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CRUISE REPORT[1]

VESSEL: NOAA Ship *Hi`ialakai*, Cruise HA-10-07

CRUISE PERIOD: 4 September–29 September 2010

AREA OF OPERATION: Northwestern Hawaiian Islands (NWHI): French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, and Lisianski Island and Neva Shoal. Main Hawaiian Islands: Five Fathom Pinnacle.

TYPE OF OPERATION: Personnel from the Coral Reef Ecosystem Division (CRED) of the Pacific Islands Fisheries Science Center (PIFSC), Papahānaumokuākea Marine National Monument (PMNM), University of Hawai`i (UH), and San Diego State University conducted interdisciplinary Pacific Reef and Assessment Program (Pacific RAMP) surveys in waters surrounding French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, Lisianski Island and Neva Shoal, and Five Fathom Pinnacle. All activities in the PMNM described in this report were covered by PMNM permit PMNM-2010-052. All research activities at Five Fathom Pinnacle in the main Hawaiian Islands were conducted in compliance with and following guidance provided by the Hawai`i Department of Land and Natural Resources, Division of Aquatic Resources.

ITINERARY:

Note: Daily field operations included Rapid Ecological Assessment (REA) benthic surveys, REA fish surveys, and towed-diver surveys of both benthic and fish communities. Unless otherwise specified in the following daily summaries, these surveys occurred during each operational day.

4 September Start of cruise. Embarked all scientific crew. Departed Pearl Harbor, Honolulu, O`ahu Island, at 1500, and began transit to French Frigate Shoals.

5 September Transit day.

[1] PIFSC Cruise Report CR-11-002
Issued 15 April 2011

6 September Arrived at French Frigate Shoals at ~ 1600. Shipboard operations included acoustic Doppler current profiler (ADCP) transects, deepwater conductivity, temperature, and density (CTD) casts, and water sampling for chlorophyll-*a* (Chl-*a*) and nutrient concentrations.

7 September Began field operations at French Frigate Shoals, and deployed and retrieved the following types of instruments: Coral Reef Early Warning System (CREWS) buoy anchor, sea-surface temperature (SST) buoy, subsurface temperature recorder (STR), autonomous reef monitoring structure (ARMS), and calcification acidification unit (CAU). Nearshore water samples were collected for nutrient, Chl-*a*, dissolved inorganic carbon (DIC), salinity, and microbial community analyses. Samples of the green algal genus *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

8 September Continued field operations at French Frigate Shoals. Deployed and retrieved the following types of instruments: STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

9 September Continued field operations at French Frigate Shoals. Deployed and retrieved the following types of instruments: STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

10 September Continued field operations at French Frigate Shoals. Deployed and retrieved the following types of instruments: SST buoy, STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations. Began transit to Pearl and Hermes Atoll.

11 September Transit day.

12 September Transit day.

13 September Arrived and began field operations at Pearl and Hermes Atoll. Deployed and retrieved the following types of instruments: acoustic Doppler profiler (ADP), ocean data platform (ODP) plate, remote access sampler (RAS), STR, temperature and salinity sensor (SBE 37 MicroCAT, Sea-Bird Electronics Inc., Bellevue, Wash.), and ARMS. Nearshore water samples were collected for microbial community analysis.

14 September Continued field operations at Pearl and Hermes Atoll, and deployed and retrieved the following types of instruments: SST buoy, STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

15 September Continued field operations at Pearl and Hermes Atoll, and deployed and retrieved the following types of instruments: STR, ARMS, ecological acoustic recorder (EAR), and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

16 September Continued field operations at Pearl and Hermes Atoll, and deployed and retrieved the following types of instruments: STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

17 September Continued field operations at Pearl and Hermes Atoll, and deployed and retrieved the following types of instruments: ODP anchor, RAS, STR, temperature and salinity sensor, and ARMS. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations. Began transit to Kure Atoll.

18 September Arrived and began field operations at Kure Atoll. Deployed and retrieved the following types of instruments: SST buoy, STR, wave-and-tide recorder (WTR), and ARMS. Samples of *Halimeda* were collected for calcification studies. Nearshore water samples were collected for microbial community analysis.

19 September Continued field operations at Kure Atoll, and deployed and retrieved the following types of instruments: STR, WTR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

20 September Continued field operations at Kure Atoll, and deployed and retrieved the following types of instruments: SST buoy, STR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations. Began transit to Lisianski Island and Neva Shoal.

21 September Transit day.

22 September Arrived and began field operations at Lisianski Island and Neva Shoal. Deployed and retrieved the following types of instruments: SST buoy, STR, WTR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

23 September Continued field operations at Lisianski Island and Neva Shoal, and deployed and retrieved the following types of instruments: STR, WTR, ARMS, and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations.

24 September Continued field operations at Lisianski Island and Neva Shoal, and deployed and retrieved the following types of instruments: ARMS and CAU. Nearshore water samples were collected for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses. Samples of *Halimeda* were collected for calcification studies. Nearshore CTD profiles were collected, and shipboard operations included ADCP transects, deepwater CTD casts, and deepwater water sampling for Chl-*a* and nutrient concentrations. Began transit to Five Fathom Pinnacle.

25 September Transit day.

26 September Transit day.

27 September Transit day.

28 September Arrived at Five Fathom Pinnacle and deployed and retrieved an EAR. Began transit to Honolulu.

29 September Arrived at Pearl Harbor, Honolulu. Disembarked all scientific crew. End of cruise.

MISSIONS:

A. Conducted ecosystem monitoring of the species composition, abundance, percentage of cover, size distribution, and general health of the fishes, corals, target macroinvertebrates, and algae of the shallow-water (≤ 30 m) coral reef ecosystems of French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, and Lisianski Island and Neva Shoal.

B. Deployed and retrieved an array of instruments—including an ADP, RAS, SST buoys, STRs, a temperature and salinity sensor (SBE 37), WTRs, ARMS, CAUs, and EARs—and collected samples of the calcified, sand-producing alga *Halimeda* to allow for remote, long-term monitoring of oceanographic, environmental, and ecological conditions affecting the coral reef ecosystems of French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, Lisianski Island and Neva Shoal, and Five Fathom Pinnacle.

C. Conducted shallow-water CTD casts and collected water samples for nutrient, Chl-*a*, DIC, salinity, and microbial community analyses to depths ≤ 30 m to examine physical and biological linkages supporting and maintaining these island and atoll ecosystems.

D. Conducted shipboard oceanographic and meteorological observations, using CTD casts deployed to a depth of 500 m, collecting water samples to a depth of 150 m, collecting ADCP data around reef ecosystems, measuring SST and salinity, and collecting fundamental meteorological data, such as air temperature, wind speed and direction, barometric pressure, and relative humidity to examine physical and biological linkages supporting and maintaining these island and atoll ecosystems.

E. Determined the existence of threats to the health of these coral reef resources from anthropogenic sources, including marine debris.

RESULTS:

This section provides tallies of research activities (Table 1), a summary of important observations, and a list of data collected during cruise HA-10-07. For more information pertaining to the data collected, methodology employed, and preliminary findings at the islands visited, see Appendices A–H.

Table 1.--Statistics for the Pacific RAMP 2010 cruise (HA-10-07) to French Frigate Shoals (FFS), Pearl and Hermes Atoll (PHR), Kure Atoll (KUR), Lisianski Island and Neva Shoal (LIS), and Five Fathom Pinnacle (FFP). "Other" includes operations conducted from the NOAA Ship *Hi`ialakai* that were not directly associated with an island (see Figure G.1.1 in Appendix G: "Northwestern Hawaiian Islands"). The total numbers for REA sites includes sites where REA benthic or fish surveys were conducted. The totals for scuba dives include all dives carried out for all activities at each island. For information about biological sample collections by REA site, see Table H.1 in Appendix H: "Biological Collections."

Research Activity	FFS	PHR	KUR	LIS	FFP	Other	Total
Scuba Dives	189	267	162	149	2	0	769
Biological Surveys							
Towed-diver Surveys: Benthic and Fish	21	26	15	14	0	0	76
Combined Length (km) of Towed-diver Surveys	46.2	55.5	33.6	29.5	0	0	164.8
REA Sites: Benthic	11	15	11	9	0	0	46
REA Sites: Fish	27	41	25	25	0	0	118
Biological Sample Collections							
Algal Voucher Specimens	6	9	4	4	0	0	23
Halimeda Samples (ocean acidification research)	125	108	20	60	0	0	313
Tissue Samples of Diseased Corals	0	0	3	0	0	0	3
Biological Moored Installations							
ARMS Retrieved	5	15	7	7	0	0	34
ARMS Deployed	6	9	9	9	0	0	33
CAUs Deployed	25	25	25	25	0	0	100
EARs Retrieved	0	1	0	0	1	0	2
EARs Deployed	0	1	0	0	1	0	2
Oceanographic Moored Instruments							
SST Buoys Retrieved	1	1	1	1	0	0	4
SST Buoys Deployed	1	1	1	1	0	0	4
STRs Retrieved	9	18	6	3	1	0	37
STRs Deployed	10	17	10	7	1	0	45
WTRs Retrieved	0	0	2	1	0	0	3
WTRs Deployed	0	0	2	2	0	0	4
Temperature and Salinity Sensors Retrieved	0	1	0	0	0	0	1
Temperature and Salinity Sensors Deployed	0	1	0	0	0	0	1
ADPs Retrieved	0	1	0	0	0	0	1
ADPs Deployed	0	1	0	0	0	0	1
Anchors Retrieved	2	2	3	3	0	0	10
Anchors Deployed	1	2	3	3	0	0	9
Hydrographic Surveys							
Shallow-water CTD Casts	5	5	5	5	0	0	20
Deepwater CTD Casts: Total	25	24	12	19	0	3	84
Deepwater CTD Casts: Permanent Sites	1	1	1	1	0	3	7
Total Length (km) of ADCP Transects	100	100	50	75	0	0	325
Water-quality Sampling							
Shallow-water Nutrient Water Samples	11	12	12	10	0	0	45
Shallow-water Chl-*a* Water Samples	10	10	12	10	0	0	42

Research Activity	FFS	PHR	KUR	LIS	FFP	Other	Total
Shallow-water Salinity Water Samples	10	10	12	9	0	0	41
Shallow-water DIC Water Samples	10	58	12	10	0	0	90
Deepwater Nutrient Water Samples	25	25	15	20	0	15	98
Deepwater Chl-*a* Water Samples	25	25	15	20	0	15	98
DIC Samples from Shipboard pCO_2 System	0	0	0	0	0	6	6
RAS Deployed and Recovered	0	1	0	0	0	0	1
Microbial Water Samples	16	20	12	12	0	0	60
Metagenomic Microbial Water Samples	3	3	3	3	0	0	12

The coral reef ecosystems of the Northwestern Hawaiian Islands are surveyed biennially through CRED's Pacific RAMP. The cruise HA-10-07 marked this program's eighth expedition around French Frigate Shoals (23.064385° N, 166.173283° W), Pearl and Hermes Atoll (27.856098° N, 175.847545° W), Kure Atoll (28.418958° N, 178.326147° W), and Lisianski Island and Neva Shoal (26.064385° N, 173.965605° W). Here, we present highlights from our observations during this latest expedition.

French Frigate Shoals

- Seasonal temperature fluctuations varied between the 2 years for which in situ data was collected; wintertime temperatures in 2010 prevailed until May at French Frigate Shoals as opposed to only until March in 2009.
- Subsurface temperature data from STRs deployed on Rapture Reef recorded 2°C–4°C temperature changes occurring multiple times per day.
- Towed-diver benthic surveys and REA benthic surveys, using the line-point-intercept and belt-transect methods, along the southern forereef found large areas of broken staghorn coral (*Acropora cytherea*), likely the result of hurricane activity in 2009. Many *Acropora* tables were overturned, exposing turf-covered calcium carbonate pavement and fragmented pieces of turf-covered *Acropora*.
- The majority of benthic surveys revealed reef conditions similar to the conditions observed during surveys in previous years.
- Coral disease surveys did not indicate a prevalence of coral bleaching at the REA benthic sites.
- REA fish surveys noted the presence of the green jobfish (*Aprion virescens*). This fish is usually seen singly or in small groups; however, at one forereef REA site, FFS-187, a school of more than 50 fish was seen.
- Findings from towed-diver fish surveys were in-line with findings from previous expeditions.

Pearl and Hermes Atoll

- In situ SST data indicate a warmer than average summer in 2010, compared to weekly climatological temperature data, and prolonged periods (7–14 d) where in situ SST exceeded the Coral Reef Watch bleaching threshold, defined as 1°C above the maximum monthly climatological mean, for Pearl and Hermes Atoll.
- From October 2009 to April 2010, SST was 0.5°C–3°C cooler than the long-term climatological average.

- Subsurface temperature data from STRs deployed on the south forereef at 13 and 38 m show diurnal and semidiurnal temperature fluctuations of 1°C–6°C, with the magnitude of variability increasing from shallow to deep.
- REA benthic surveys recorded extensive populations of the green alga *Boodlea composita* within this atoll's lagoon. The density and distribution seemed considerable; however, the benthic team surveyed too few sites in the lagoon to map the extent of the distribution.
- REA benthic surveys, using the line-point-intercept and belt-transect methods, revealed similar diversity of organisms and cover percentages of benthic plants and animals when compared to results from the previous Pacific RAMP surveys conducted by CRED at this atoll.
- Elevated levels of stressed-coral cover of the Hawaiian rice coral (*Montipora capitata*) were observed along the southwestern backreef. Cover of stressed corals was detected as high as 75% for select segments of towed-diver surveys, although low coral cover was observed during the majority of surveys.
- On the northeastern forereef of Pearl and Hermes Atoll, at site PHR-334, divers conducting REA fish surveys were surrounded by a large school of giant trevally (*Caranx ignobilis*). This school included ~ 100 individuals ranging in size from 90–130 cm in total length.
- The schools of giant trevally, or *ulua* in the Hawaiian language, encountered during towed-diver surveys along the southern forereef of this atoll contained more individuals than the schools observed at this atoll in previous years.

Kure Atoll

- In situ SST data from the lagoon at Kure Atoll show that average temperature was 0.5°C higher from July–September in 2010 than the average recorded during the same time frame in 2009.
- In situ SST exceeded the Coral Reef Watch bleaching threshold multiple times during the summers of 2009 and 2010.
- Subsurface temperature data from STRs deployed on the northwest forereef at a depth of 20 m show 1°C–5°C temperature changes on diurnal to semidiurnal return periods, whereas same-depth temperature data from STRs on the southeast forereef show no such oscillations, indicating strong differences in the prevailing physical forcing mechanisms driving thermal variability.
- Localized coral bleaching was observed in the west and northwest shallow-water backreefs. Bleaching was mostly limited to species of *M. capitata* and *Pocillopora*, with the former showing an increase in bleaching levels from previous years and the extent of bleaching for the latter observed to be relatively normal.
- Blooms of *B. composita* were dramatically reduced from the populations reported in 2008 and 2009.
- Elevated levels of stressed-coral cover of *M. capitata* were observed along the northern backreef. Cover of stressed corals was detected as high as 75% for select segments of towed-diver surveys, although low coral cover was observed during the majority of surveys.

- On the southeast end of Kure Atoll, at site KUR-171, divers were visited by about 10 Galapagos reef sharks (*Carcharhinus galapagensis*), who accompanied the divers on their 5-m safety stop and were joined by more than 24 other sharks until their numbers reached almost 40.
- Increased sightings of the spotted knifejaw (*Oplegnathus punctatus*) occurred during surveys along the forereef.

Lisianski Island and Neva Shoal

- SST and subsurface temperature data from SST buoys and STRs deployed at depths up to 20 m are highly similar with respect to magnitude and variability throughout the year.
- From September 2009 to March 2010, in situ SST is often 0.5°C cooler than subsurface temperature recorded by STRs deployed at a depth of 20 m.
- The above 2 observations are atypical for the NWHI, where subsurface temperatures are typically much colder and have increased variability compared to surface temperatures.
- Paling and bleaching among *M. capitata* colonies were observed throughout the survey areas at Lisianski Island and Neva Shoal; however, levels were not to the extent seen at Kure Atoll and Pearl and Hermes Atoll. Values of stressed-coral cover rarely exceeded 20%.

The following data and samples were collected during this expedition:

REA Benthic Surveys:

- Digital still photos of overall site character and typical benthos
- Digital photoquadrat images of the benthos
- Quantitative assessments of benthic composition from line-point-intercept surveys
- Algal voucher specimens necessary for algal species identification
- Samples of the algal genus *Halimeda* to determine degree of calcification for ocean acidification research
- Field notes of algal species diversity and relative abundance
- Number of coral colonies by genus, within belt transects of known area, and overall coral colony density
- Size-class metrics of corals within belt transects of known area
- Number of coral colonies exhibiting signs of bleaching and disease within belt transects of known area
- Tissue samples of diseased corals for histopathological analysis
- Digital photographs of diseased corals and algae
- Analyses of microbial communities from water samples collected at REA sites

REA Fish Surveys:

- Number, species, and estimated sizes of all fishes observed within a 7.5-m radius from stationary-point-count surveys
- Visual estimates of benthic cover, habitat type, and habitat complexity
- Digital photoquadrat images to characterize benthic cover

- Digital photographs of rare or interesting fish species
- Species presence checklists for estimates of fish community diversity

Towed-diver Surveys:

- Benthic habitat characterization, including visual estimates of habitat complexity, habitat type, and cover of corals, stressed corals, macroalgae, and crustose coralline algae
- Quantitative assessments of large (≥ 50 cm in total length) reef fishes to species level
- Counts of target macroinvertebrates, including crown-of-thorns seastars, sea cucumbers, and sea urchins
- Quantitative and qualitative assessments of key protected species and species of concern, including cetaceans, sea turtles, and rare fishes
- Digital photographs and video of benthic habitats
- Temperature data

Shipboard Oceanography:

- Deepwater CTD profiles to a depth of 500 m
- Measurements recorded by CTD sensor: dissolved oxygen, turbidity, fluorescence, and pH
- Nutrient and Chl-*a* concentrations from water samples collected at variable depths
- Transects of profiles of ocean current velocity and direction collected using a shipboard ADCP unit
- Solar radiation, air temperature, barometric pressure, and wind speed and direction
- Surface measurements of partial pressure of carbon dioxide (pCO_2)
- Surface temperature and salinity measurements

Nearshore Oceanography from Small Boats:

- Shallow-water CTD profiles to depths ≤ 30 m with dissolved oxygen and turbidity measurements at all REA sites where CAUs were installed
- Nutrient, Chl-*a*, DIC, and salinity water samples collected in concert with shallow-water (≤ 30 m) CTD casts at all REA sites where CAUs were installed
- Nutrient concentrations from water samples collected at additional REA sites.
- Temporary high-resolution carbonate chemistry from RAS deployments

Moored Biological Installations:

- Assessment of taxonomic diversity of coral reef species by collection of invertebrate specimens from retrieved ARMS
- Environmental acoustics of reefs, marine mammals, and boat traffic from EARs
- Location of CAUs deployed

Moored Oceanographic Instruments:

- Sea-surface and subsurface temperature at variable depths
- Sea-surface and subsurface salinity at variable depths
- Spectral wave and tidal elevation

- Single-point and directional ocean currents
- Subsurface pH measurements at variable depths
- ADP current profiles and wave spectra
- Surface air temperature, wind speed and direction, barometric pressure, and ultraviolet radiation

SCIENTIFIC PERSONNEL:

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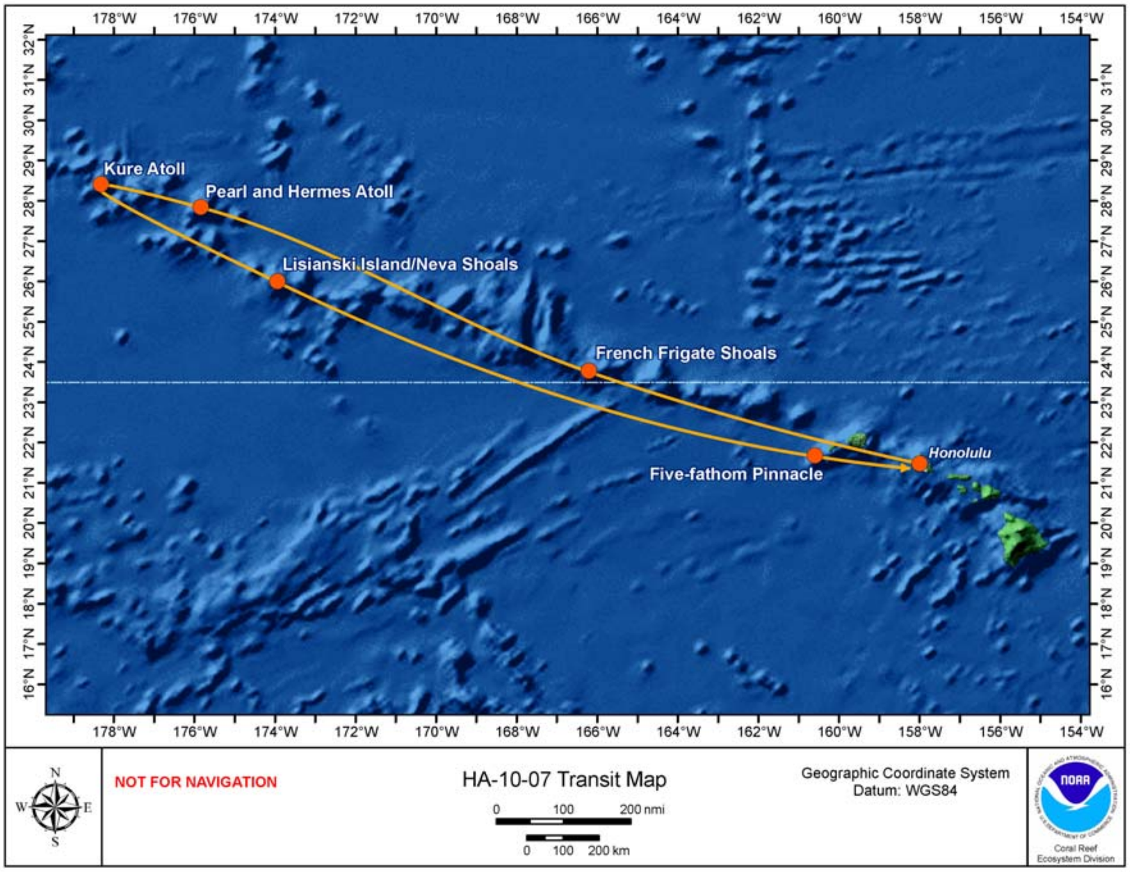

Figure 1.--Track of the NOAA Ship *Hi`ialakai* for the cruise HA-10-07, September 4–September 29, 2010, with French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, Lisianski Island and Neva Shoal, and Five Fathom Pinnacle surveyed. Satellite image © 2002 Environmental Systems Research Institute Inc. (ESRI) and © 1998 WorldSat International Inc. All rights reserved.

