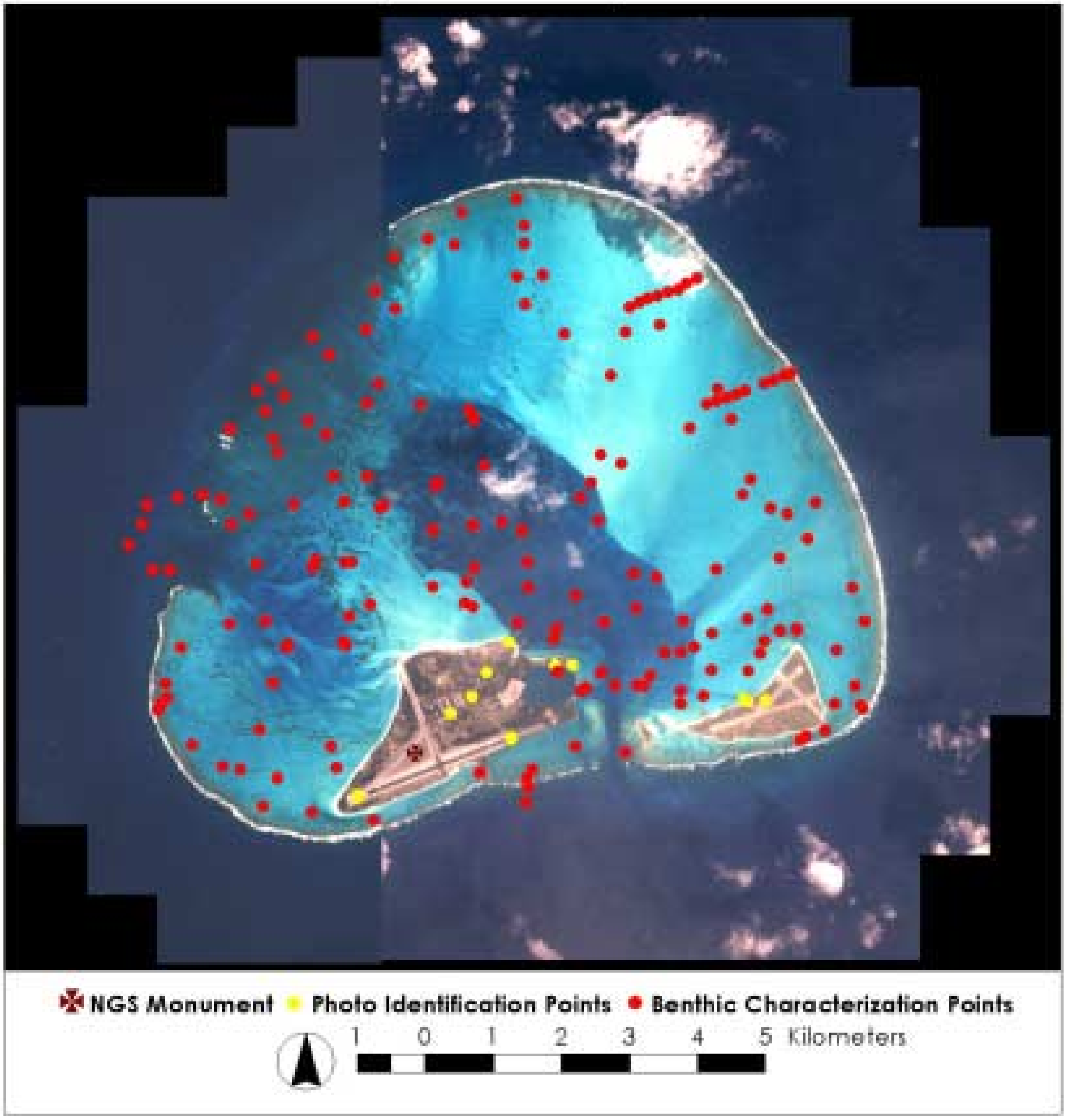

Figure 2 - Kure Atoll