APPENDIX A: METHODS

This appendix describes the methods and procedures used by the Coral Reef Ecosystem Division (CRED) of the NOAA Pacific Islands Fisheries Science Center for its Pacific Reef Assessment and Monitoring Program (Pacific RAMP) cruise HA-10-07 on the NOAA Ship *Hi`ialakai* during the period of September 4–September 29, 2010. The first Pacific RAMP expedition to French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, and Lisianski Island was conducted in 2000, and Pacific RAMP cruises have occurred in the Northwest Hawaiian Islands (NWHI) on a biennial basis since then.

A.1. Oceanography and Water Quality

(Jamison Gove, Frank Mancini, Daniel Merritt, and Russell Reardon)

To assess the oceanographic, bioacoustic, and water-quality parameters influencing the coral reef ecosystems in the NWHI, the oceanography team performed the following activities: (1) conducted deepwater oceanographic surveys characterizing prevailing water properties and ocean currents around the island and atolls surveyed, (2) completed nearshore oceanographic and water-quality surveys, (3) deployed and retrieved an array of surface and subsurface moored instruments designed to provide continuous, high-resolution time-series observations, and (4) deployed calcification acidification units (CAUs) to assess calcification rates of crustose coralline algae (for information on procedures for CAU deployments, see Section A.2.3: "Moored Installations for Monitoring Benthic Communities"). In addition, shipboard meteorological observations, including wind speed and direction, relative humidity, air temperature, and barometric pressure, were recorded.

A.1.1. Moored Instruments for Time-series Observations

CRED accomplishes long-term oceanographic and assessment and monitoring through the deployment and retrieval of a variety of instrument platforms that internally record in situ observations and telemeter that data in near real time. The following types of instruments were retrieved or deployed during this cruise.

Sea-surface Temperature (SST) Buoys: provide high-resolution SST (Airborne Technologies Inc., of Wasilla, Alaska, with SBE 39 sensor, Sea-Bird Electronics Inc., Bellevue, Wash., accuracy of 0.002°C). Data are sampled at 30-min intervals and internally recorded. Subsets of these data are transmitted daily via satellite telemetry.

Subsurface Temperature Recorder (STR): provides near-real-time, high-resolution temperature data (SBE 39 sensor). Data are internally recorded at 30-min intervals. This type of subsurface instrument is deployed at depths of 0.5–40 m.

Acoustic Doppler Profiler (ADP): provides directional current profiles and wave spectra using a 3-beam-configured 1-MHz Aquadopp Profiler (Nortek, Rud, Norway, accuracy of accuracy of 0.005 m s^{-1} in current and 0.1% in pressure). Sample intervals for current and wave data vary depending on duration of deployment. This type of subsurface instrument is deployed at depths of 5–20 m. ADPs are typically deployed on an ocean data platform (ODP).

Wave-and-tide Recorder (WTR): provides high-resolution wave and tide records (SBE 26*plus* Seagauge recorder, accuracy of 0.01% in pressure). Data are internally recorded and sample intervals vary depending on duration of deployment. This type of subsurface instrument typically is deployed at depths of 10–25 m.

Remote Access Sampler (RAS): a McLane Remote Access Sampler (East Falmouth, Mass.) is an autonomous water sampling instrument which collects samples for dissolved inorganic carbon (DIC) and total alkalinity (TA). This RAS collects up to 48 water samples, each 500 mL, over a programmer-dictated time series. This instrument has the capability for high-frequency, hourly sampling. CRED uses this RAS in depths up to 30 m, but it has a maximum sampling depth of 5500 m.

Temperature and Salinity Sensor: provides high-resolution temperature and conductivity data (SBE 37 MicroCAT). Conductivity data is used to calculate salinity. These sensors are typically deployed on an ODP.

A.1.2. Hydrographic Surveys

Detailed oceanographic and water-quality surveys were conducted using the following sampling techniques and equipment.

Shallow-water (Nearshore) Conductivity, Temperature, and Depth (CTD) Casts: a CTD profiler deployed from a small boat provided data on temperature; conductivity, which is related to salinity; and pressure, which is related to depth (SBE 19*plus* Seacat Profiler, accuracy of 0.005 S m^{-1} in conductivity, 0.0002°C in temperature, and 0.1% in pressure). A transmissometer (C-Star, WET Labs, Philomath, Ore.) provided profiles of beam transmittance, which is related to turbidity. A dissolved oxygen sensor (SBE 43, accuracy of 2% of saturation) was also attached and measurements were made in concert with CTD measurements. A CTD cast was performed at each of the Rapid Ecological Assessment (REA) sites where calcification acidification units (CAUs) were deployed. Data were collected by hand lowering this profiler off a small boat at a descent rate of ~ 0.5–0.75 m s^{-1} to a maximum depth of 30 m.

Deepwater (Shipboard) CTD Casts: a ship-based CTD profiler provided high-resolution conductivity, temperature, and pressure data (Sea-Bird Electronics, SBE 911*plus* CTD, accuracy of 0.003 S m^{-1} in conductivity, 0.001°C in temperature, and 0.015% in pressure). Measurements of dissolved oxygen (SBE43) and fluorescence and turbidity (*ECO* FLNTU, WET Labs, accuracy of 0.01 μg l^{-1} in fluorescence and 0.01 NTU in turbidity) were performed in concert with CTD measurements. Data were collected at depths up to 500 m.

Shipboard Acoustic Doppler Current Profiler (ADCP): a ship-based sensor provided transects of directional ocean current data (75-kHz Ocean Surveyor, Teledyne RD

Instruments Inc., Poway, Calif.). The system was configured with an 8-m pulse length, 16-m depth bins starting at 25 m and extending typically to 600 m (range depended on density and abundance of scatterers), and 15 min averaged ensembles. Data were continuously collected throughout the research cruise.

Water Chemistry: water samples for analyses of concentrations of chlorophyll-*a* (Chl-*a*), DIC, TA, and the nutrients phosphate, PO_4^{3-}; silicate, $Si(OH)_4$; nitrate, NO_3^-; and nitrite, NO_2^- were collected at select locales concurrently with shallow-water and shipboard CTD casts.

A.2. Benthic Surveys, Biological Collections, Monitoring Installations, and Microbial Sampling

(Jeff Anderson, Edmund Coccagna, Zoe Dagan, Scott Godwin, Kerry Grimshaw, Jason Helyer, Erin Looney, Cristi Richards, Rodney Withall, and Peter Vroom)

CRED collected integrated information on the species composition (diversity), condition, abundance, and distribution of communities of corals, algae, and target macroinvertebrates and on benthic habitat complexity and substrates using 2 primary methodologies: Rapid Ecological Assessment (REA) surveys and towed-diver surveys. Performed at selected hardbottom locations, REA benthic surveys include multiple methodologies that use two 25-m transect lines deployed at each REA site. Towed-diver surveys, which follow a depth contour of ~ 15 m and encompass various substrates, cover an area that is much broader than the area surveyed using fine-scale REA techniques. In addition, 3 types of moored installations, autonomous reef monitoring structures (ARMS) CAUs, and EARs, serve as mechanisms to quantify marine invertebrates that are not easily identifiable during REA surveys, help to determine accretion rates of crustose red coralline algae and scleractinian (hard) corals, or monitor the sounds of marine life and vessel traffic. Note that the sites where REA benthic surveys were conducted typically are different locations from the REA sites selected for fish surveys. REA sites for benthic surveys are selected for long-term monitoring of specific benthic communities over time, whereas REA sites for fish surveys are selected using a stratified random sampling design to provide statistically accurate coverage of 3 depth strata.

A.2.1. Benthic Composition

Using a line-point-intercept (LPI) method, hard corals, octocorals, macroalgae, crustose coralline red algae, and target macroinvertebrates, were identified to the highest possible taxonomic resolution and recorded at 20-cm intervals along two 25-m transect lines set in a single file row (separated by 5 m). These surveys generate 125 points per transect (250 points per site) that can be used to generate percentage of cover of benthic organisms at each REA site. Additionally, in concert with LPI surveys, photoquadrat images were collected to record the benthos at predetermined points along the same 2 transect lines using a high-resolution digital camera mounted on a photoquadrat pole. This work generates 30 photographs per site that are later analyzed by staff at CRED and partners at Scripps Institution of Oceanography, University of California San Diego, using the computer program Coral Point Count with Excel extensions (CPCe), to determine the benthic composition at higher taxonomic levels for each REA site (photographs from similar surveys at REA sites surveyed by the fish team will also be analyzed).

Time permitting at each REA site, roving-diver surveys were conducted after LPI surveys, covering a swath of 3–5 m on either side of the transect lines to record algal species richness.

If algal species encountered during LPI or roving-diver surveys were not identifiable in the field, an example was collected for a voucher specimen. These specimens are subsequently catalogued and critically analyzed in a CRED laboratory to ensure positive species identification. Provisions were made to ensure appropriate preservation and curation of each algal specimen. These voucher specimens along with the photoquadrat images form permanent historical records, the former of algal diversity and the latter of the composition of benthic communities at each REA site. Also, samples of the green algal genus *Halimeda* were collected at some REA sites for calcium carbonate ($CaCO_3$) and ocean acidification analysis as part of an ongoing project with Scripps Institution of Oceanography to determine spatial and temporal differences in carbonate accretion of this sand-producing species.

In addition to site-specific REA surveys, broad-scale towed-diver surveys were used to determine the benthic composition of shallow-water habitats around each island or atoll and to quantify the abundance of target macroinvertebrates, including crown-of-thorns seastars, sea urchins, and sea cucumbers. A pair of divers, by means similar to a manta-tow technique, were towed 60 m behind a small boat, a 6-m survey launch from SAFE Boats International (Port Orchard, Wash.), with one diver quantifying the benthos and the other quantifying fish populations. Each towed-diver survey lasted 50 min, broken into 10 segments of 5 min each, and covered ~ 2 km. To georeference the survey launch's track, latitude and longitude coordinates were recorded at 5-s intervals using a Garmin GPSMap 76 global positioning system (GPS) unit on the boat. A custom algorithm was used to calculate the track of the divers based on speed and course of the boat and depth of the diver. Each towed-diver platform, or towboard, was equipped with an SBE 39 temperature and depth recorder programmed to record at 5-s intervals. At the end of each day, data were downloaded, processed, and presented in ArcGIS and can be displayed in conjunction with IKONOS satellite imagery, NOAA chart data, or other spatial data layers.

Towed-diver benthic surveys recorded habitat type and complexity; percentages of cover of benthic fauna, including hard corals, stressed hard corals, octocorals, macroalgae, and crustose coralline red algae and of physical features, including sand and rubble; and counts of target macroinvertebrates and marine debris. Towed divers classified percentage of cover using a system of 10 bins, ranging from 0% to 100% cover of the benthos. Target macroinvertebrates were counted up to 25 individuals per segment and then binned into larger groups when exceeding 25. The benthic towboard was equipped with a downward-facing, high-resolution digital still camera. The camera took a photo of the substrate every 15 s. These photos, like the SBE 39 data, are linked spatially with

GPS track files taken aboard the survey launch. Benthic photos can be analyzed later for community structure information.

A.2.2. Coral Community Structure and Coral and Coralline Algal Disease

Generic richness, colony density, and size class of coral colonies were assessed quantitatively at each REA site by means of a belt-transect method using two 25-m transect lines . On each transect, 5 segments of 2.5 m^2 each were surveyed (0–2.5 m, 5.0–7.5 m, 10–12.5 m, 15–17.5 m, and 20–22.5 m), whereby all coral colonies whose center fell within 0.5 m on either side of each transect line were identified to the highest possible taxonomic resolution and measured using 2 planar size metrics: maximum diameter and diameter perpendicular to the maximum diameter.

For each coral colony identified during belt-transect surveys, the extent of mortality, both recent and old, was estimated and signs of disease or compromised health were recorded, including type of lesion (bleaching, skeletal growth anomaly, white syndrome, tissue loss other than white syndrome, trematodiasis, necrosis, pigmentation responses, algal overgrowth, or other), extent (percentage of colony affected), severity (mild, moderate, marked, severe, or acute). Photographic documentation of affected corals was taken and opportunistic tissue samples were collected. Tissue samples were catalogued and fixed in buffered zinc-formalin solution for further histopathological analyses. Levels of predation of corals were also recorded. In tandem with these coral disease surveys at each REA site, the belt-transect method also was used to quantify coralline-algal disease and syndromes, including coralline lethal orange disease, coralline white band syndrome, and coralline cyanobacterial disease. Photographic documentation of affected algae was performed.

A.2.3. Moored Installations for Monitoring Benthic Communities

CRED accomplishes long-term monitoring of benthic biodiversity, the growth rates of corals and algae, and the sounds of marine animals and vessel activity through the use of the following types of instruments that were retrieved or deployed during this cruise.

Autonomous Reef Monitoring Structures (ARMS): deployed at several sites at each island or atoll, ARMS provide a mechanism to quantify marine invertebrates that were not easily identifiable or accountable on the transect lines used for REA surveys. ARMS were installed on the benthos by pounding stainless steel rods by hand into bare substrate. They will remain on the benthos for 2 years, enabling the recruitment and colonization of lesser known, cryptic marine invertebrates, which will be collected and analyzed when the ARMS are retrieved.

ARMS previously deployed during the NWHI RAMP 2008 cruise were retrieved. First, on the seafloor, the ARMS were covered in a mesh-lined lid to trap the contents, and then they were removed and transported to the ship. There, each unit was systematically disassembled and photo-documented, and all organisms contained in these structures were preserved in ethanol for later genetic and other molecular analyses.

Ecosystem Acoustic Recorder (EAR): the EAR is a passive acoustic device developed specifically for monitoring marine mammals, fishes, crustaceans, other sound-producing marine life, and human activity in marine habitats. The EAR is a digital, low-power system that records ambient sounds up to 30 kHz on a programmable schedule and can also respond to transient acoustic events that meet specific criteria, such as motorized vessels passing nearby or cetaceans. This type of subsurface instrument typically was deployed at depths of 5–25 m. Note: information about retrievals and deployments of EARs performed during this cruise are provided along with information about STR installations in the island appendices of this report, since those instruments are sometimes moored to the same anchor and EARs are typically installed by members of the oceanography team.

Calcification Acidification Unit (CAU): deployed at several sites at each island or atoll, CAUs provide mechanisms to quantify accretion rates by crustose coralline red algae and hard corals. Each CAU consists of 2 gray PVC plates (10 × 10 cm) separated by a 1-cm spacer. CAUs were installed on the benthos by pounding stainless steel rods by hand into bare substrate and then bolting plate assemblies to those rods. It has been demonstrated that PVC encourages growth of crustose coralline red algae and recruitment of corals, and the net weight gain of $CaCO_3$ on the surfaces of the CAUs can be an indicator of net calcification. The CAUs installed during this cruise will remain on the benthos for 2 years, enabling the recruitment and colonization of crustose coralline red algae and hard corals, upon which time they will be collected and analyzed. The data obtained via CAUs will enable a comparison of net calcification rates among islands and atolls and between archipelagos and form a baseline of accretion rates throughout the U.S. Pacific, allowing for future comparisons to determine possible consequences of increased ocean acidity and lowered aragonite saturation states.

A.2.4. Collections for Calcification Analysis

Species of the green algal genus *Halimeda* are among the most important producers of calcified sediments in reef systems. As the acidity of our oceans increases, calcification rates and the ability of *Halimeda* to produce sediments may fall precipitously. To gain baseline understanding of calcification levels in *Halimeda*, a joint project between CRED and Scripps Institution of Oceanography is sampling *Halimeda* populations across the Pacific to determine ambient levels of $CaCO_3$ among different species from different geographic areas. To accomplish project goals, 8 individuals of 3 species of *Halimeda* (when present) will be collected haphazardly by hand from each established REA site visited in the NWHI. Specimens will be dried in an oven after collection and shipped to Scripps for analysis of percent calcification.

A.2.5. Microbial Communities and Water Chemistry

Microbes are a fundamental aspect of all marine ecosystems. The amount of energy from primary production remineralized within the microbial fraction determines the amount of energy available for the entire food web. The abundance and function of the microbial community on reefs may also play an important role in coral health.

Microbial and viral communities on coral reefs have been found to change along with coral reef health. Degraded coral reefs support microbial communities that include a high abundance of potential pathogens and are primarily heterotrophic (a heterotrophic organism obtains food only from organic material, such as carbon and nitrogen, and is unable to use inorganic matter to form proteins and carbohydrates). In contrast, near-pristine reefs support microbial communities that are balanced between heterotrophs and autotrophs and contain very few potential pathogens (an autotrophic organism can synthesize food from inorganic material). A primarily heterotrophic and pathogenic microbial community in the water column could potentially lead to coral disease and death.

Collection of Microbial Water Samples: At select REA sites, 4 water samples of 2 L each were collected daily from < 1 m above the benthos using diver-deployable Niskin bottles (4–5 L). These water samples were returned to the ship, where samples were collected first for analyses of dissolved organic carbon (DOC) and particulate organic carbon (POC) and then for determining microbial size and abundance, including bacteria and archaea (single-celled microorganisms). These samples are used for the analyses described here. Also, at 1 REA site at each island or atoll, ~ 60 L of water was collected at reef crevices and surfaces for more in-depth analysis on the microbial community.

Microscopy: It is well known that bacteriophages (bacterial viruses) are the most abundant form of life in the ocean, ranging from 1×10^6 virus-like particles (VLPs) per milliliter of seawater in the open ocean to 1×10^8 VLPs per milliliter in more productive coastal waters. The number of microbial and protistan cells in seawater is typically 1×10^6 and 1×10^3 cells per milliliter, respectively. Microbial and viral loading and the dominance of heterotrophic bacteria in reef water are linked to coral disease. Trophic-level interactions among bacteria, phages, and protists also affect global nutrient and carbon cycling. The most direct method for assessing and monitoring changes in the abundance of these microbiological components is by fluorescent microscopy using nucleic acid staining.

Enumeration of microbes and viruses. Two replicate 5-mL samples were collected and fixed using paraformaldehyde and filtered through 0.2-µm filters. These filters were stained using SYBR Gold (Molecular Probes Inc., Eugene, Ore.), a general nucleic acid stain, and mounted onto a microscope slide.

Enumeration of protists. 50-mL of water from each sample was fixed with glutaraldehyde; stained with 4’,6-Diamidino-2-phenylindole (DAPI), a general nucleic acid stain for staining double-stranded DNA (dsDNA); and filtered onto a 0.8-µm black polycarbonate filter.

Frequency of dividing cells. Two replicate 5-mL samples were fixed with glutaraldehyde and filtered through 0.2-µm filters. These filters were then stained with DAPI and mounted onto a glass microscope slide.

The filters described above will be used to count the number and size of microbial components and quantify actively dividing microbial cells. This enumeration will be performed using fluorescent microscopy at San Diego State University. All filters will be stored at –20ºC for archival purposes.

Water Chemistry (DOC/POC): Spatial assessment of microbial, viral, and protist components with respect to levels of DOC, nutrients, and particulate organics within coral reef ecosystems may identify important predictors of coral reef ecosystem degradation—information that will be essential for designing the most effective coral reef ecosystem monitoring strategy possible.

To assess dissolved organic carbon (DOC) concentrations, ~ 30 mL of seawater was filtered through pre-combusted glass fiber filters from each of the 4 Niskin bottles and the filtrate was collected in pre-combusted glass bottles. Hydrochloric acid was added to each bottle to remove DIC, and the bottles were stored upright at 4ºC. To assess particulate organic carbon (POC), a total of 500 mL of seawater was filtered through a glass fiber filter, one for each Niskin bottle, and the filters were stored at –20°C. DOC and POC and stable isotopes of carbon and nitrogen will be later analyzed via standard protocols after return to shore.

Microbial DNA Samples: The structure of the bacterial community will be assessed by metagenomic analysis, which involves collection of environmental DNA via filtration followed by 454 sequencing. Metagenomics is a powerful tool for studying environmental populations, as < 1% of all environmental microbial diversity is currently cultivable. The remaining water in each Niskin bottle was pushed through a 20-µm pre-filter to remove large eukaryotic organisms. This 20-µm filtrate was then pushed through 0.22-µm Sterivex filters to trap microbes (2 filters, ~ 2.5 L each). These filters were stored at –20ºC and will be used to determine microbial community diversity and function. DNA isolation and metagenomic analysis will be completed at San Diego State University.

Flow Cytometry: Flow cytometry will be used primarily to characterize the size structure of microbial communities (e.g., autotroph vs. heterotroph abundance and viral abundance). This technique will also provide complementary data for abundance counts, metagenomic analysis, and Chl-*a* analysis.

Five 1-mL samples of water from each REA site were pushed through a 20-µm filter. This filtrate was dispensed into cryovials (5 × 1 mL) and fixed with glutaraldehyde. Vials were inverted to mix and incubated in the dark for 15 min. Glutaraldehyde-preserved samples were flash frozen in liquid nitrogen contained in a dry shipper to prevent damage to microbial cells. These samples were shipped upon return to Honolulu on dry ice to San Diego State University for flow cytometry analysis.

Large Water Samples at Reef Crevices: At a single REA site per island or atoll, ~ 60 L of water was collected using a manual bilge pump, which fills four 20-L collapsible carboys with water from reef crevices. This sample was then pre-filtered through 100-µm mesh upon return to the ship and then concentrated using tangential flow filtration, which concentrates the bacteria and viruses in the water. The initial ~ 60 L of water was brought to a final volume of ~ 500 mL. This concentrate was then filtered through 0.45-µm filters to capture microbes (bacteria and archaea). These filters were then frozen. The DNA of the entire community will be extracted and sequenced at San Diego State University, and the diversity and function of the microbial communities on the sampled reefs will be analyzed. The filtrate from this sample was also kept and contains concentrated viruses. Chloroform was added to this filtrate to kill any small microbes, and then this sample was stored at 4°C. Once shipped to San Diego State University, viruses will be isolated from the viral concentrate, and community DNA will be extracted and sequenced. This extracted and sequenced DNA will then be analyzed for viral community diversity and function.

A.3. Surveys of Reef Fishes

(Paula Ayotte, Marie Ferguson Mark Manuel, Kaylyn McCoy, Hailey Ramey, and Benjamin Richards)

Four divers conducted REA fish surveys using a stationary-point-count (SPC) method at preselected REA sites. Two separate teams performed these surveys. Each team consisted of 2 divers and conducted either 1 or 2 SPC surveys per site. All fish REA sites visited were selected using a stratified random sampling design in shallow (0–6 m), moderate (6–18 m), or deep (18–30 m) depth strata. Three habitat strata were surveyed, if available: forereef, backreef, and lagoon. Surveys were performed using a 30-m transect line set along a single depth contour. The REA sites selected for fish surveys typically are different locations from the sites where REA benthic surveys were conducted.

Once a transect line was deployed, 2 divers moved to the 7.5-m and 22.5-m marks on this transect line to start their SPC surveys. Each of these marks or points, with one diver at each, served as the center of a visually estimated cylindrical survey area with a radius of 7.5 m. During the first 5 min, divers only recorded the presence of species within their respective cylinders. Afterwards, divers went down their respective species lists, which were created from their work during the initial 5 min of a survey, sizing and counting all individuals within their cylinder, one species at a time. Cryptic species missed during the initial 5 min of a survey could still be counted, sized, and added to the original species list. All fishes observed off transect were recorded for presence data, as were more mobile, non-cryptic fishes that were seen after the initial 5 min of a survey.

After a survey was completed, divers recorded benthic habitat information from their respective cylindrical survey areas. Divers visually estimated habitat complexity, habitat type, and percentage of cover for hard corals, macroalgae, crustose coralline red algae, turf algae, and sand. Every 2 m along the transect line, photoquadrat images were taken of the benthos at a distance of 1 m from the right side of the line. If only one complete survey was done at a REA site (because of insufficient air pressure or bottom time), photoquadrat images were taken at each meter mark.

If bottom time and air permitted, the 30-m transect line was moved to another location 5–10 m away at the same depth stratum, and this procedure was repeated.

In addition to site-specific REA surveys, broad-scale towed-diver surveys were used to characterize the fish communities of shallow-water habitats around each island or atoll. A pair of divers, by means similar to a manta-tow technique, was towed 60 m behind a small boat, a 6-m survey launch from SAFE Boats International, with one diver quantifying fish populations and the other quantifying the benthos. Each towed-diver survey lasted 50 min, broken into 10 segments of 5 min each, and covered ~ 2 km. To georeference the survey launch's track, latitude and longitude coordinates were recorded at 5-s intervals using a Garmin GPSMap 76 GPS unit on the boat. A custom algorithm was used to calculate the track of the divers based on the track, speed, and course of the boat and depth of the diver. Each towed-diver platform, or towboard, was equipped with an SBE 39 temperature and depth recorder set to record at 5-s intervals. At the end of each day, data were downloaded, processed, and presented in ArcGIS and can be displayed in conjunction with IKONOS satellite imagery, NOAA chart data, or other spatial data layers.

Towed-diver fish surveys record, to the lowest possible taxon, all fishes > 50 cm in total length along a 10-m swath during each 5-min segment. Individual fishes were counted and their species (or lowest possible taxon) and length in centimeters recorded. Sightings of species of particular concern observed outside the survey swath were classified as presence/absence data and were recorded separately from the quantitative swath data. At the end of each day, data were transcribed from field data sheets into a centralized Microsoft Access database. Biomass values are calculated using species-specific length-weight parameters and are normalized by area (i.e., kg 100 m^{-2}). The fish towboard was equipped with a forward-looking digital video camera that created a visual archive of the survey track that can be used to evaluate stochastic changes in reef environments, particularly following episodic events, such as coral bleaching and grounding of a vessel.

APPENDIX B: FRENCH FRIGATE SHOALS

French Frigate Shoals, located at 23.064385° N, 166.173283° W, is the largest atoll in the Northwestern Hawaiian Islands (NWHI), Papahānaumokuākea Marine National Monument (PMNM). For information about the methods used to perform the activities discussed in this appendix, please see Appendix A: "Methods."

B.1. Oceanography and Water Quality

Oceanographic operations at French Frigate Shoals during cruise HA-10-07 entailed numerous retrievals and deployments of oceanographic moored instruments, installation of calcification acidification units (CAUs), nearshore water sampling and conductivity, temperature, and depth (CTD) casts at this island to depths up to 30 m at Rapid Ecological Assessment (REA) sites, and shipboard water sampling and CTD casts offshore to a depth of 500 m.

Nine subsurface temperature recorders (STRs) were retrieved and 10 STRs were deployed at French Frigate Shoals (Table B.1.1). Two of these swapped STRs were each moored with 1 of 2 environmental acoustic recorders (EAR) that were deployed during a previous cruise and were inspected during this cruise. A sea-surface temperature (SST) buoy was retrieved and its anchor removed, and, in the same location, an SST buoy was deployed with a new anchor. A Coral Reef Early Warning System (CREWS) buoy anchor was retrieved. For information about CAU deployments completed at French Frigate Shoals, see Table B.2.1 in Section B.2: "Benthic Environment."

At nearshore locations at French Frigate Shoals, 5 shallow-water CTD casts were performed at each of the 5 REA sites where CAUs were installed (Fig. B.1.2). In concert with the CTD cast at each of these same 5 REA sites, 2 water samples were taken to measure the following parameters: dissolved inorganic carbon (DIC), total alkalinity (TA), salinity, and nutrient, and chlorophyll-*a* (Chl-*a*) concentrations. A total of 10 DIC and TA, 10 salinity, 11 nutrient, and 10 Chl-*a* water samples were collected, 1 from the surface and 1 near the reef at each site for each parameter and 1 nutrient sample collected near the reef at 1 additional REA site.

From the NOAA Ship *Hi`ialakai*, 4 ADCP transect lines of 25 km each were run in the 4 cardinal directions away from this island during night operations. On the reciprocal course, 6 CTD casts to depths of 500 m were conducted per transect line approximately every 5 km for a total of 24 shipboard CTD casts (Fig. B.1.2). Water samples were collected concurrently with select deepwater CTD casts at 5 depths per cast between the surface and 200 m, depending on the depth of mixed layer as determined by the CTD downcast. Additionally, a CTD cast was performed at the French Frigate Shoals permanent deepwater CTD site, and water samples were collected there. A total of 25 nutrient and 25 Chl-*a* deepwater samples were collected near French Frigate Shoals.

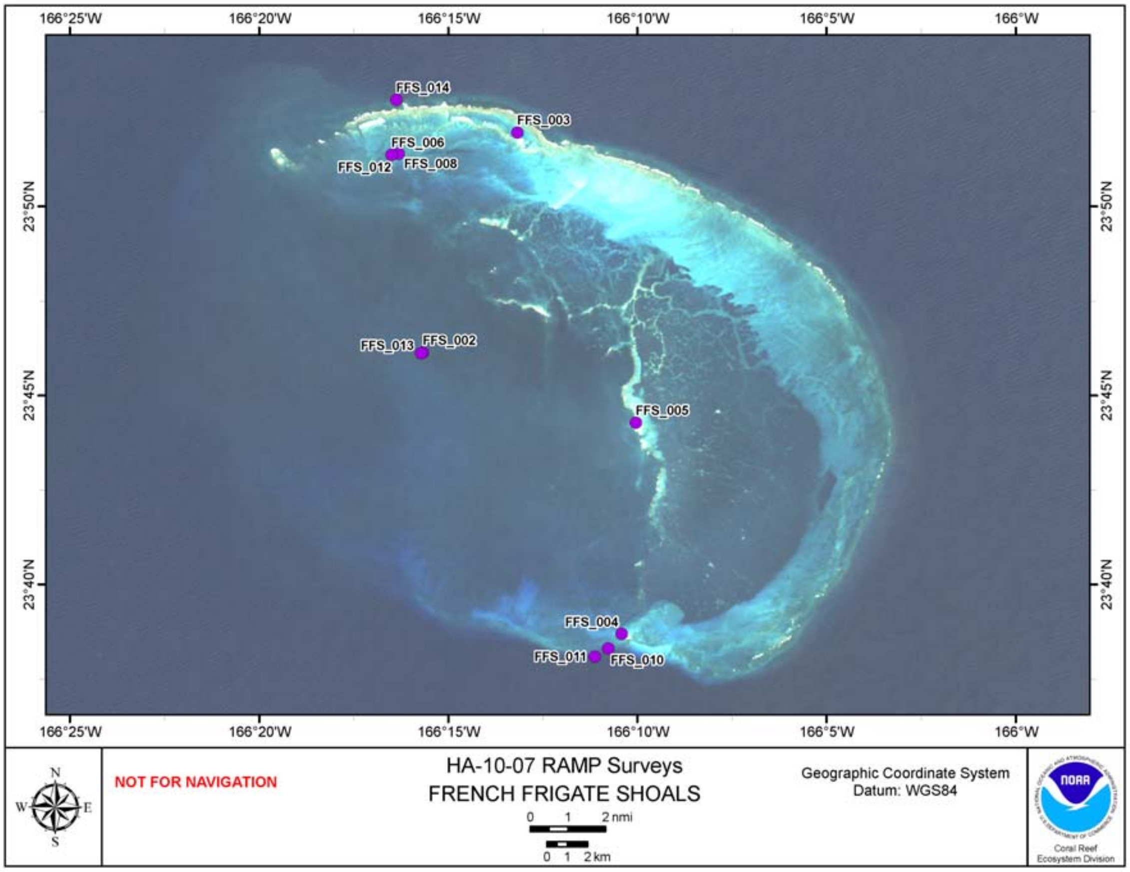

Figure B.1.1.--Mooring sites at French Frigate Shoals where oceanographic instruments were retrieved or deployed during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table B.1.1.--Geographic coordinates and sensor depths of the moored oceanographic instruments and anchors that were retrieved or deployed at French Frigate Shoals during cruise HA-10-07.

Mooring Site	Instrument Type	Latitude	Longitude	Depth (m)	Retrieval	Deployment
FFS-002	STR	23.7690413	–166.261298	4.3	1	1
FFS-003	STR	23.8660532	–166.219697	3.0	1	1
FFS-004	STR	23.6451582	–166.173743	2.1	1	1
FFS-005	STR	23.7381291	–166.167497	2.7	1	1
FFS-006	SST	23.8562738	–166.275184	0.2	1	1
FFS-006	STR	23.8562613	–166.275172	0.3	1	1
FFS-008	Anchor	23.8567383	–166.271861	7.3	1	–
FFS-010	STR	23.6388059	–166.179702	10.4	1	1
FFS-011	STR	23.6350900	–166.185531	23.8	1	1
FFS-012	STR	23.8562617	–166.275159	7.3	1	1
FFS-012	Anchor	23.8562617	–166.275159	7.3	1	1
FFS-013	STR	23.7688683	–166.261973	11.0	1	1
FFS-014	STR	23.8804853	–166.273073	8.8	–	1

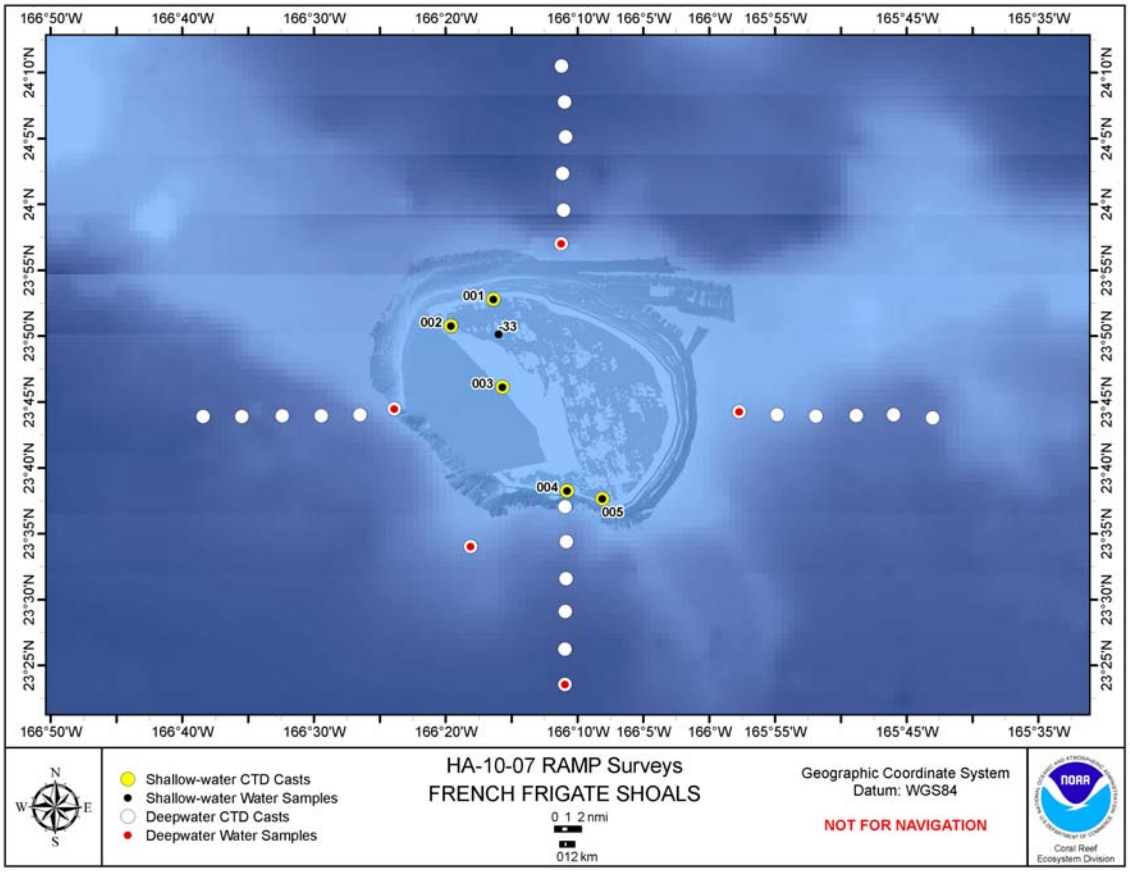

Figure B.1.2.--Locations of CTD casts and water sampling performed at French Frigate Shoals during cruise HA-10-07. Satellite image SIO, NOAA, U.S. Navy, NGA, GEBCO (Becker, 2009; Smith and Sandwell, 1997) © 2008 The Regents of the University of California.

Preliminary Results: Temperature

Temperature data from 7 locations at French Frigate Shoals show typical seasonal variability superimposed with diurnal–intraseasonal temperature excursions observed at select locations. Seasonal changes were recorded in the temperature time series from each of the SST buoys and STRs deployed at this atoll, with warm temperatures (~ 28°C) observed during the summer months (July–October) and cooler temperatures (~ 22°C) during the winter months (January–March). SST data (Fig. B.1.3, top panel) show daily fluctuations of ~ 0.5°C, typical of diel heating and cooling of surface waters. In addition, intraseasonal temperature fluctuations of 1°C–2°C were observed every few months, with the greatest occurring in April 2010, when SST dropped ~ 3°C then increased ~ 4°C within a few weeks. Subsurface temperature data from depths of 2–3 m show patterns similar to observations seen in SST data, although the data record from STRs extends back to 2008 (Fig. B.1.3, middle panel). Compared to winter-time temperatures in 2008, temperatures in 2009 were cooler later in the year (until May as opposed to March). Temperature data from 7–11 m show the same general patterns as those from 2–3 m; however, temperature excursions of 1°C–3°C occurring on semidiurnal and diurnal time scales were recorded at FFS-013, variability likely indicative of internal wave or internal tidal activity (Fig. B.1.3, bottom panel).

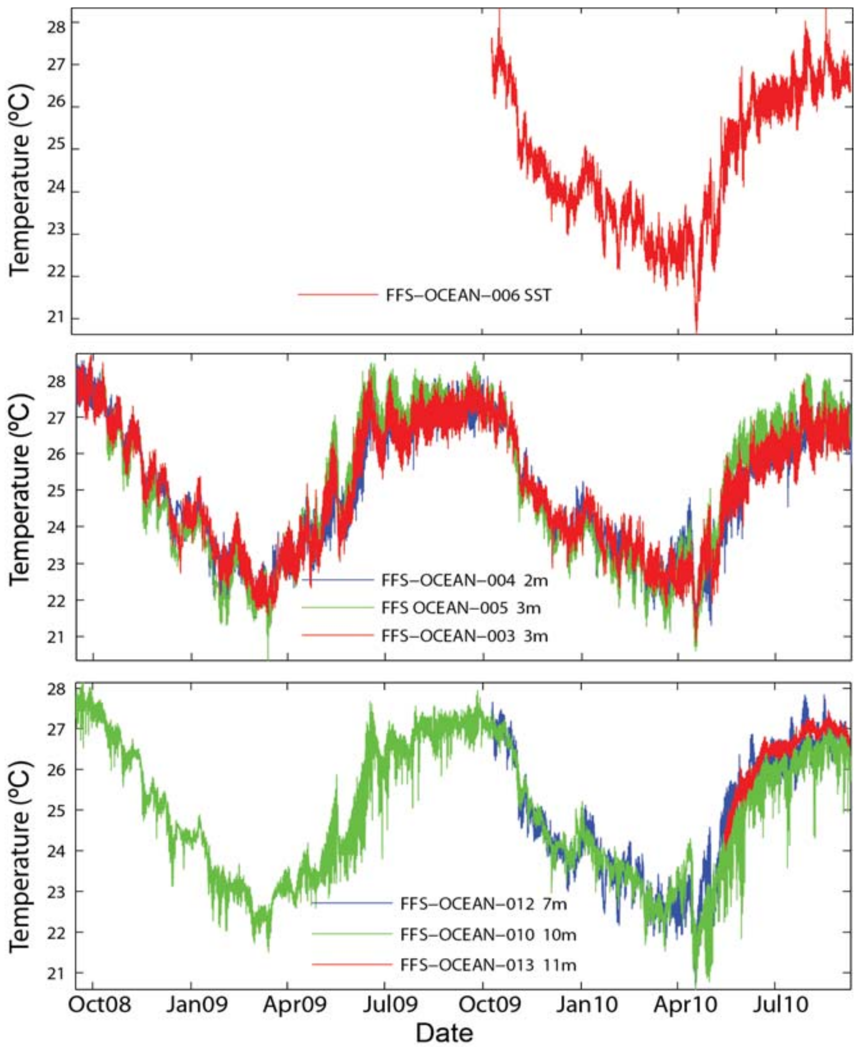

Figure B.1.3.--Time-series observations of temperature data for the period from October 2008 to October 2010 from the SST buoy and STRs deployed at French Frigate Shoals**.**

B.2. Benthic Environment

Belt-transect and line-point-intercept (LPI) surveys were conducted and photoquadrat images were collected at 11 REA sites at French Frigate Shoals to assess benthic composition, coral and algal community structure, and coral and algal disease (Fig. B.2.1 and Table B.2.1). At the end of LPI surveys, roving-diver algal surveys were conducted at all sites.

Various samples were collected at 9 REA sites: 6 algal voucher specimens at 3 REA sites for taxonomic identification, 125 individuals of the algal genus *Halimeda* at 5 REA sites for calcification studies, and 19 water samples for microbial analyses at 4 REA sites with

4 water samples of 2 L each at each site and 3 water samples of 20 L each at REA site FFS-34. For more information about collections made at REA sites, see Table H.1 in Appendix H: "Biological Collections."

Five autonomous reef monitoring structures (ARMS) were recovered: 1 ARMS each from FFS-H6 and FFS-12 and 3 ARMS from FFS-34. Six ARMS were deployed with 3 ARMS each at FFS-12 and FFS-34 (Table B.2.1). At each of 5 select REA sites, an array of 5 CAUs was deployed for a total of 25 CAUs installed at French Frigate Shoals (Table B.2.1).