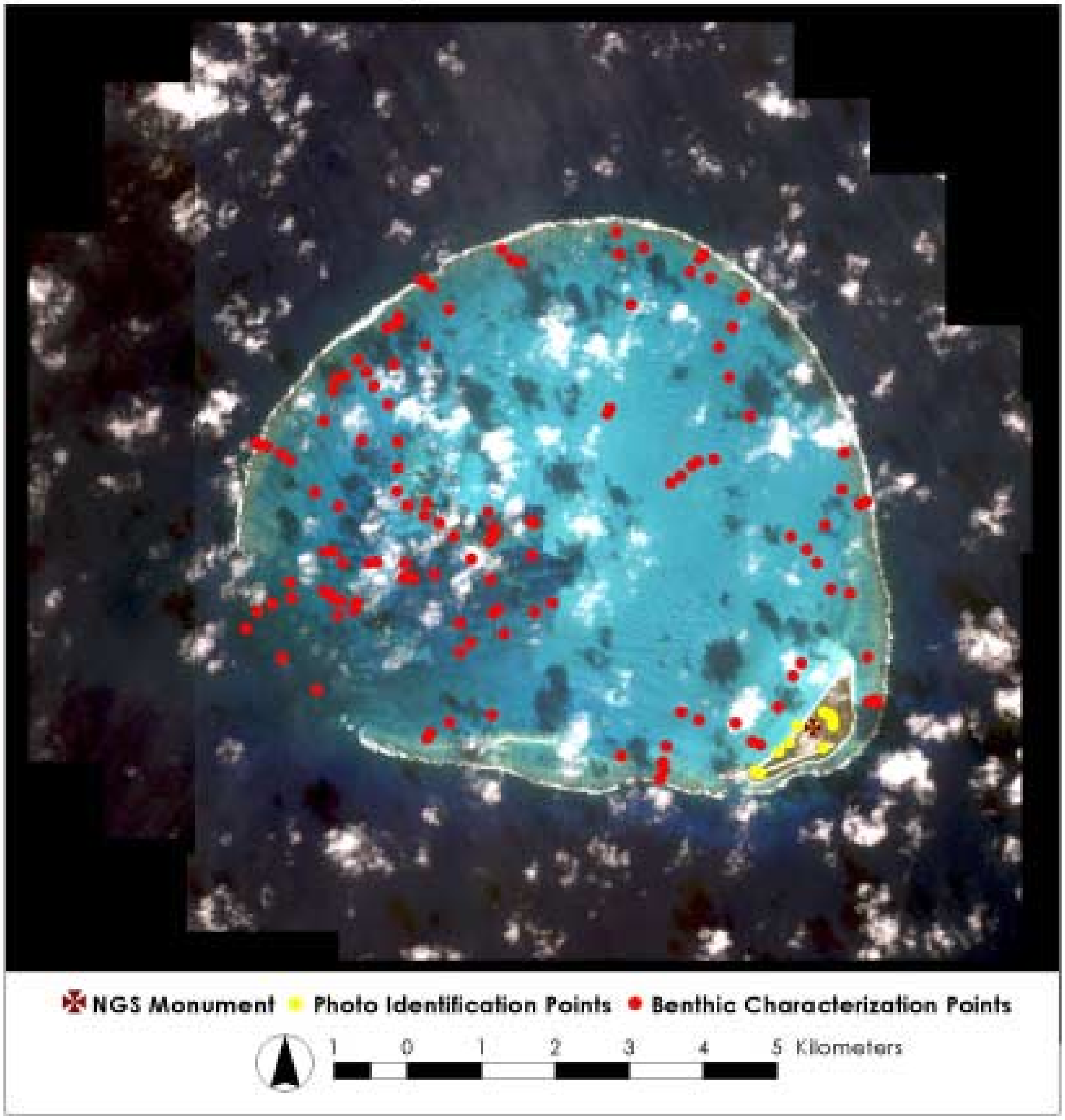

Figure 3 - Pearl and Hermes Atoll