In total, the benthic team conducted 53 individual dives at REA sites at French Frigate Shoals.

CRED also completed 21 towed-diver surveys at French Frigate Shoals, covering a total length of 46.2 km (an area of 46.2 ha) of the ocean floor (Fig. B.2.2). The mean survey length was 2.2 km with a range of 1.4–3.2 km. The mean survey depth was 13.8 m with a range of 10.8–17.1 m. The mean temperature from data recorded during these surveys was 26°C with a range of 25.5°C–26.9°C.

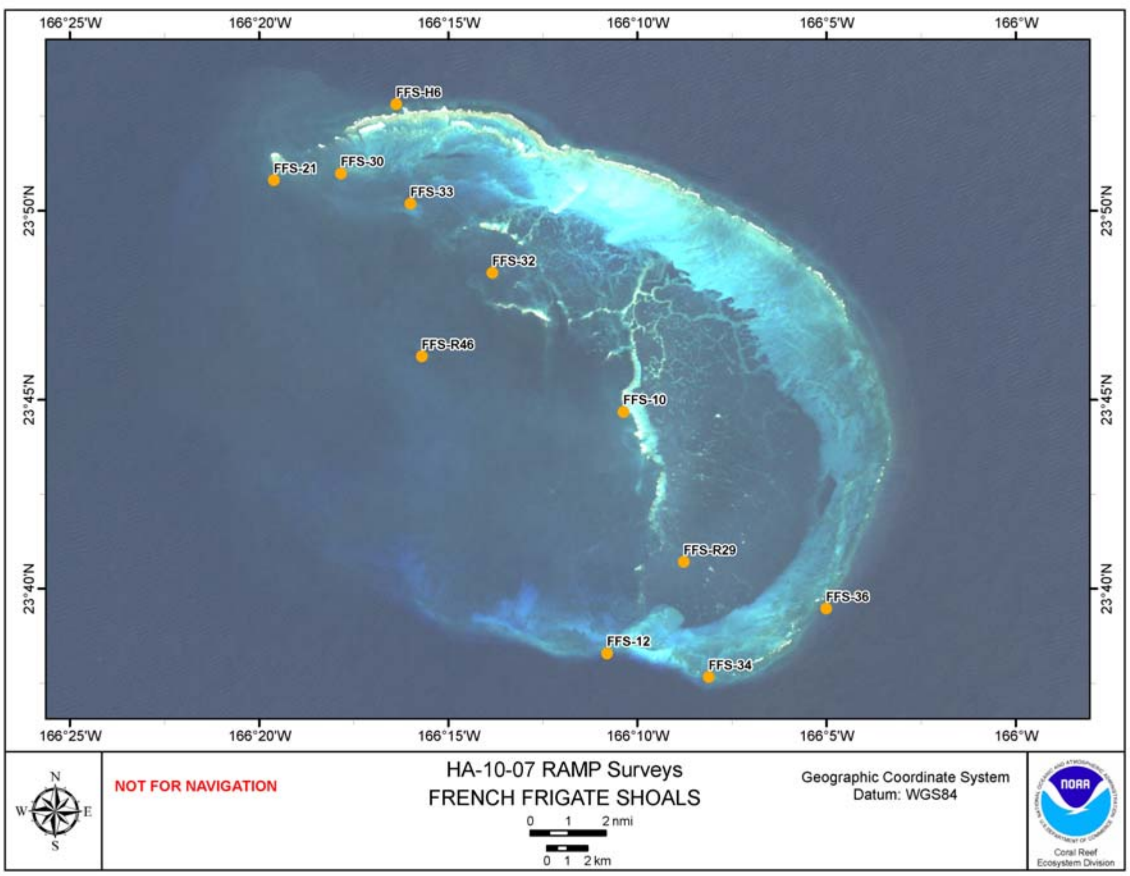

Figure B.2.1.--Locations of REA benthic sites surveyed at French Frigate Shoals during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table B.2.1.--Summary of REA benthic surveys, CAU installations, and ARMS retrievals (Ret.) and deployments (Dep.) performed as well as algal specimens and microbial water samples collected at French Frigate Shoals during cruise HA-10-07. Indication that an LPI survey was completed also means that photoquadrat images were collected and roving-diver algal surveys were conducted.

REA Site	Date	Latitude	Longitude	REA Surveys		Installations and Collections			
				LPI	Corals	CAUs	ARMS Ret/Dep	Algae	Microbial Samples
FFS-21	7-Sept	23.8469537	–166.3269575	×	×	5	–	31	–
FFS-30	7-Sept	23.8498866	–166.2973491	×	×		–	20	–
FFS-H6	7-Sept	23.8804552	–166.2730599	×	×	5	1/0	–	4
FFS-32	8-Sept	23.8061000	–166.2306300	×	×	–	–	–	–
FFS-33	8-Sept	23.8365143	–166.2666948	×	×		–	–	4
FFS-R46	8-Sept	23.7692800	–166.2617300	×	×	5	–	4	–
FFS-12	9-Sept	23.6383500	–166.1800500	×	×	5	1/3	31	4
FFS-R29	9-Sept	23.6786508	–166.1463565	×	×	–	–	14	–
FFS-10	10-Sept	23.7448102	–166.1728963	×	×	–	–	31	–
FFS-34	10-Sept	23.6279200	–166.1353800	×	×	5	3/3	–	7
FFS-36	10-Sept	23.6580331	–166.0835433	×	×	–	–	–	–

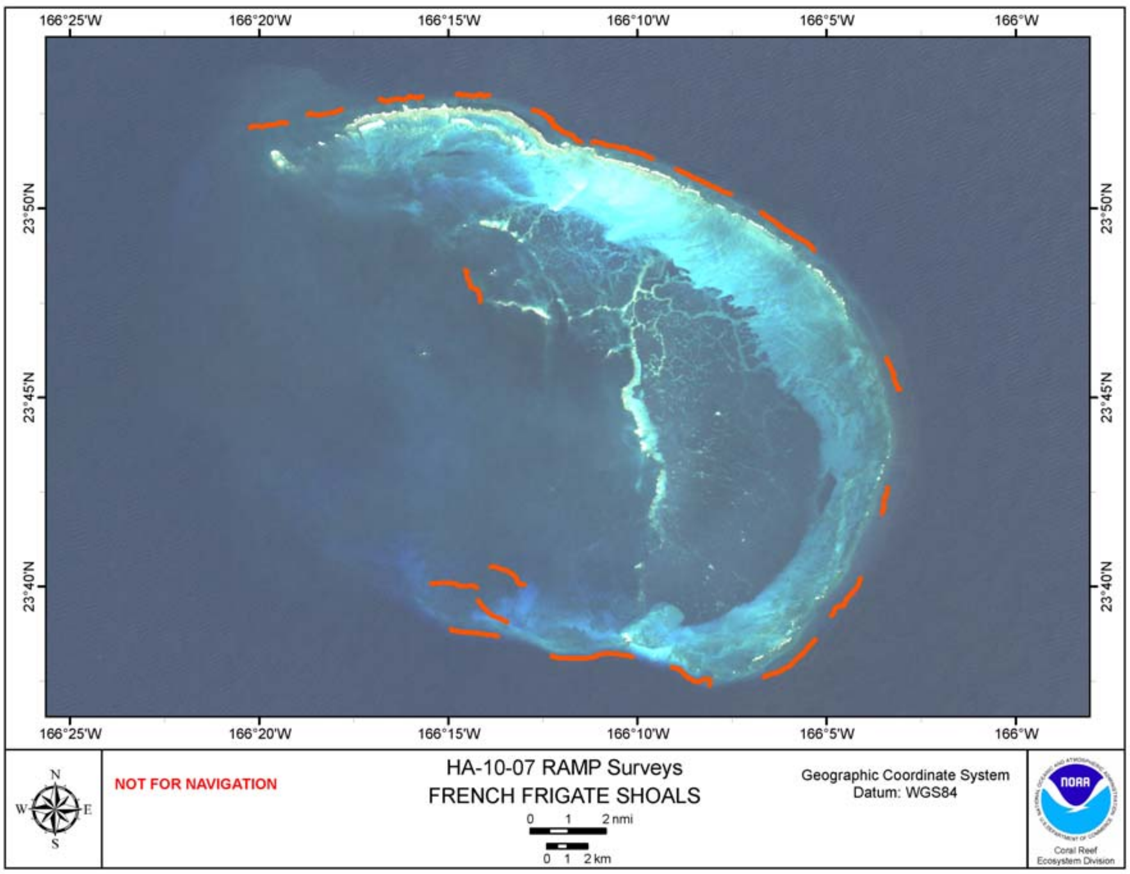

Figure B.2.2.--Track locations of towed-diver surveys conducted at French Frigate Shoals during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

B.3. Reef Fish Community

REA fish survey sites were chosen using a stratified random design. Stationary-point-count surveys were conducted at 27 REA sites at French Frigate Shoals over 6 different habitat strata: deep forereef, moderate forereef, shallow forereef, deep lagoon, moderate lagoon, and shallow lagoon (Fig. B.3.1 and Table B.3.1). No fishes were collected during these surveys.

In addition, CRED completed a total of 21 towed-diver surveys at French Frigate Shoals, as described previously in Section B.2 of this appendix.

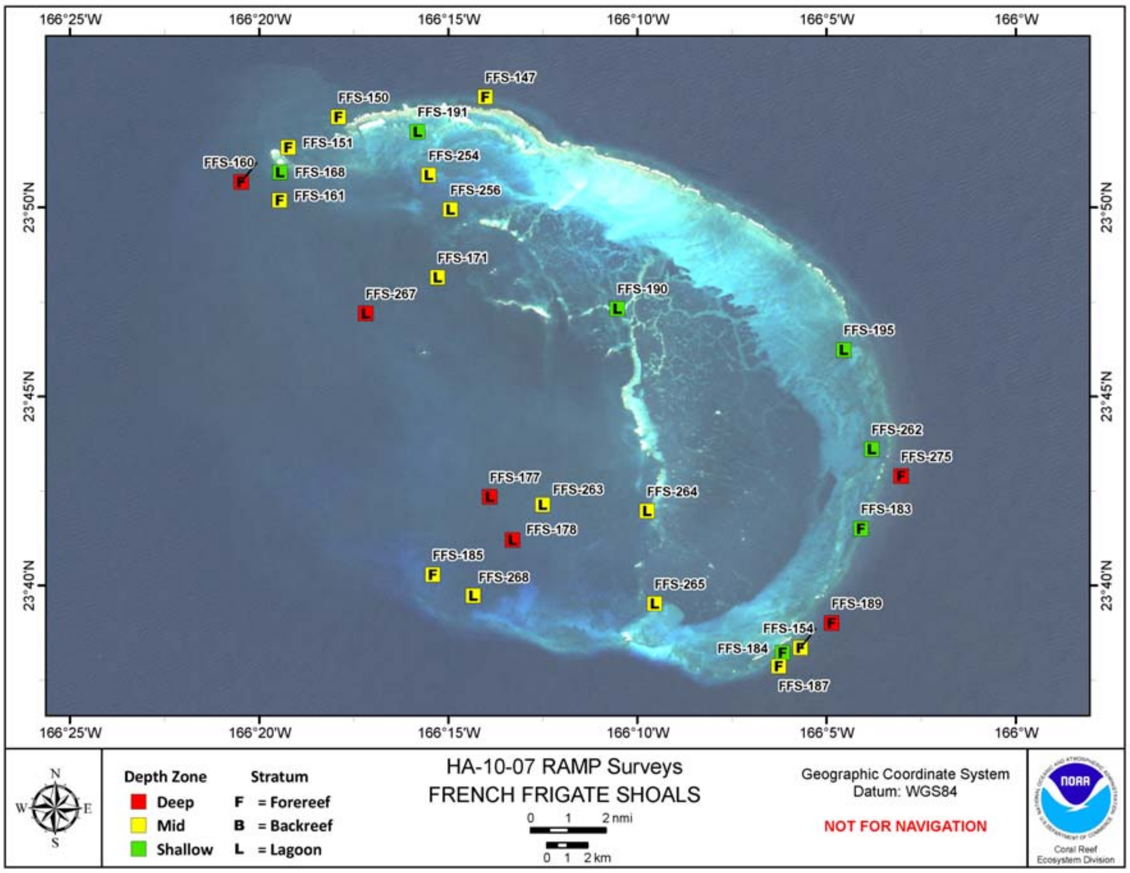

Figure B.3.1.--Locations of REA fish sites surveyed at French Frigate Shoals during cruise HA-10-07. All of these REA sites were selected using a stratified random design. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table B.3.1.--Summary of sites where REA fish surveys were conducted at French Frigate Shoals during cruise HA-10-07.

REA Site	Date	Depth Zone	Stratum	Depth (m)	Latitude	Longitude
FFS-147	7-Sept	Moderate	Forereef	11	23.88210903	–166.2337431
FFS-150	7-Sept	Moderate	Forereef	7	23.87322949	–166.2985042
FFS-160	7-Sept	Deep	Forereef	24	23.84464561	–166.3411943
FFS-168	7-Sept	Shallow	Lagoon	4	23.84894301	–166.3241134
FFS-151	8-Sept	Moderate	Forereef	9	23.85988575	–166.3205941
FFS-161	8-Sept	Moderate	Forereef	17	23.83657845	–166.3242699
FFS-171	8-Sept	Moderate	Lagoon	12	23.80262570	–166.2546837
FFS-190	8-Sept	Shallow	Lagoon	2	23.78879087	–166.1755718
FFS-191	8-Sept	Shallow	Lagoon	3	23.86679999	–166.2635772
FFS-254	8-Sept	Moderate	Lagoon	9	23.84763074	–166.2587562
FFS-256	8-Sept	Moderate	Lagoon	14	23.83248431	–166.2491037
FFS-267	8-Sept	Deep	Lagoon	26	23.78673655	–166.2863706
FFS-177	9-Sept	Deep	Lagoon	27	23.70583249	–166.231729
FFS-178	9-Sept	Deep	Lagoon	22	23.68688134	–166.2216744
FFS-185	9-Sept	Moderate	Forereef	15	23.67157054	–166.2568668
FFS-263	9-Sept	Moderate	Lagoon	14	23.70241947	–166.2084433
FFS-264	9-Sept	Moderate	Lagoon	11	23.69965402	–166.1624063
FFS-265	9-Sept	Moderate	Lagoon	11	23.65881630	–166.1591232
FFS-268	9-Sept	Moderate	Lagoon	15	23.66236621	–166.2390705
FFS-154	10-Sept	Moderate	Forereef	10	23.63931715	–166.0947435
FFS-183	10-Sept	Shallow	Forereef	4	23.69184343	–166.0681813
FFS-184	10-Sept	Shallow	Forereef	6	23.63723064	–166.1027381
FFS-187	10-Sept	Moderate	Forereef	12	23.63130011	–166.1044543
FFS-189	10-Sept	Deep	Forereef	23	23.65031965	–166.0811213
FFS-195	10-Sept	Shallow	Lagoon	5	23.77070482	–166.0757976
FFS-262	10-Sept	Shallow	Lagoon	6	23.72693184	–166.0634891
FFS-275	10-Sept	Deep	Forereef	23	23.71500766	–166.0505021

APPENDIX C: PEARL AND HERMES ATOLL

Pearl and Hermes Atoll, located at 27.856098° N, 175.847545° W, is a large atoll in the Northwestern Hawaiian Islands (NWHI), Papahānaumokuākea Marine National Monument (PMNM). For information about the methods used to perform the activities discussed in this appendix, please see Appendix A: "Methods."

C.1. Oceanography and Water Quality

Oceanographic operations at Pearl and Hermes Atoll during cruise HA-10-07 entailed numerous retrievals and deployments of oceanographic moored instruments, installation of calcification acidification units (CAUs), nearshore water sampling and conductivity, temperature, and depth (CTD) casts to depths up to 30 m at select Rapid Ecological Assessment (REA) sites, and shipboard water sampling and CTD casts offshore to a depth of 500 m.

Eighteen subsurface temperature recorders (STRs) were retrieved and 17 STRs were deployed at Pearl and Hermes Atoll (Fig. C.1.1). A sea-surface temperature (SST) buoy and anchor were retrieved and replaced. One previously deployed environmental acoustic recorder (EAR) was inspected, and a second EAR was swapped (Table C.1.1). An anchor and ocean data platform (ODP) that had on it an acoustic Doppler profiler (ADP) and salinity and temperature sensor (SBE 37 MicroCAT, Sea-Bird Electronics Inc., Bellevue, Wash.) were recovered, and an ADP and SBE 37 salinity and temperature sensor, along with an anchor and battery, were newly deployed at a slightly shallower location inshore of the ODP mooring site. The new ADP will capture both current profiles and wave spectra. For information about CAU deployments completed at Pearl and Hermes Atoll, see Table C.2.1 in Section C.2: "Benthic Environment."

At nearshore locations at Pearl and Hermes Atoll, 5 shallow-water CTD casts were performed at each of the 5 REA sites where CAUs were installed (Fig. C.1.2). In concert with the CTD cast at each of these same REA sites, 2 water samples were taken to measure the following parameters: dissolved inorganic carbon (DIC), total alkalinity (TA), salinity, nutrient, and chlorophyll-*a* (Chl-*a*) concentrations. A total of 10 DIC and TA, 10 salinity, 12 nutrient, and 10 Chl-*a* water samples were collected, 1 from the surface and 1 near the reef at each site for each parameter and, at each of 2 additional REA sites, 1 nutrient sample near the reef. In addition to this discrete water sampling, a remote auto sampler (RAS) was deployed at REA site PHR-24, where it collected 48 water samples hourly over a 48-h period for DIC and TA analysis. An SBE 19*plus* Seacat Profiler attached to this RAS collected conductivity and temperature measurements during the same deployment.

From the NOAA Ship *Hi`ialakai*, 4 ADCP transect lines of 25 km each were run in the 4 cardinal directions away from this atoll during night operations. On the reciprocal course, 6 CTD casts to depths of 500 m were conducted primarily along each transect line every 5 km for a total of 24 shipboard CTD casts. Water samples were collected concurrently with select deepwater CTD casts at 5 depths per cast between the surface and 200 m, depending on the depth of mixed layer as determined by the CTD downcast. One of the CTD casts was performed at the Pearl and Hermes Atoll permanent deepwater CTD site, and water samples were collected there. A total of 25 nutrient and 25 Chl-*a* deepwater samples were collected near Pearl and Hermes Atoll.

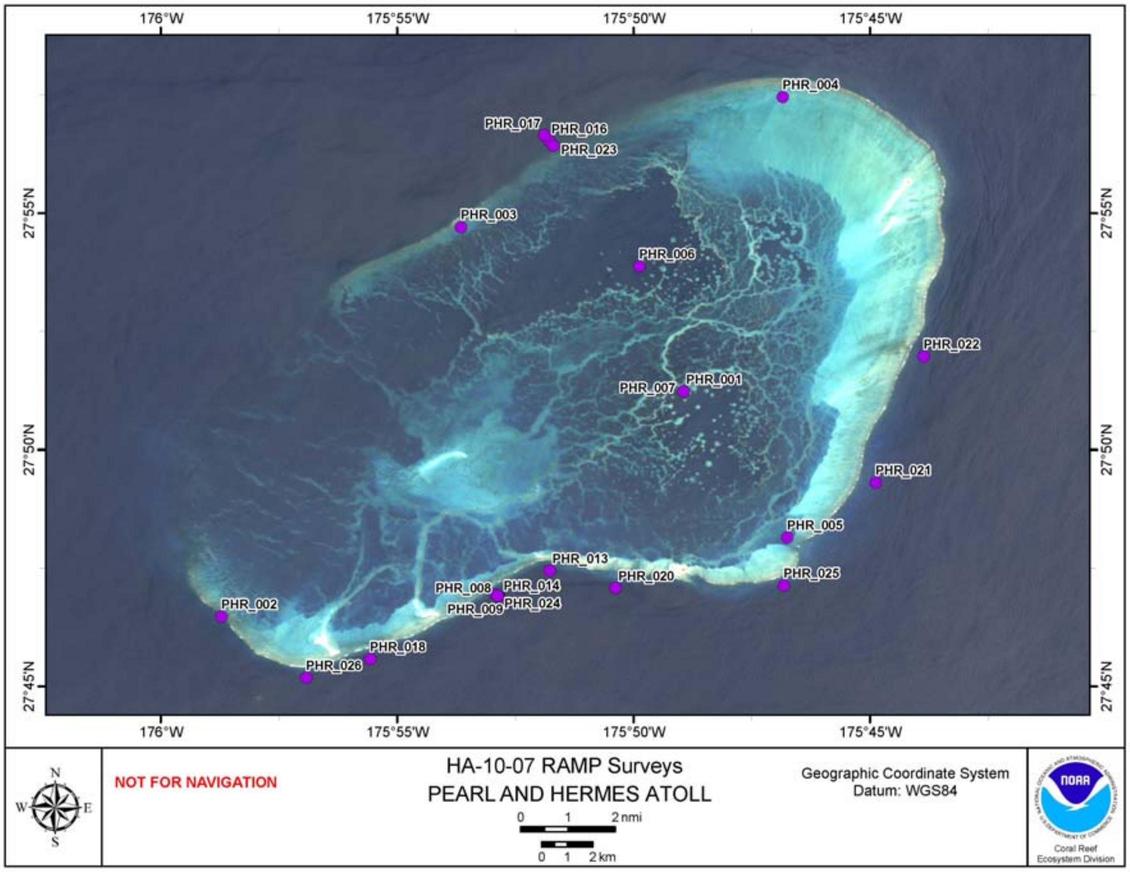

Figure C.1.1.--Mooring sites at Pearl and Hermes Atoll where oceanographic instruments and EARs were retrieved or deployed during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table C.1.1.--Geographic coordinates and sensor depths of the moored oceanographic instruments, EAR, anchors, and battery that were retrieved or deployed at Pearl and Hermes Atoll during cruise HA-10-07.