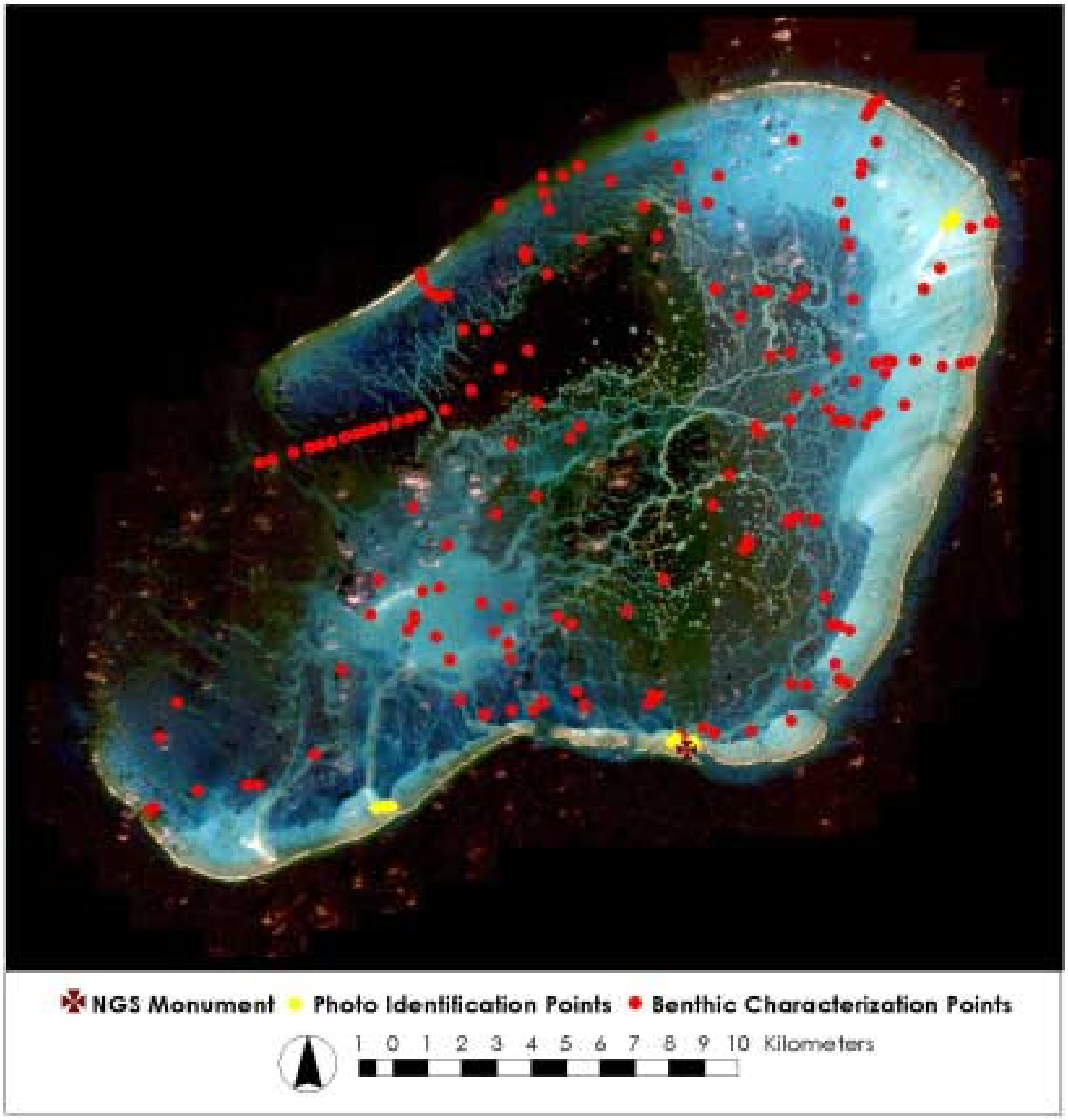

Figure 4 - Lisianski Island

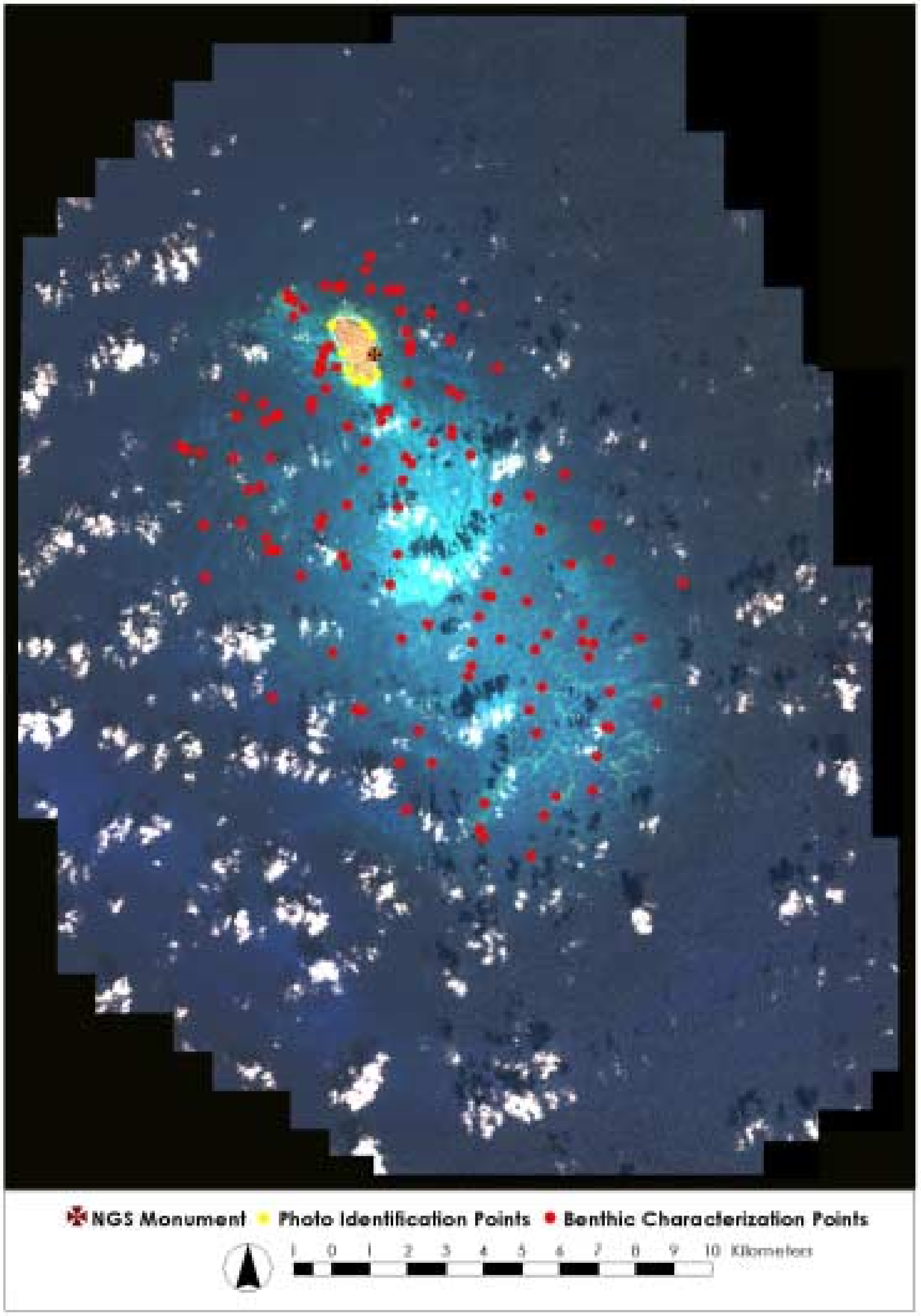

Figure 5 - Laysan Island