Mooring Site	Instrument Type	Latitude	Longitude	Depth (m)	Retrieval	Deployment
PHR-001	SST	27.8539269	–175.8158758	0.2	1	1
PHR-001	STR	27.8539269	–175.8158758	0.3	1	1
PHR-002	STR	27.7747392	–175.9787157	1.8	1	1
PHR-003	STR	27.9118428	–175.8943118	3.0	1	1
PHR-004	STR	27.9576793	–175.7808380	1.2	1	1
PHR-005	STR	27.8026194	–175.7793350	2.1	1	1
PHR-006	STR	27.8980052	–175.8313905	1.2	1	1
PHR-007	Anchor	27.8539269	–175.8158758	7.9	1	1
PHR-007	STR	27.8539269	–175.8158758	7.9	1	1
PHR-008	STR	27.7820618	–175.8809973	22.9	1	1
PHR-009	STR	27.7816469	–175.8809328	38.1	1	1
PHR-012	STR	27.7825017	–175.8821370	13.4	1	1
PHR-013	STR	27.7909804	–175.8630068	11.6	1	1
PHR-014	ADP	27.7820428	–175.8811372	21.9	1	–
PHR-014	SBE 37	27.7820428	–175.8811372	21.9	1	–
PHR-014	Anchor	27.7820693	–175.8810997	21.6	1	–
PHR-016	STR	27.9423542	–175.8634055	24.7	1	1
PHR-017	STR	27.9443163	–175.8649835	35.7	1	1
PHR-018	STR	27.7597060	–175.9263167	21.9	1	–
PHR-020	STR	27.7848580	–175.8398282	23.2	1	–
PHR-021	STR	27.8219981	–175.7481300	21.6	1	–
PHR-022	STR	27.8661964	–175.7311846	22.3	1	1
PHR-023	EAR	27.9406032	–175.8617209	17.1	1	1
PHR-023	STR	27.9406032	–175.8617209	17.1	1	1
PHR-024	ADP	27.7821195	–175.8814290	19.5	–	1
PHR-024	SBE 37	27.7821195	–175.8814290	19.5	–	1
PHR-024	Anchor	27.7821195	–175.8814290	19.5	–	1
PHR-024	SBE 19*plus*	27.7821323	–175.8814081	19.1	1	1
PHR-024	RAS	27.7821323	–175.8814081	19.1	1	1
PHR-025	STR	27.7857144	–175.7804599	13.7	–	1
PHR-026	STR	27.7531288	–175.9489414	15.2	–	1

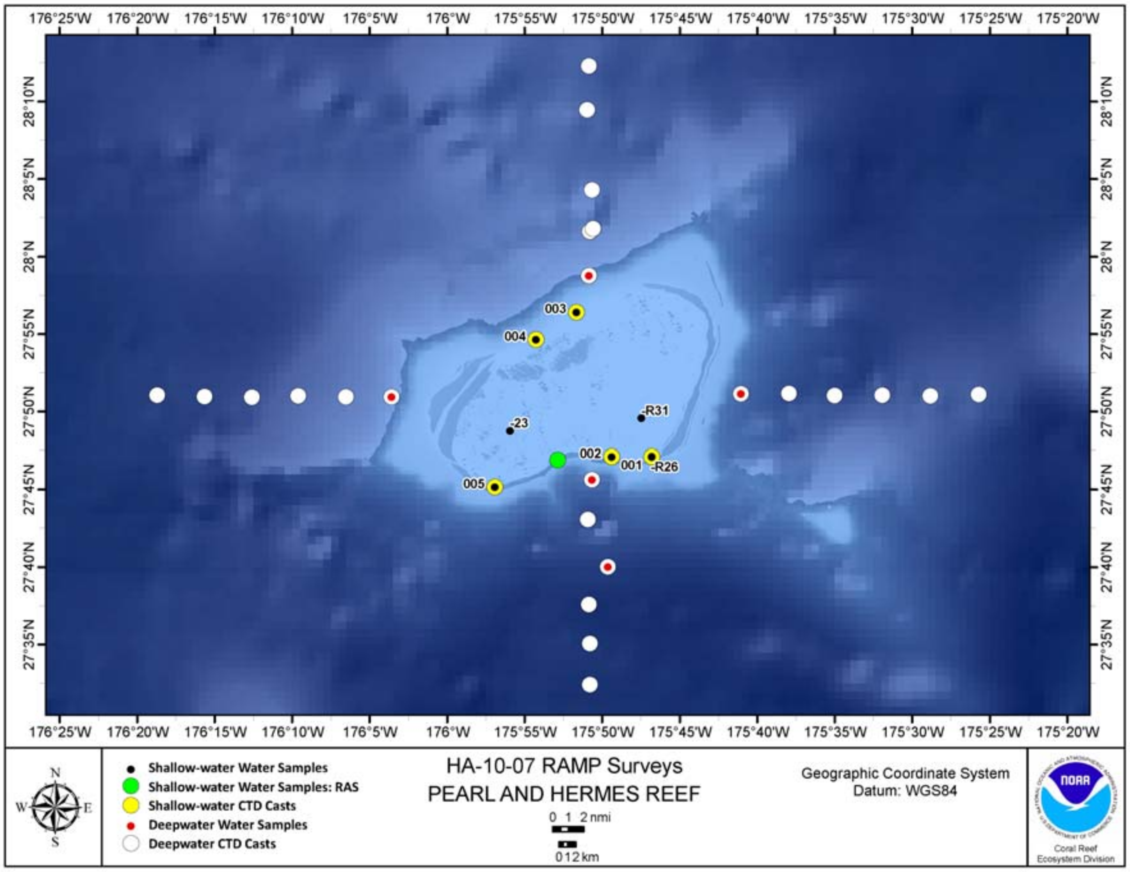

Figure C.1.2.--Locations of CTD casts and water sampling performed at Pearl and Hermes Atoll during cruise HA-10-07. Satellite image SIO, NOAA, U.S. Navy, NGA, GEBCO (Becker, 2009; Smith and Sandwell, 1997) © 2008 The Regents of the University of California.

Preliminary Results: Temperature

SST data for Pearl and Hermes Atoll indicate a warmer than average summer in 2010 when compared to weekly climatological temperature data. In addition, prolonged periods (7–14 d) where SST exceeded the Coral Reef Watch (CRW) bleaching threshold for Pearl and Hermes Atoll, defined as 1°C above the maximum monthly climatological mean (Fig. C.1.3). During winter, from October 2009 to April 2010, SST was 0.5°C–3°C cooler than the long-term climatological average, likely because of interannual forcing. Additionally, intraseasonal temperature fluctuations of 1°C–3°C can be seen throughout the time series; it is unknown what physical forcing mechanism is causing these observed fluctuations.

Subsurface temperature data from the 2 STRs moored on the south forereef at 13 and 38 m show diurnal and semidiurnal temperature fluctuations of 1°C–6°C, with the magnitude of variability increasing from shallow to deep (Fig. C.1.4). Such temperature fluctuations are likely indicative of internal tides, which drive vertical oscillations of isotherms at tidal frequencies.

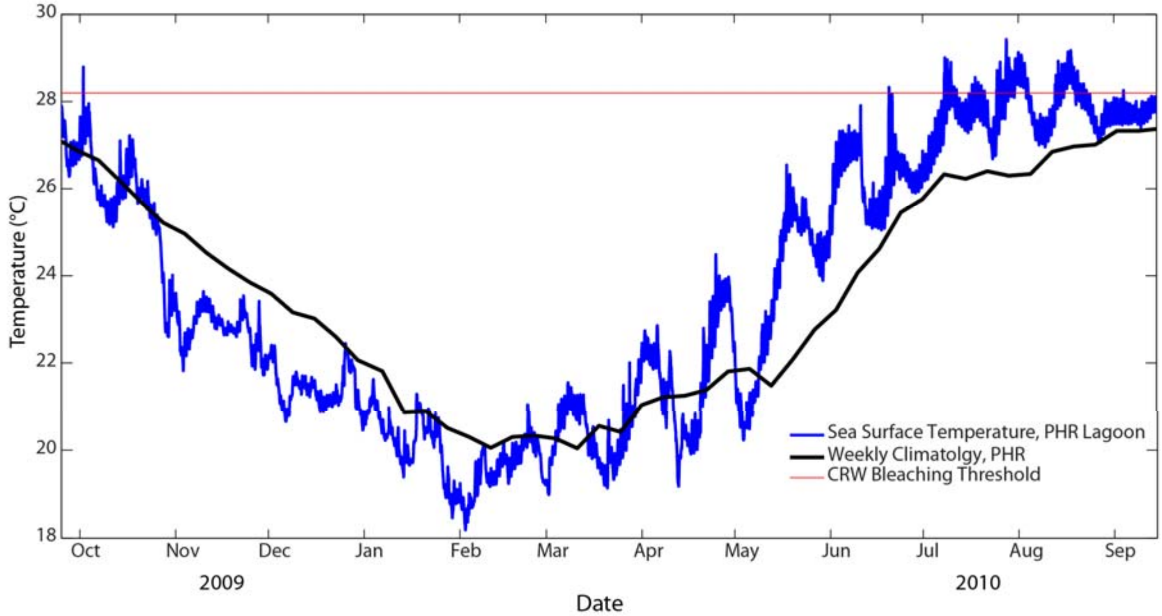

Figure C.1.3.--Time-series observations of temperature data for the period from September 2009 to October 2010 from an SST buoy moored in the central lagoon at Pearl and Hermes Atoll (blue), weekly satellite-derived (Pathfinder) SST climatology using 1981–2007 data, and the CRW bleaching threshold for Pearl and Hermes Atoll, defined as 1°C above the maximum climatological monthly mean.

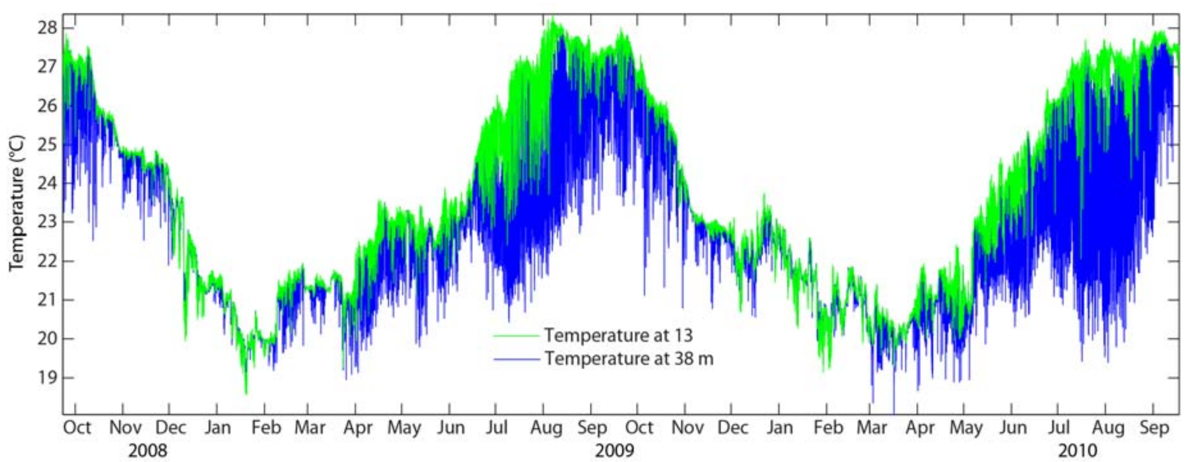

Figure C.1.4.--Time-series observations of temperature data for the period from September 2008 to September 2010 from 2 STRs deployed on the south side of Pearl and Hermes Atoll.

C.2. Benthic Environment

Belt-transect and line-point-intercept (LPI) surveys were conducted and photoquadrat images were collected at 15 REA sites at Pearl and Hermes Atoll to assess benthic composition, coral and algal community structure, and coral and algal disease (Fig. C.2.1 and Table C.2.1). At the end of LPI surveys, roving-diver algal surveys were conducted at all sites.

Various samples were collected at 11 REA sites: 9 total voucher specimens of algae at 5 REA sites for taxonomic identification, 108 individuals of the genus *Halimeda* at 5 REA sites for calcification studies, and 23 water samples for microbial analysis at 5 REA sites with 4 water samples of 2 L each at each site and 3 water samples of 20 L each at REA site PHR-R42. For more information about collections made at REA sites, see Table H.1 in Appendix H: “Biological Collections.”

Fifteen autonomous reef monitoring structures (ARMS) were recovered: 3 ARMS each at 5 REA sites). Nine ARMS were deployed with 3 ARMS each at PHR-33, PHR-R26, and PHR-R42 (Table C.2.1). At each of 5 select REA sites, an array of 5 CAUs was deployed for a total of 25 CAUs installed at Pearl and Hermes Atoll (Table C.2.1).

In total, the benthic team conducted a total of 75 individual dives at REA sites around Pearl and Hermes Atoll.

CRED also completed 26 towed-diver surveys at Pearl and Hermes Atoll, covering a total length of 55.5 km (an area of 55.5 ha) of the ocean floor (Fig. C.2.2). The mean survey length was 2.1 km with a range of 1.2–3.0 km. The mean survey depth was 12.9 m with a range of 1.0–16.9 m. The mean temperature from data recorded during these surveys was 27.6°C with a range of 27.2°C–28.4°C.

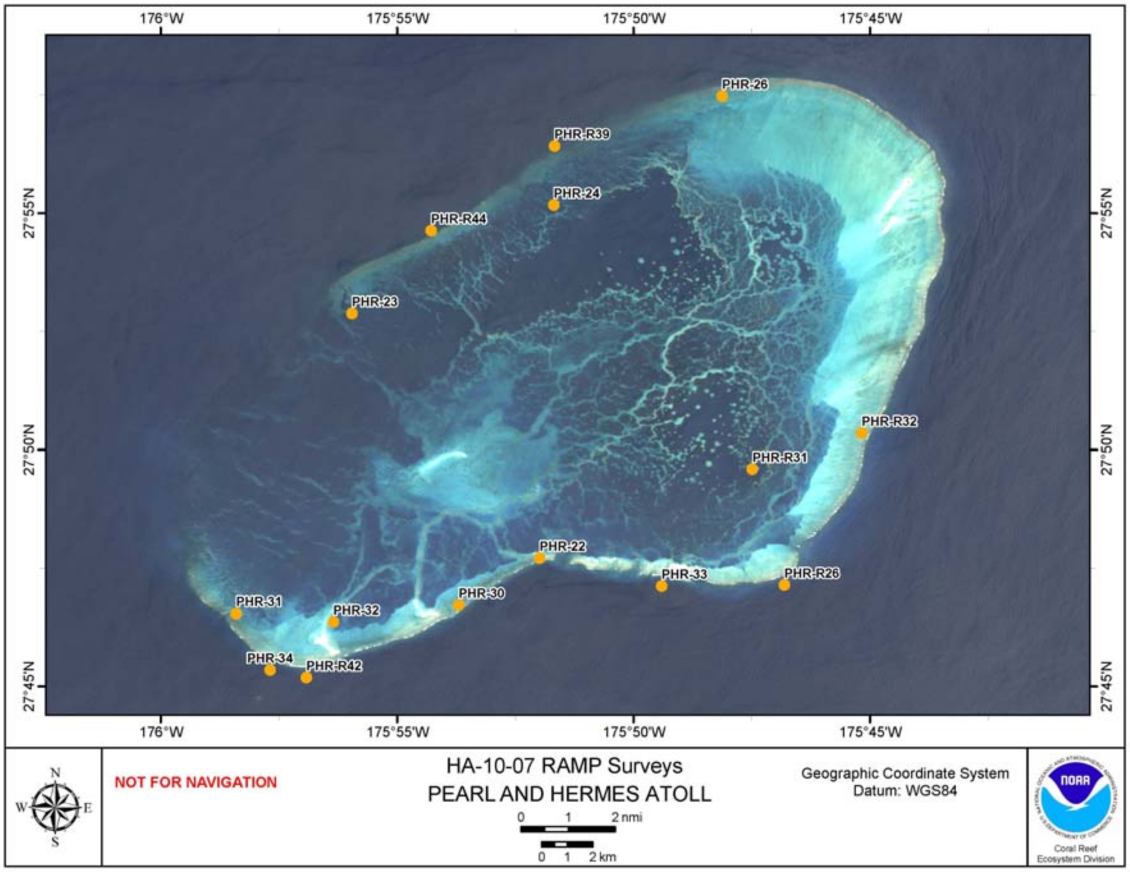

Figure C.2.1.--Locations of REA benthic sites surveyed at Pearl and Hermes Atoll during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table C.2.1.-- Summary of REA benthic surveys, CAU installations, and ARMS retrievals (Ret.) and deployments (Dep.) performed as well as algal specimens and microbial water samples collected at Pearl and Hermes Atoll during cruise HA-10-07. Indication that an LPI survey was completed also means that photoquadrat images were collected and roving-diver algal surveys were conducted.

				REA Surveys		Installations and Collections			
REA Site	Date	Latitude	Longitude	LPI	Corals	CAUs	ARMS Ret/Dep	Algae	Microbial Samples
PHR-22	13-Sept	27.795350	–175.866550	×	×	–	–	–	–
PHR-R26	13-Sept	27.785833	–175.780283	×	×	5	3/3	–	4
PHR-R32	13-Sept	27.839167	–175.753033	×	×	–	–	1	–
PHR-30	14-Sept	27.778700	–175.895083	×	×	–	–	–	–
PHR-32	14-Sept	27.772780	–175.939282	×	×	–	–	–	–
PHR-33	14-Sept	27.785438	–175.823543	×	×	5	3/3	–	4
PHR-26	15-Sept	27.957989	–175.802182	×	×	–	–	38	–
PHR-R31	15-Sept	27.826642	–175.791537	×	×	–	3/0	–	4
PHR-R39	15-Sept	27.940460	–175.861310	×	×	5	–	13	–
PHR-23	16-Sept	27.881315	–175.932732	×	×	–	3/0	3	4
PHR-24	16-Sept	27.919583	–175.861583	×	×	–	–	20	–
PHR-R44	16-Sept	27.910617	–175.904833	×	×	5	–	21	–
PHR-31	17-Sept	27.775750	–175.973480	×	×	–	–	–	–
PHR-34	17-Sept	27.755833	–175.961583	×	×	–	–	20	–
PHR-R42	17-Sept	27.753133	–175.948767	×	×	5	3/3	1	7

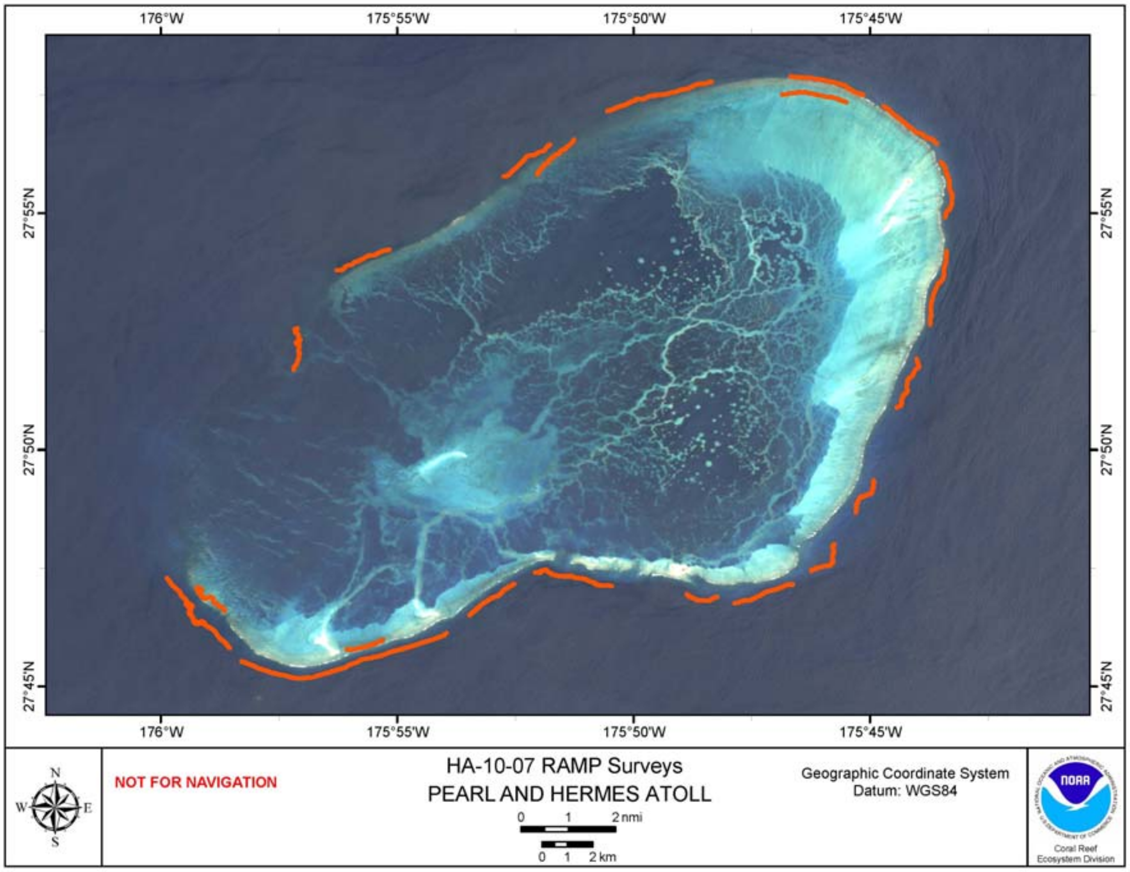

Figure C.2.2. Track locations of towed-diver surveys conducted at Pearl and Hermes Atoll during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

C.3. Reef Fish Community

REA fish survey sites were chosen using a stratified random design. Stationary-point-count surveys were conducted at 41 REA sites at Pearl and Hermes Atoll over 6 different habitat strata: deep forereef, moderate forereef, shallow forereef, moderate lagoon, shallow lagoon, and shallow backreef (Fig. C.3.1 and Table C.3.1). No fishes were collected during these surveys.