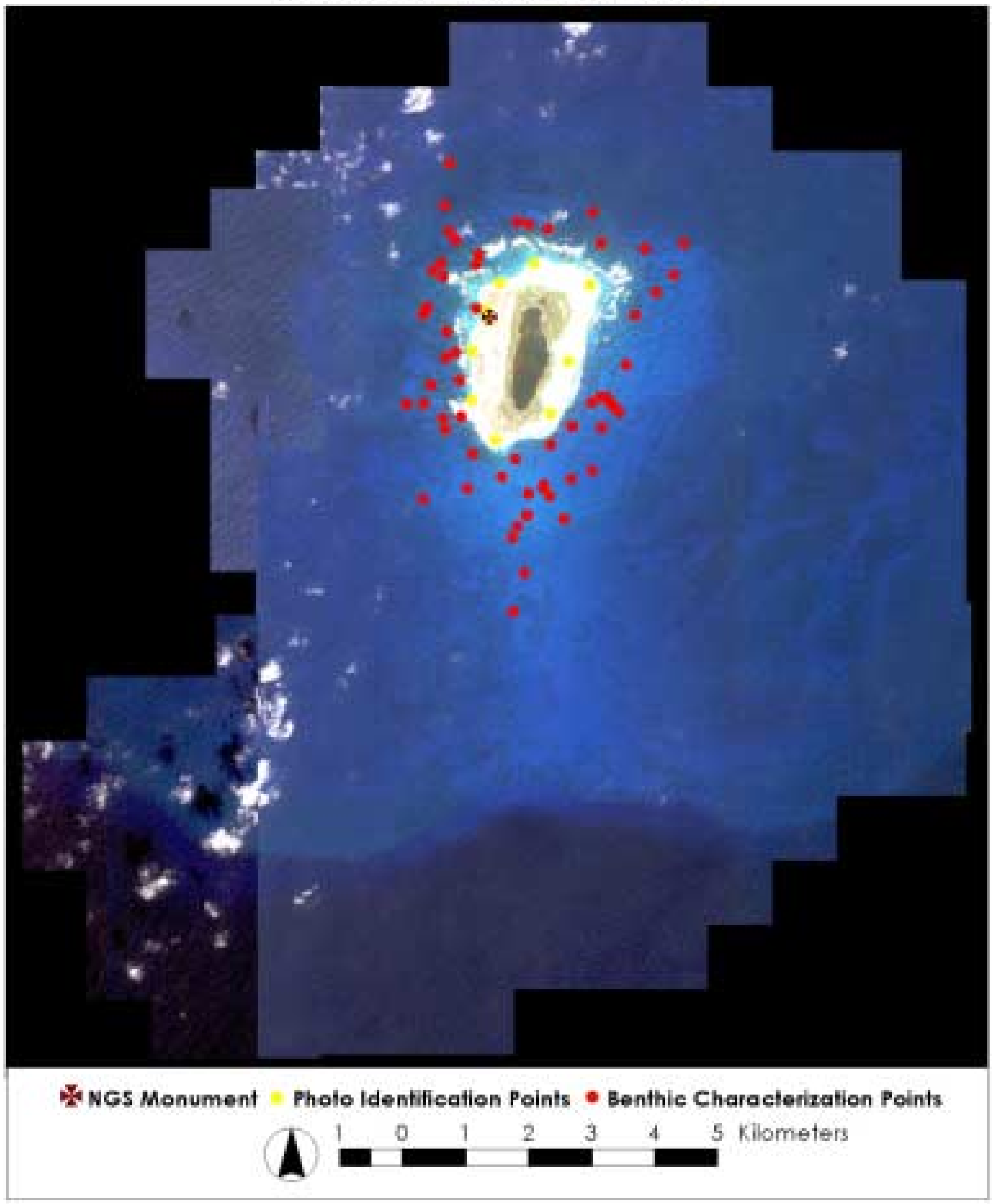

Figure 6 - Maro Reef

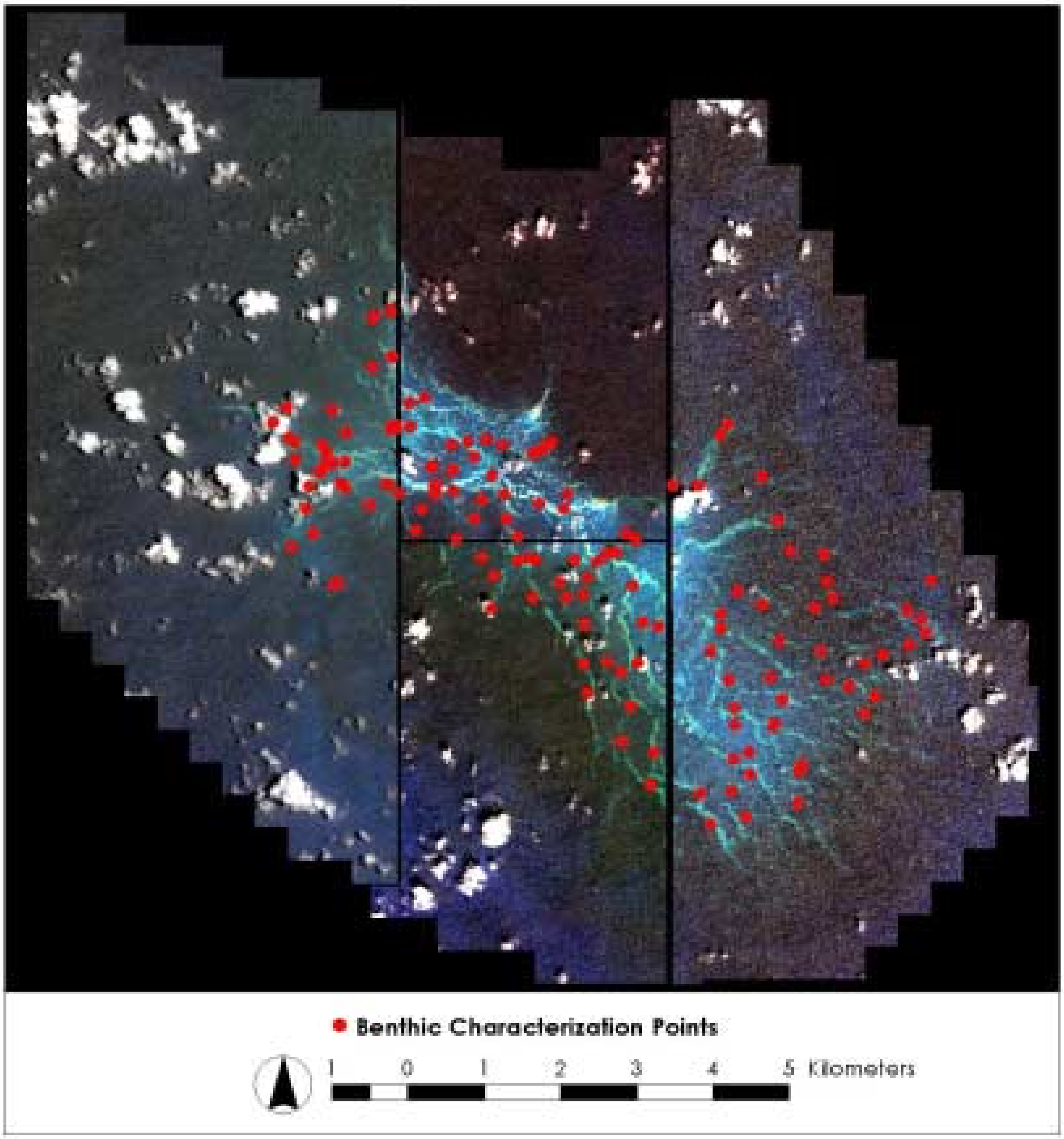