In addition, CRED completed a total of 26 towed-diver surveys at Pearl and Hermes Atoll, as described previously in Section C.2 of this appendix

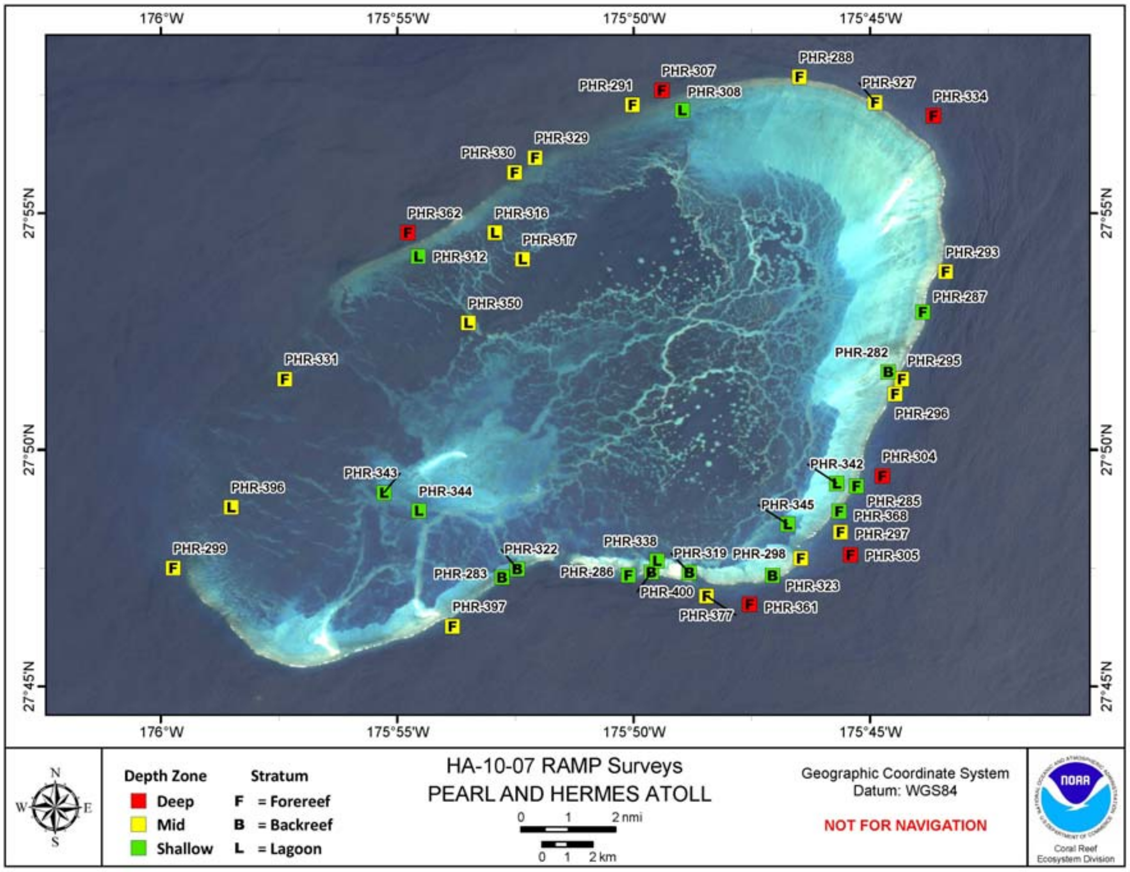

Figure C.3.1.--Locations of REA fish sites surveyed at Pearl and Hermes Atoll during cruise HA-10-07. All of these REA sites were selected using a stratified random design. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table C.3.1.--Summary of sites where REA fish surveys were conducted at Pearl and Hermes Atoll during cruise HA-10-07.

REA Site	Date	Depth Zone	Stratum	Depth (m)	Latitude	Longitude
PHR-295	13-Sept	Moderate	Forereef	11	27.85814401	–175.7388367
PHR-296	13-Sept	Moderate	Forereef	11	27.85297304	–175.7411513
PHR-297	13-Sept	Moderate	Forereef	17	27.80441986	–175.7603631
PHR-298	13-Sept	Moderate	Forereef	8	27.79518628	–175.7744761
PHR-304	13-Sept	Deep	Forereef	23	27.82418716	–175.7457169
PHR-305	13-Sept	Deep	Forereef	23	27.79643971	–175.7568471
PHR-368	13-Sept	Shallow	Forereef	7	27.81172327	–175.7608537
PHR-285	14-Sept	Shallow	Forereef	5	27.82068352	–175.7547732
PHR-286	14-Sept	Shallow	Forereef	5	27.78918249	–175.8351727
PHR-287	14-Sept	Shallow	Forereef	6	27.88181534	–175.7313967
PHR-293	14-Sept	Moderate	Forereef	18	27.89610179	–175.7233362
PHR-319	14-Sept	Shallow	Backreef	1	27.79014179	–175.8137620
PHR-361	14-Sept	Deep	Forereef	25	27.77897375	–175.7924646
PHR-377	14-Sept	Moderate	Forereef	9	27.78196097	–175.8076581
PHR-288	15-Sept	Moderate	Forereef	15	27.96477883	–175.7749091
PHR-291	15-Sept	Moderate	Forereef	13	27.95490604	–175.8337022
PHR-307	15-Sept	Deep	Forereef	24	27.96006560	–175.8233988
PHR-308	15-Sept	Shallow	Lagoon	4	27.95292305	–175.8162440
PHR-327	15-Sept	Moderate	Forereef	14	27.95581950	–175.7481797
PHR-329	15-Sept	Moderate	Forereef	13	27.93632898	–175.8680760
PHR-330	15-Sept	Moderate	Forereef	13	27.93110101	–175.8752455
PHR-334	15-Sept	Deep	Forereef	27	27.95101063	–175.7275938
PHR-299	16-Sept	Moderate	Forereef	10	27.79172891	–175.9956690
PHR-312	16-Sept	Shallow	Lagoon	4	27.90138901	–175.9092794
PHR-316	16-Sept	Moderate	Lagoon	14	27.90983026	–175.8822643
PHR-317	16-Sept	Moderate	Lagoon	12	27.90046390	–175.8725244
PHR-331	16-Sept	Moderate	Forereef	9	27.85824560	–175.9563388
PHR-343	16-Sept	Shallow	Lagoon	6	27.81839266	–175.9213367
PHR-344	16-Sept	Shallow	Lagoon	5	27.81203072	–175.9090734
PHR-350	16-Sept	Moderate	Lagoon	11	27.87803762	–175.8916741
PHR-362	16-Sept	Deep	Forereef	26	27.90985239	–175.9129906
PHR-396	16-Sept	Moderate	Lagoon	15	27.81328901	–175.9751839
PHR-282	17-Sept	Shallow	Backreef	2	27.86071365	–175.7435754
PHR-283	17-Sept	Shallow	Backreef	3	27.78846466	–175.8796720
PHR-322	17-Sept	Shallow	Backreef	3	27.79144585	–175.8742823
PHR-323	17-Sept	Shallow	Backreef	2	27.78912490	–175.7844276
PHR-338	17-Sept	Shallow	Lagoon	4	27.79435446	–175.8251005
PHR-342	17-Sept	Shallow	Lagoon	2	27.82164275	–175.7617430
PHR-345	17-Sept	Shallow	Lagoon	4	27.80721338	–175.7790809
PHR-397	17-Sept	Moderate	Forereef	14	27.77124245	–175.8972808
PHR-400	17-Sept	Shallow	Backreef	2	27.79034967	–175.8270988

APPENDIX D: KURE ATOLL

Kure Atoll, located at 28.418958° N, 178.326147° W, is the northernmost atoll in the world and is part of the Northwestern Hawaiian Islands (NWHI), Papahānaumokuākea Marine National Monument (PMNM). For information about the methods used to perform the activities discussed in this appendix, please see Appendix A: “Methods.”

D.1. Oceanography and Water Quality

Oceanographic operations at Kure Atoll during HA-10-07 entailed numerous retrievals and deployments of oceanographic moored instruments, installation of calcification acidification units (CAUs), nearshore water sampling and conductivity, temperature, and depth (CTD) casts to depths up to 30 m at select Rapid Ecological Assessment (REA) sites, shipboard water sampling and CTD casts offshore to a depth of 500 m, and assistance with autonomous reef monitoring structures (ARMS) recoveries and line-point-intercept (LPI) surveys.

Six subsurface temperature recorders (STRs) were retrieved and 10 STRs were deployed (Fig. D.1.1). One of these swapped STRs was moored with an environmental acoustic recorder (EAR) that was deployed during a previous cruise and was inspected during this cruise. A sea-surface temperature (SST) buoy and anchor were recovered and replaced. Two wave-and-tide recorders (WTRs) and their associated anchors were swapped. For information about CAU deployments completed at Kure Atoll, see Table C.2.1 in Section D.2: “Benthic Environment.”

At nearshore locations at Kure Atoll, 5 shallow-water CTD casts were performed at each of the 5 REA sites where CAUs were installed (Fig. D.1.2). In concert with the CTD cast at each of these same REA sites, 2 water samples were taken to measure the following parameters: dissolved inorganic carbon (DIC), total alkalinity (TA), salinity, and nutrient, and chlorophyll-*a* (Chl-*a*) concentrations. At 1 REA site, 3 samples, known as a triplicate, were collected to test the precision and accuracy of the sampling and analytical methods, resulting in the collection of a total of 12 DIC and TA, 12 salinity, 12 nutrient, and 12 Chl-*a* water samples. At each site, 1 sample was collected from the surface and 1 near the reef for each parameter. The triplicate sample was performed near the reef.

From the NOAA Ship *Hi`ialakai*, 2 ADCP transect lines of 25 km each were run to the north and south away from this atoll during night operations. On the reciprocal course, 6 CTD casts to depths of 500 m were conducted primarily along the transect line every 5 km for a total of 12 shipboard CTD casts. Water samples were collected concurrently with select deepwater CTD casts at 5 depths per cast between the surface and 200 m, depending on the depth of mixed layer as determined by the CTD downcast. One of the CTD casts was performed at the Kure permanent deepwater CTD site, and water samples were collected there. A total of 15 nutrient and 15 Chl-*a* deepwater samples were collected near Kure Atoll.

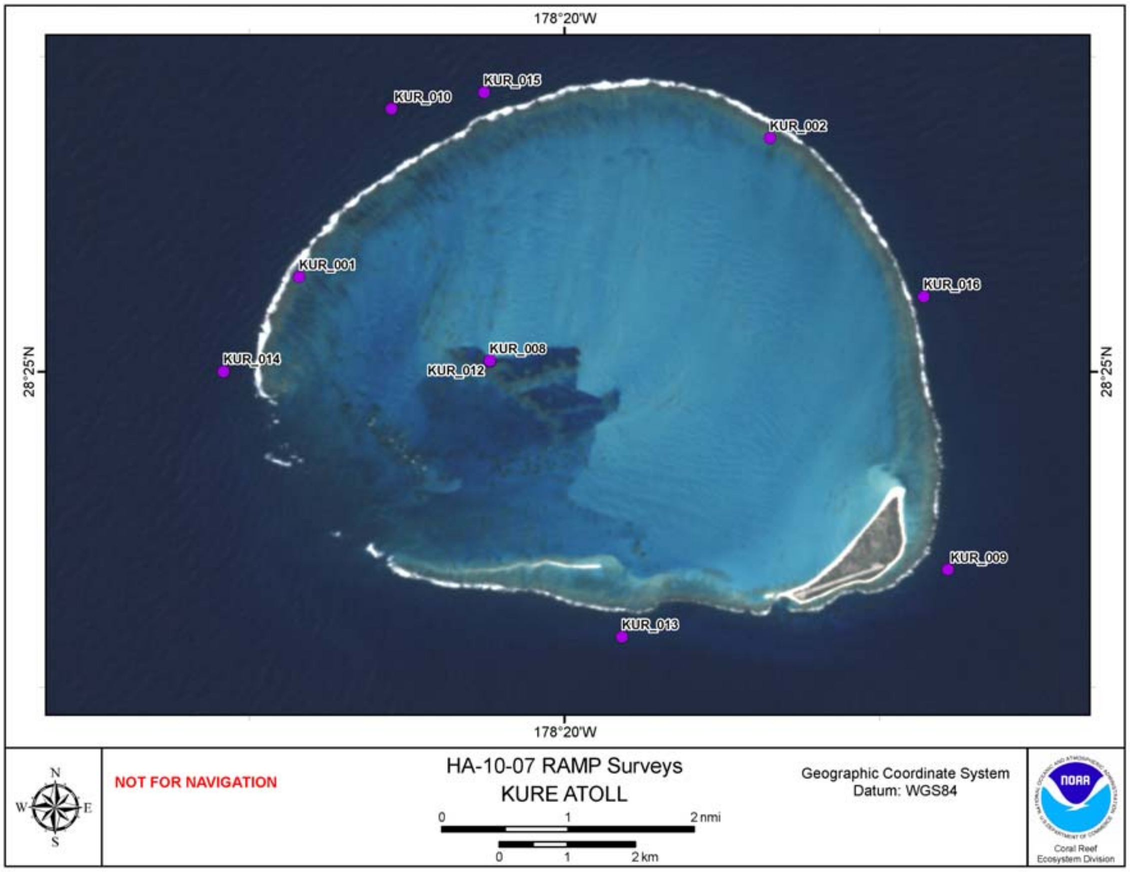

Figure D.1.1. Mooring sites at Kure Atoll where oceanographic instruments were retrieved or deployed during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table D.1.1. Geographic coordinates and sensor depths of the moored oceanographic instruments that were retrieved or deployed at Kure Atoll during cruise HA-10-07.

Mooring Site	Instrument Type	Latitude	Longitude	Depth (m)	Retrieval	Deployment
KUR-001	STR	28.42924406	–178.3684171	1.2	1	1
KUR-002	STR	28.44760646	–178.3062184	0.9	1	1
KUR-008	SST	28.41815287	–178.3432335	0.2	1	1
KUR-008	STR	28.41821607	–178.3432223	0.3	–	1
KUR-009	STR	28.39066685	–178.2826889	18.3	1	1
KUR-009	WTR	28.39066685	–178.2826889	18.3	1	1
KUR-009	Anchor	28.39066685	–178.2826889	18.3	1	1
KUR-010	STR	28.45151955	–178.3562116	19.8	1	1
KUR-010	WTR	28.45151955	–178.3562116	19.8	1	1
KUR-010	Anchor	28.45151955	–178.3562116	19.8	1	1
KUR-012	STR	28.41819696	–178.3432160	10.0	1	1
KUR-012	Anchor	28.41819696	–178.3432160	10.4	1	1
KUR-013	STR	28.38175152	–178.3257407	12.5	1	1
KUR-014	STR	28.41675653	–178.3784283	15.8	–	1
KUR-015	STR	28.45365015	–178.3439881	11.9	–	1
KUR-016	STR	28.42664827	–178.2858767	11.6	–	1

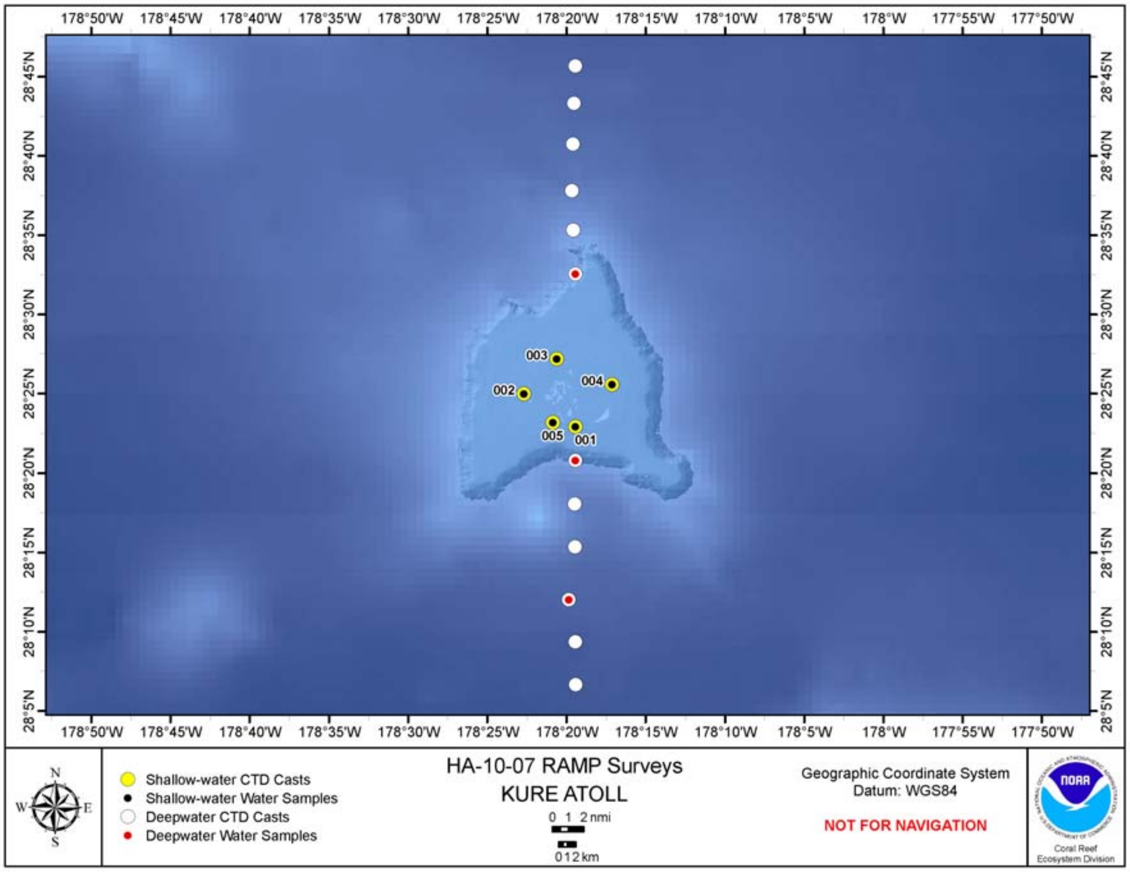

Figure D.1.2. Locations of CTD casts and water sampling performed at Kure Atoll during cruise HA-10-07. Satellite image SIO, NOAA, U.S. Navy, NGA, GEBCO (Becker, 2009; Smith and Sandwell, 1997) © 2008 The Regents of the University of California.

Preliminary Results: Temperature

SST data from Kure Atoll indicates that the average temperature over the past 4 weeks was 27.89°C (Fig. D.1.3). When comparing data from the summer months (July–September) in 2009 to data from the same period in 2010, SST was slightly warmer (0.5°C) in 2010, with average temperatures of 27.45°C and 27.95°C, respectively. In addition, SST was regularly 0.5°C–2°C above weekly climatological temperatures throughout the 2-year period of October 2008 to September 2010 and exceeded the Coral Reef Watch (CRW) bleaching threshold (28°C), defined as 1°C above the maximum monthly climatological mean, multiple times in 2009 and 2010.

Temperature data from STRs moored on the northwest of Kure Atoll at a depth of 20 m and the southeast at a depth of 18 m indicate distinctly different physical forcing mechanisms driving temperature variability at high frequencies (Fig. D.1.4). Data from the northwest shows large temperature changes of 1°C–5°C occurring on diurnal and semidiurnal return periods, whereas similar temperature data from a similar depth on the southeast show diurnal changes of < 1°C. The latter variability is most likely due to diel solar heating and cooling of the upper water column, whereas the former temperature variability is most likely indicative of internal tides, which drive vertical oscillations of isotherms at tidal frequencies. This difference in prevailing physical forcing mechanisms around Kure Atoll has profound implications for nutrient input to the benthic coral reef community.