Figure 7 - Nihoa Island

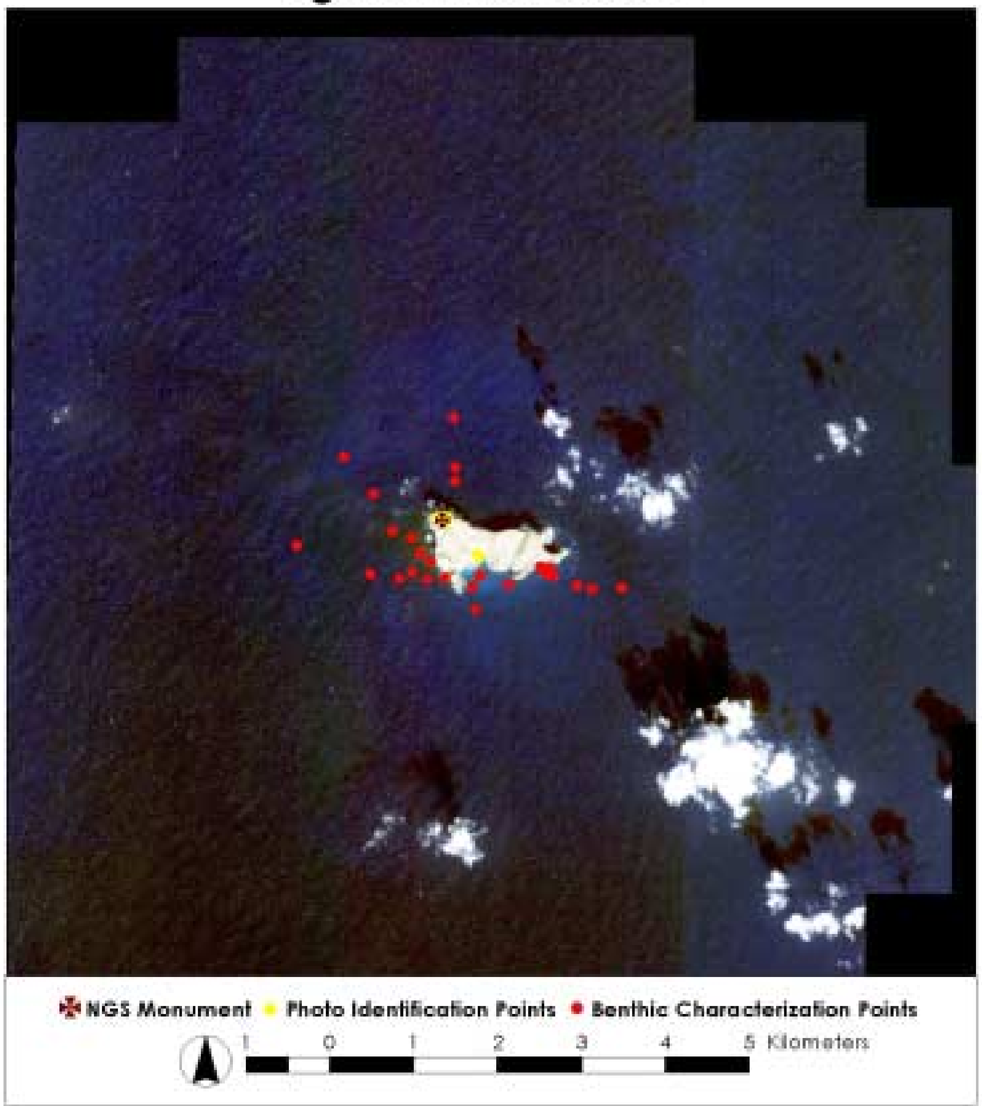