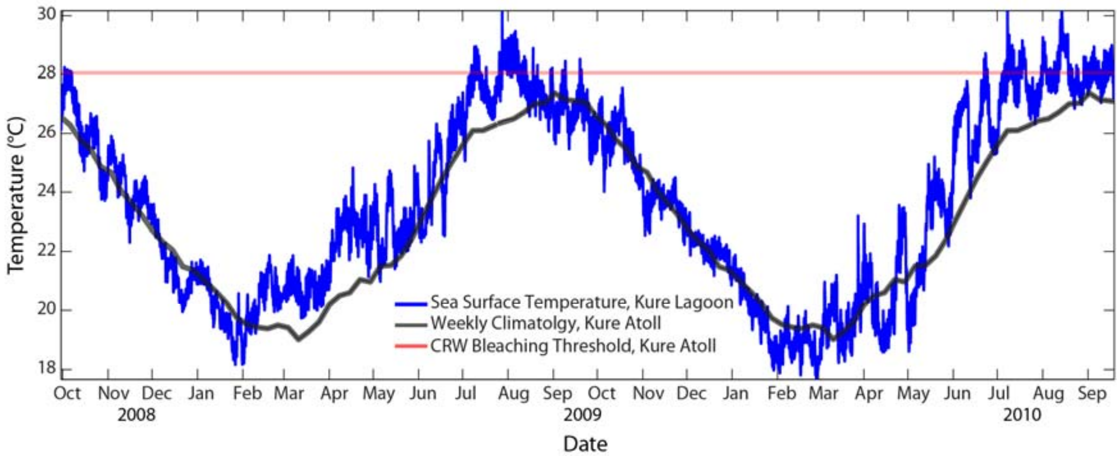

Figure D.1.3.--Time-series observations of temperature data for the period from October 2008 to September 2010 from the SST buoy moored in the central lagoon at Kure Atoll (blue), weekly satellite-derived (Pathfinder) SST climatology using data from 1981 to 2007, and the CRW bleaching threshold for Kure Atoll, defined as 1°C above the maximum climatological monthly mean.

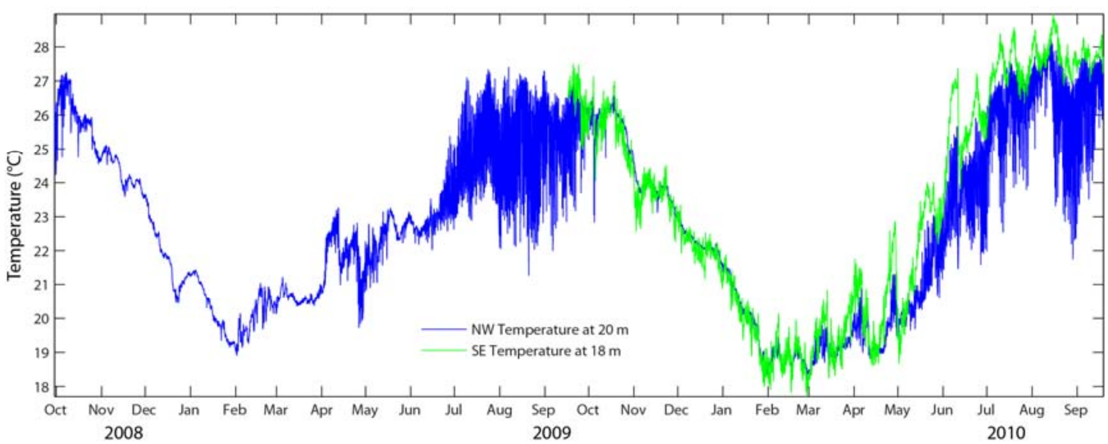

Figure D.1.4. Time-series observations of temperature data from an STR moored on the northwest forereef at a depth of 20 m (blue) for the period from October 2008 September 2010 and from an STR moored on the southeast forereef at a depth of 18 m (green) for the period from October 2009 to September 2010.

D.2. Benthic Environment

Belt-transect and line-point-intercept (LPI) surveys were conducted and photoquadrat images were collected at 9 REA sites at Kure Atoll, and LPI surveys were conducted at 2 additional sites, to assess benthic composition, coral and algal community structure, and coral and algal disease (Fig. D.2.1 and Table D.2.1). At the end of LPI surveys, roving-diver algal surveys were conducted at 9 of the 11 sites.

Various samples were collected at 8 REA sites: 4 total voucher specimens of algae at 2 REA sites for taxonomic identification, 20 individuals of the algal genus *Halimeda* from 2 different REA sites for calcification studies, 3 fragments of the coral, *Pocillopora meandrina*, for histopathological analysis at REA site KUR-09, and 15 water samples for microbial analyses at 3 REA sites with 4 water samples of 2 L each and at each site and 3 water samples of 20 L each at KUR-12. For a list of collections made at these REA sites, see Table H.1 in Appendix H: “Biological Collections.”

Seven autonomous reef monitoring structures (ARMS) were recovered: 3 ARMS each from KUR-12 and KUR-18 and 1 ARMS from KUR-R33. Nine ARMS were deployed with 3 each at KUR-02, KUR-12, and KUR-R33 (Table D.2.1). At each of 5 select REA sites, an array of 5 CAUs was deployed for a total of 25 CAUs installed at Kure Atoll (Fig. D.2.1).

In total, the benthic team conducted 46 individual dives at REA sites around Kure Atoll.

CRED also completed 15 towed-diver surveys at Kure Atoll, covering a total length of 33.6 km (an area of 33.6 ha) of the ocean floor (Fig. D.2.2). The mean survey length was 2.2 km with a range of 1.8–2.6 km. The mean survey depth was 10 m with a range of 1.4–16.8 m. The mean temperature from data recorded during these surveys was 27.6°C with a range of 27.1°C–27.9°C.

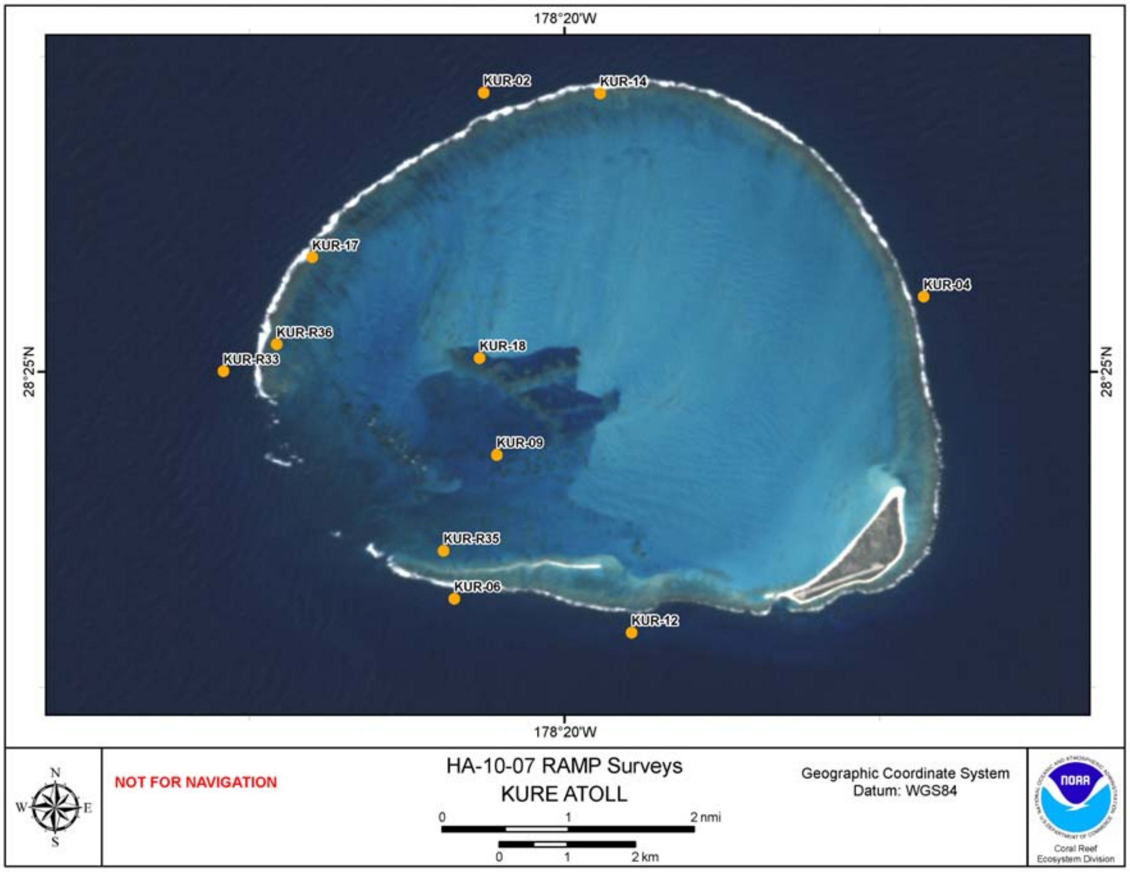

Figure D.2.1. Locations of REA benthic sites surveyed at Kure Atoll during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table D.2.1.--Summary of REA benthic surveys, CAU installations, and ARMS retrievals (Ret.) and deployments (Dep.) performed as well as algal specimens, tissue samples of diseased corals, and microbial water samples collected at Kure Atoll during cruise HA-10-07. Indication that an LPI survey was completed also means that photoquadrat images were collected, and roving-diver algal surveys (Algae) were conducted at most sites.

REA Site	Date	Latitude	Longitude	REA Surveys			Installations and Collections				
				LPI	Algae	Corals	CAUs	ARMS Ret/Dep	Algae	Coral Disease	Microbial Samples
KUR-12	18-Sept	28.382308	–178.324479	×	×	×	5	3/3	–	–	7
KUR-18	18-Sept	28.418535	–178.344575	×	×	×	–	3/0	2	–	–
KUR-R35	18-Sept	28.393133	–178.349333	×	×	×	–	–	2	–	–
KUR-17	19-Sept	28.431866	–178.366682	×	×	×	–	–	–	–	–
KUR-R33	19-Sept	28.416767	–178.378433	×	×	×	5	1/3	–	–	4
KUR-R36	19-Sept	28.420350	–178.371417	×	×	×	–	–	10	–	–
KUR-02	20-Sept	28.453633	–178.344017	×	×	×	5	0/3	–	–	4
KUR-04	20-Sept	28.426650	–178.285870	×	–	–	5	–	–	–	–
KUR-06	20-Sept	28.386780	–178.347920	×	–	–	5	–	–	–	–
KUR-09	20-Sept	28.405767	–178.342283	×	×	×	–	–	–	3	–
KUR-14	20-Sept	28.453510	–178.328637	×	×	×	–	–	10	–	–

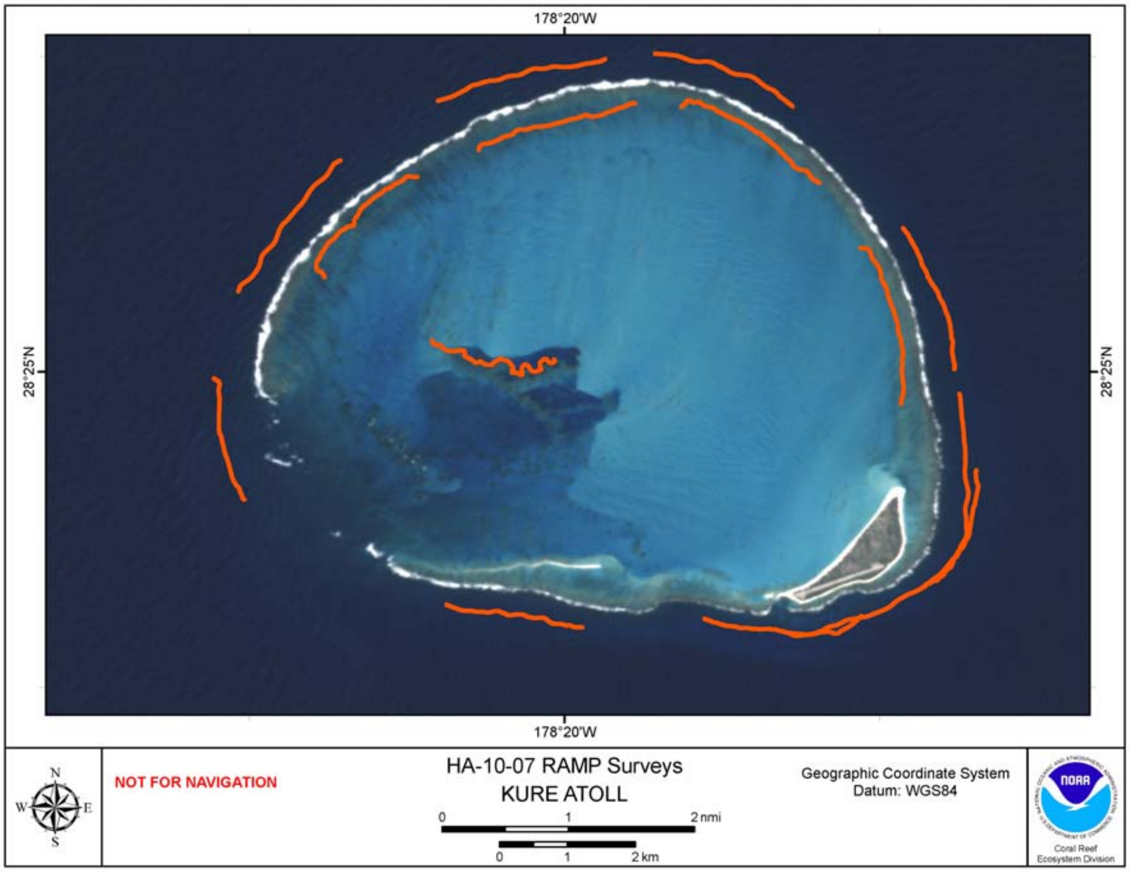

Figure D.2.2. Track locations of towed-diver surveys conducted at Kure Atoll during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

D.3 Reef Fish Community

REA fish survey sites were chosen using a stratified random design. Stationary-point-count surveys were conducted at 25 REA sites at Kure Atoll over 6 different habitat strata: deep forereef, moderate forereef, shallow forereef, moderate lagoon, shallow lagoon, and shallow backreef (Fig. D.3.1 and Table D.3.1). No fishes were collected during these surveys.

In addition, CRED completed 15 towed-diver fish surveys at Kure Atoll, as described previously in Section D.2 of this appendix.

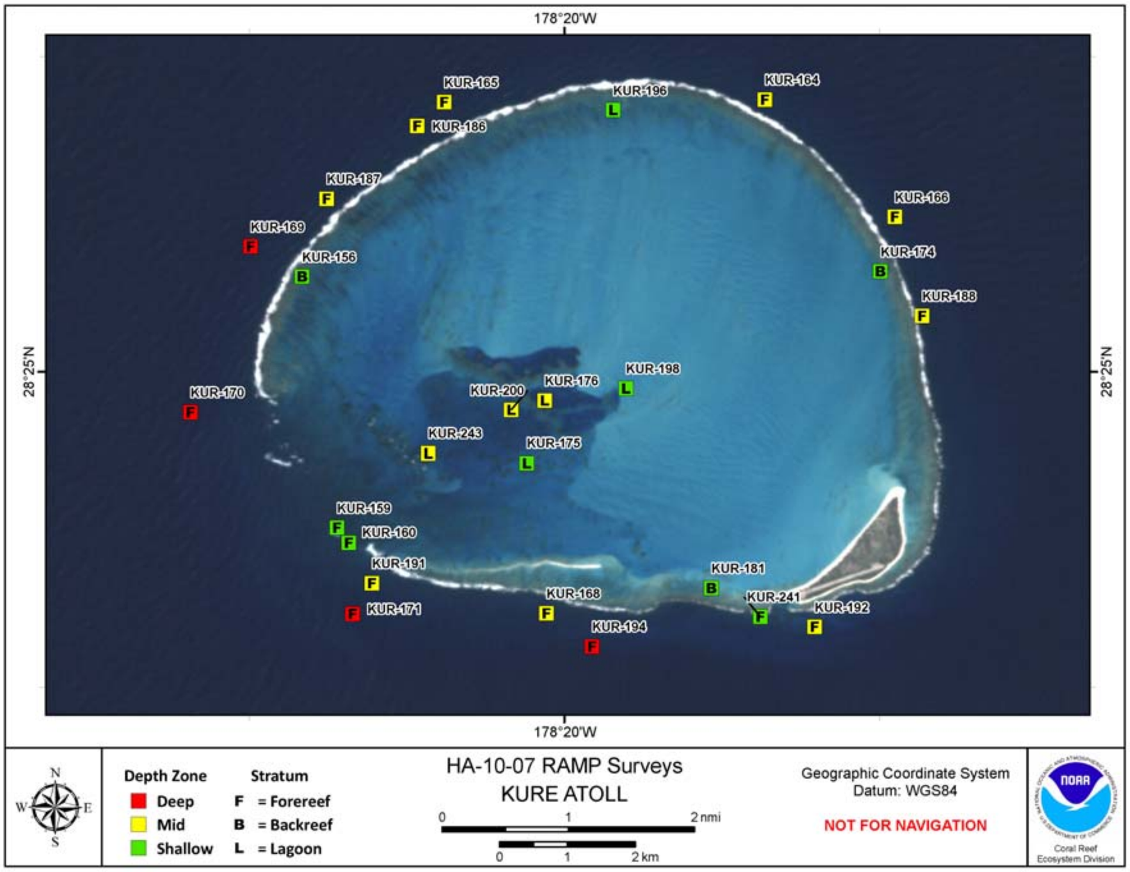

Figure D.3.1.--Locations of REA fish sites surveyed at Kure Atoll during cruise HA-10-07. All of these REA sites were selected using a stratified random design. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table D.3.1.--Summary of sites where REA fish surveys were conducted at Kure Atoll during cruise HA-10-07.

REA Site	Date	Depth Zone	Stratum	Depth (m)	Latitude	Longitude
KUR-168	18-Sept	Moderate	Forereef	12	28.38486146	–178.3357237
KUR-171	18-Sept	Deep	Forereef	28	28.38477010	–178.3613476
KUR-174	18-Sept	Shallow	Backreef	2	28.42997471	–178.2915580
KUR-181	18-Sept	Shallow	Backreef	1	28.38819461	–178.3139050
KUR-191	18-Sept	Moderate	Forereef	14	28.38883541	–178.3588074
KUR-192	18-Sept	Moderate	Forereef	11	28.38306614	–178.3002650
KUR-194	18-Sept	Deep	Forereef	29	28.38047706	–178.3296686
KUR-156	19-Sept	Shallow	Backreef	2	28.42930432	–178.3680295
KUR-159	19-Sept	Shallow	Forereef	6	28.39618198	–178.3634197
KUR-160	19-Sept	Shallow	Forereef	6	28.39416655	–178.3618592
KUR-175	19-Sept	Shallow	Lagoon	3	28.40468994	–178.3383107
KUR-176	19-Sept	Moderate	Lagoon	10	28.41291226	–178.3359306
KUR-196	19-Sept	Shallow	Lagoon	3	28.45132618	–178.3268989
KUR-198	19-Sept	Shallow	Lagoon	3	28.41451622	–178.3251918
KUR-200	19-Sept	Moderate	Lagoon	8	28.41166830	–178.3404009
KUR-241	19-Sept	Shallow	Forereef	5	28.38440247	–178.3074384
KUR-243	19-Sept	Moderate	Lagoon	8	28.40597313	–178.3513340
KUR-164	20-Sept	Moderate	Forereef	13	28.45271339	–178.3068335
KUR-165	20-Sept	Moderate	Forereef	13	28.45236302	–178.3492277
KUR-166	20-Sept	Moderate	Forereef	14	28.43719161	–178.2896484
KUR-169	20-Sept	Deep	Forereef	22	28.43325983	–178.3748214
KUR-170	20-Sept	Deep	Forereef	24	28.41135699	–178.3827830
KUR-186	20-Sept	Moderate	Forereef	12	28.44921973	–178.3528083
KUR-187	20-Sept	Moderate	Forereef	10	28.43960493	–178.3647671
KUR-188	20-Sept	Moderate	Forereef	10	28.42410763	–178.2860534

APPENDIX E: LISIANSKI ISLAND AND NEVA SHOAL

Lisianski Island and the surrounding atoll, Neva Shoal, are located at 26.064385° N, 173.965605° W and are part of the Northwestern Hawaiian Islands (NWHI), Papahānaumokuākea Marine National Monument (PMNM). For information about the methods used to perform the activities discussed in this appendix, please see Appendix A: "Methods."

E.1. Oceanography and Water Quality

Oceanographic operations at Lisianski Island and Neva Shoal during HA-10-07 entailed numerous retrievals and deployments of oceanographic moored instruments, installation of calcification acidification units (CAUs), nearshore water sampling and conductivity, temperature, and depth (CTD) casts to depths up to 30 m at select Rapid Ecological Assessment (REA) sites, and shipboard water sampling and CTD casts offshore to a depth of 500 m.

Three subsurface temperature recorders (STRs) were retrieved and 7 STRs were deployed at Lisianski Island and Neva Shoal (Table E.1.1). A sea-surface temperature (SST) buoy and anchor were recovered and replaced. The original SST buoy had to be redeployed, after data was downloaded from it and it was cleaned and recharged, because of technical problems with a number of new SST buoys. One previously deployed environmental acoustic recorder (EAR) was visually inspected. One wave-and-tide recorders (WTR) was recovered, and 2 WTRs were deployed on anchors that were swapped (Table E.1.1). The second deployed WTR and its associated STR were accidentally recovered by a collaborating scientist during a previous cruise. For information about CAU deployments completed at Lisianski Island, see Table E.2.1 in Section E.2: "Benthic Environment."

At nearshore locations at Lisianski Island and Neva Shoal, 5 shallow-water CTD casts were performed at each of the 5 REA sites where CAUs were installed (Fig. E.1.2). In concert with the CTD cast at each of these same REA sites, 2 water samples were taken to measure the following parameters: dissolved inorganic carbon (DIC), total alkalinity (TA), salinity, and nutrient, and chlorophyll-*a* (Chl-*a*) concentrations. A total of 10 DIC and TA, 9 salinity (1 sample lost because of human error), 10 nutrient, and 10 Chl-*a* water samples were collected, 1 from the surface and 1 near the reef at each site for each parameter.