Figure 8 - Necker Island

Figure 9 - French Frigate Shoals

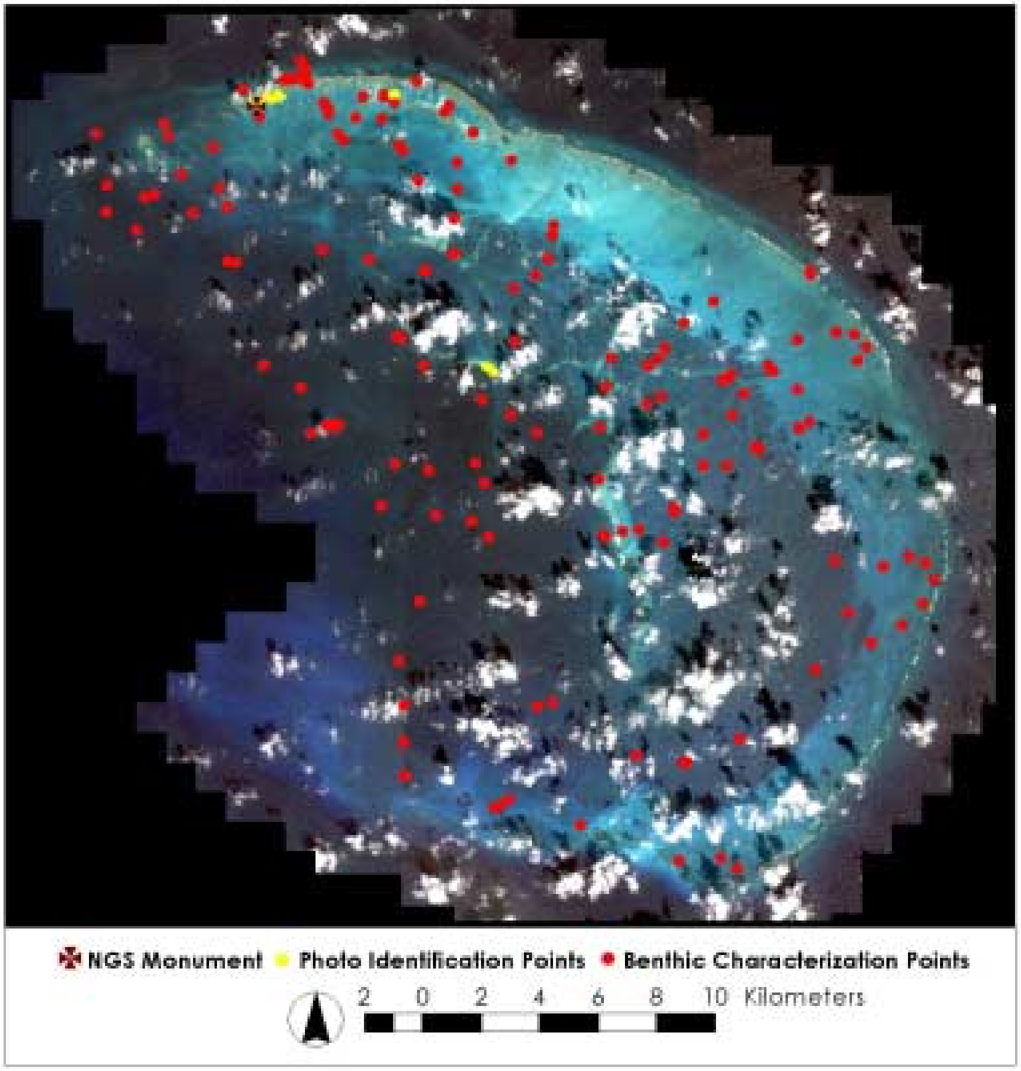

Figure 10 - Gardner Pinnacles