From the NOAA Ship *Hi`ialakai*, 3 ADCP transect lines of 25 km each were run to the north, south, and west away from Lisianski Island and Neva Shoal during night operations. On the reciprocal course, 6 CTD casts to depths of 500 m were conducted per transect line every 5 km for a total of 18 shipboard CTD casts. Water samples were collected concurrently with select deepwater CTD cast at 5 depths per cast between the surface and 200 m, depending on the depth of mixed layer as determined by the CTD downcast. Additionally, a CTD cast was performed at the Lisianski Island permanent deepwater CTD site, and water samples were collected there. A total of 20 nutrient and 20 Chl-*a* deepwater samples were collected near Lisianski Island.

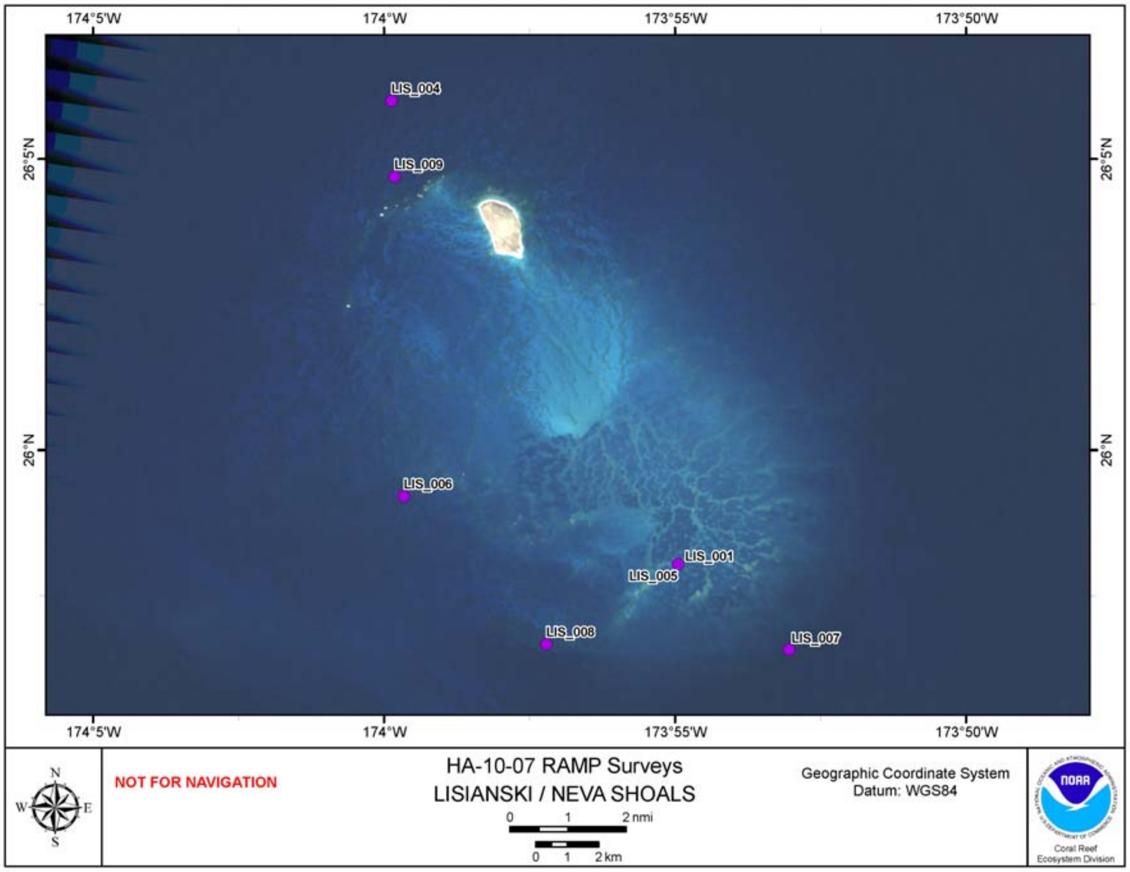

Figure E.1.1.--Mooring sites at Lisianski Island and Neva Shoal where oceanographic instruments were retrieved or deployed during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table E.1.1.--Geographic coordinates and sensor depths of the moored oceanographic instruments that were retrieved or deployed at Lisianski Island and Neva Shoal during cruise HA-10-07.

Mooring Site	Instrument Type	Latitude	Longitude	Depth (m)	Retrieval	Deployment
LIS-001	SST	25.96761576	–173.9158538	0.2	1	1
LIS-001	STR	25.96761991	–173.9158715	0.3	–	1
LIS-004	STR	26.10017301	–173.9979678	23.2	–	1
LIS-004	WTR	26.10017301	–173.9979678	23.2	–	1
LIS-004	Anchor	26.10017301	–173.9979678	23.2	1	1
LIS-005	STR	25.96761991	–173.9158715	9.1	1	1
LIS-005	Anchor	25.96761991	–173.9158715	9.1	1	1
LIS-006	STR	25.98699016	–173.9943768	14.6	1	1
LIS-007	STR	25.94301567	–173.8841434	20.7	1	1
LIS-007	WTR	25.94301567	–173.8841434	20.7	1	1
LIS-007	Anchor	25.94301567	–173.8841434	20.7	1	1
LIS-008	STR	25.94461746	–173.9536197	13.4	–	1
LIS-009	STR	26.07838458	–173.9970317	14.6	–	1

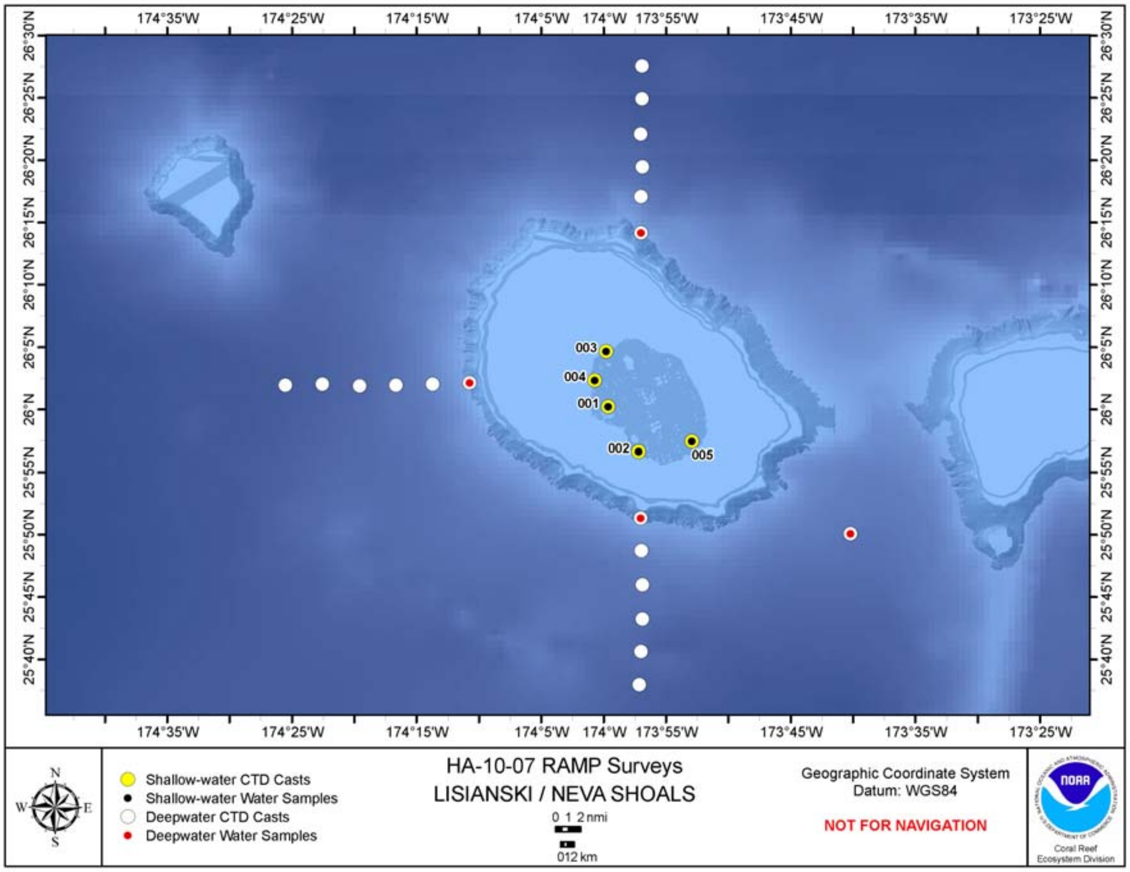

Figure E.1.2. Locations of CTD casts and water sampling performed at Lisianski Island and Neva Shoal during cruise HA-10-07. Satellite image SIO, NOAA, U.S. Navy, NGA, GEBCO (Becker, 2009; Smith and Sandwell, 1997) © 2008 The Regents of the University of California.

Preliminary Results

Temperature data from instruments deployed on the southeast side of Lisanski Island, an SST buoy and an STR moored at a depth of 20 m, show similar seasonal and intraseasonal fluctuations (Fig. E.1.3). Throughout the concurrent data set for the period of October 2009 to September 2010, SST and subsurface temperatures are highly similar in both magnitude and variability, indicative of a fairly uniform water column with respect to temperature, which is atypical compared to other locations within the NWHI. Additionally, from October 2009 to April 2010, SST is often colder than subsurface temperatures, whereas from April–September, SST is warmer. The latter temperature pattern is more typical, as solar energy heats up the surface ocean leading to warmer temperatures in the few upper meters and decreasing steadily with depth. The former pattern, where temperatures at a depth of 20 m are warmer than temperatures at the sea surface, is an anomaly and requires further study to elucidate the mechanisms driving it.

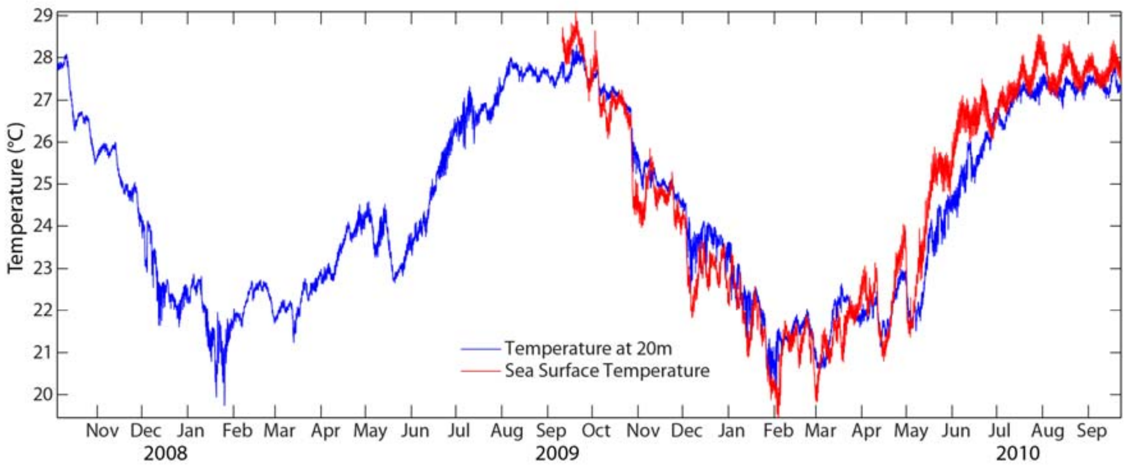

Figure E.1.3. Time-series observations of SST (red) and subsurface temperature (blue) data for the period from October 2008 to September 2010 from instruments deployed on the southeast side of Lisianski Island, an SST buoy and an STR moored at a depth of 20 m.

E.2. Benthic Environment

Belt-transect and line-point-intercept (LPI) surveys were conducted and photoquadrat images were collected at 9 REA sites at Lisianski Island and Neva Shoal to assess benthic composition, coral and algal community structure, and coral and algal disease (Fig. E.2.1 and Table E.2.1). At the end of LPI surveys, roving-diver algal surveys were conducted at all sites.

Various samples were collected at 7 REA sites: 4 total voucher specimens of algae from 3 REA sites for taxonomic identification, 60 individuals of the algal genus *Halimeda* from 4 REA sites for calcification studies, and 15 water samples for microbial analysis at 3 REA sites with 4 water samples of 2 L each at each site and 3 water samples of 20 L each at REA site LIS-R14. For more information about collections made at REA sites, see Table H.1 in Appendix H: "Biological Collections."

Seven autonomous reef monitoring structures (ARMS) were recovered: 3 ARMS each from LIS-R14 and LIS-R10 and 1 ARMS from LIS-18. Nine ARMS were deployed with 3 ARMS each at these 3 REA sites (Table E.2.1). At each of 5 select REA sites, an array of 5 CAUs was deployed for a total of 25 CAUs installed at Lisianski Island and Neva Shoal.

In total, the benthic team conducted a total of 46 individual dives at REA sites around Lisianski Island and Neva Shoal.

CRED also completed 14 towed-diver surveys at Lisianski Island and Neva Shoal, covering a total length of 29.5 km (and area of 29.5 ha) of the ocean floor (Fig. E.2.2). The mean survey length was 2.1 km with a range of 0.6–2.6 km. The mean survey depth was 10.6 m with a range of 1.3–17.1 m. The mean temperature from data recorded during these surveys was 27.7°C with a range of 27.3°C–28.2°C.

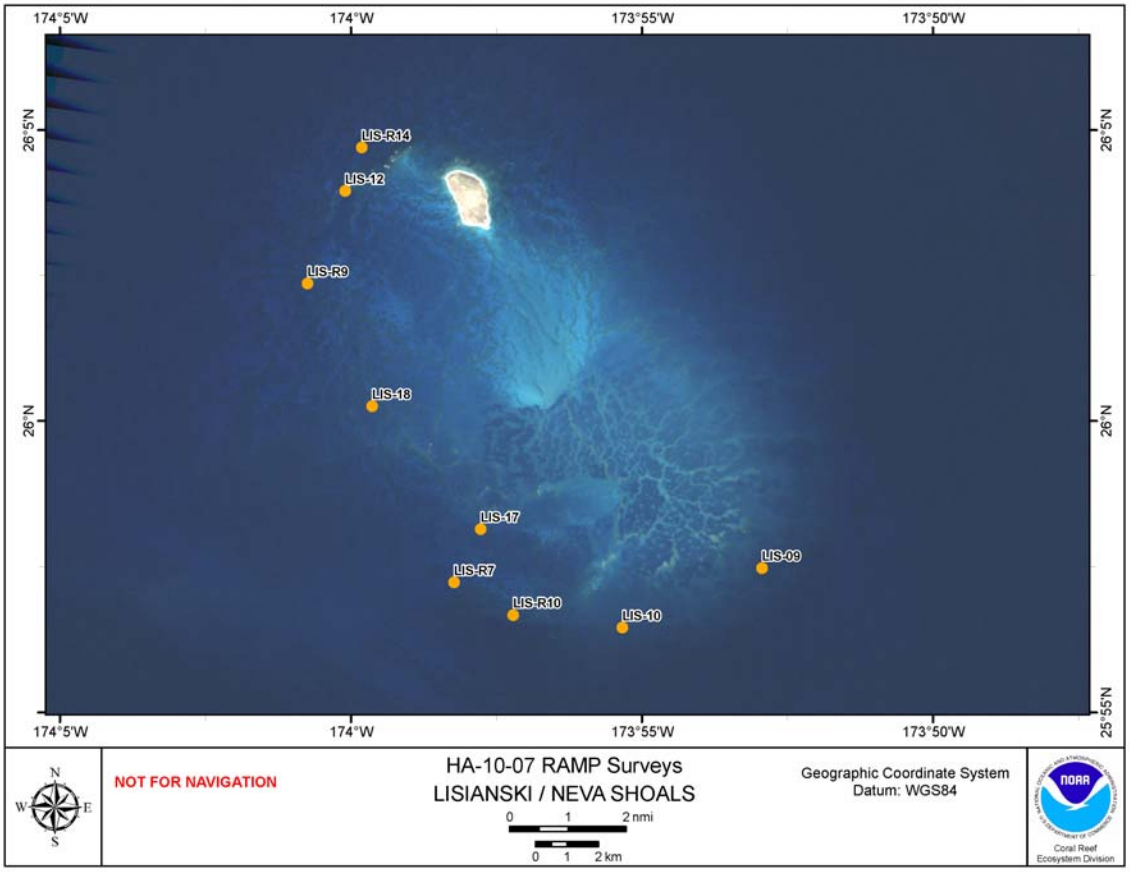

Figure E.2.1.--Locations of REA benthic sites surveyed at Lisianski Island and Neva Shoal during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table E.2.1.-- Summary of REA benthic surveys, CAU installations, and ARMS retrievals (Ret.) and deployments (Dep.) performed as well as algal specimens and microbial water samples collected at Lisianski Island and Neva Shoal during cruise HA-10-07. Indication that an LPI survey was completed also means that photoquadrat images were collected and roving-diver algal surveys were conducted.

REA Site	Date	Latitude	Longitude	REA Surveys		Installations and Collections			
				LPI	Corals	CAUs	ARMS Ret/Dep	Algae	Microbial Samples
LIS-17	22-Sept	25.969250	–173.962900	×	×	–	–	12	–
LIS-18	22-Sept	26.004283	–173.994028	×	×	5	1/3	–	4
LIS-R7	22-Sept	25.953950	–173.970536	×	×	–	–	–	–
LIS-12	23-Sept	26.065963	–174.001752	×	×	–	–	11	–
LIS-R14	23-Sept	26.078415	–173.997011	×	×	5	3/3	–	7
LIS-R9	23-Sept	26.039408	–174.012545	×	×	5	–	20	–
LIS-09	24-Sept	25.958073	–173.882380	×	×	5	–	–	–
LIS-10	24-Sept	25.941001	–173.922380	×	×	–	–	21	–
LIS- R10	24-Sept	25.944620	–173.953610	×	×	5	3/3	–	4

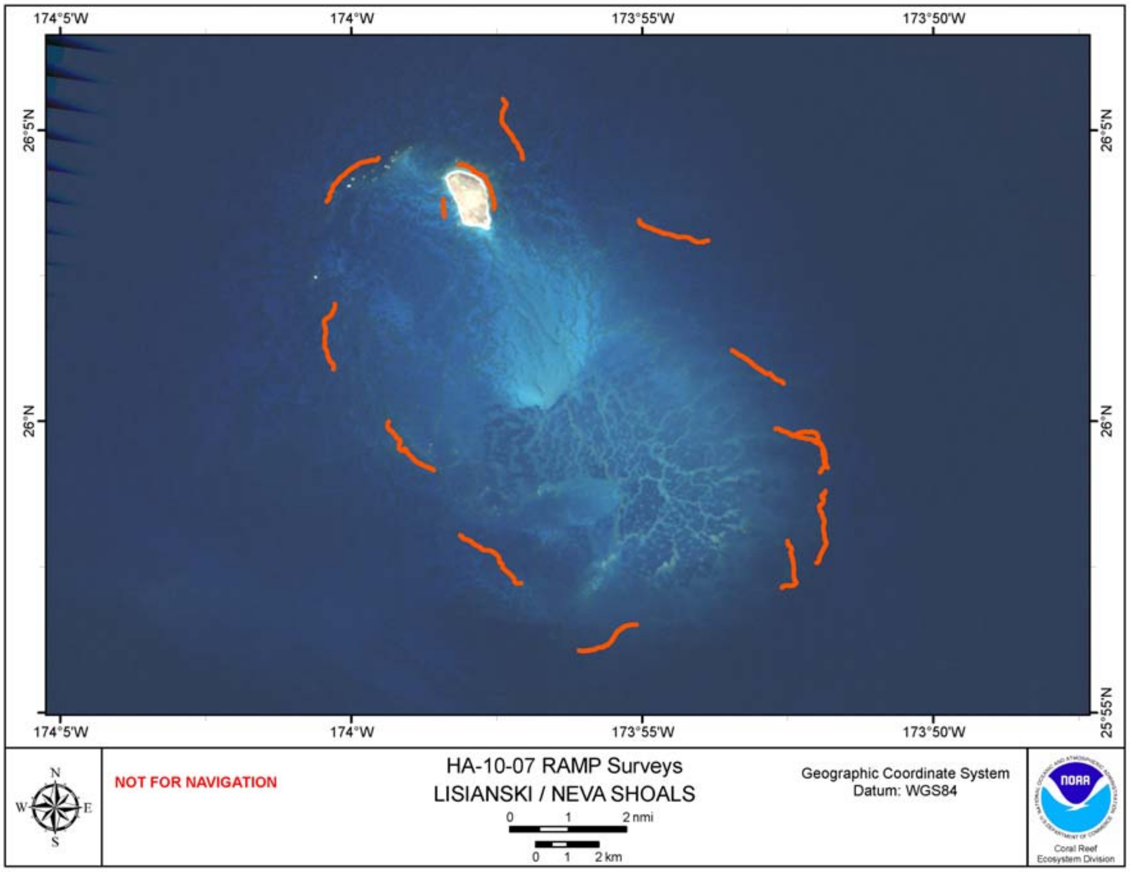

Figure E.2.2.--Track locations of towed-diver surveys conducted at Lisianski Island and Neva Shoal during cruise HA-10-07. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

E.3 Reef Fish Community

REA fish survey sites were chosen using a stratified random design. Stationary-point-count surveys were conducted at 25 REA sites at Lisianski Island and Neva Shoal over 3 different habitat strata: deep forereef, moderate forereef, and shallow forereef (Fig. E.3.1 and Table E.3.1). No fishes were collected during these surveys.

During cruise HA-10-07, CRED completed 14 towed-diver surveys at Lisianski Island and Neva Shoal, as described previously in Section E.2 of this appendix.

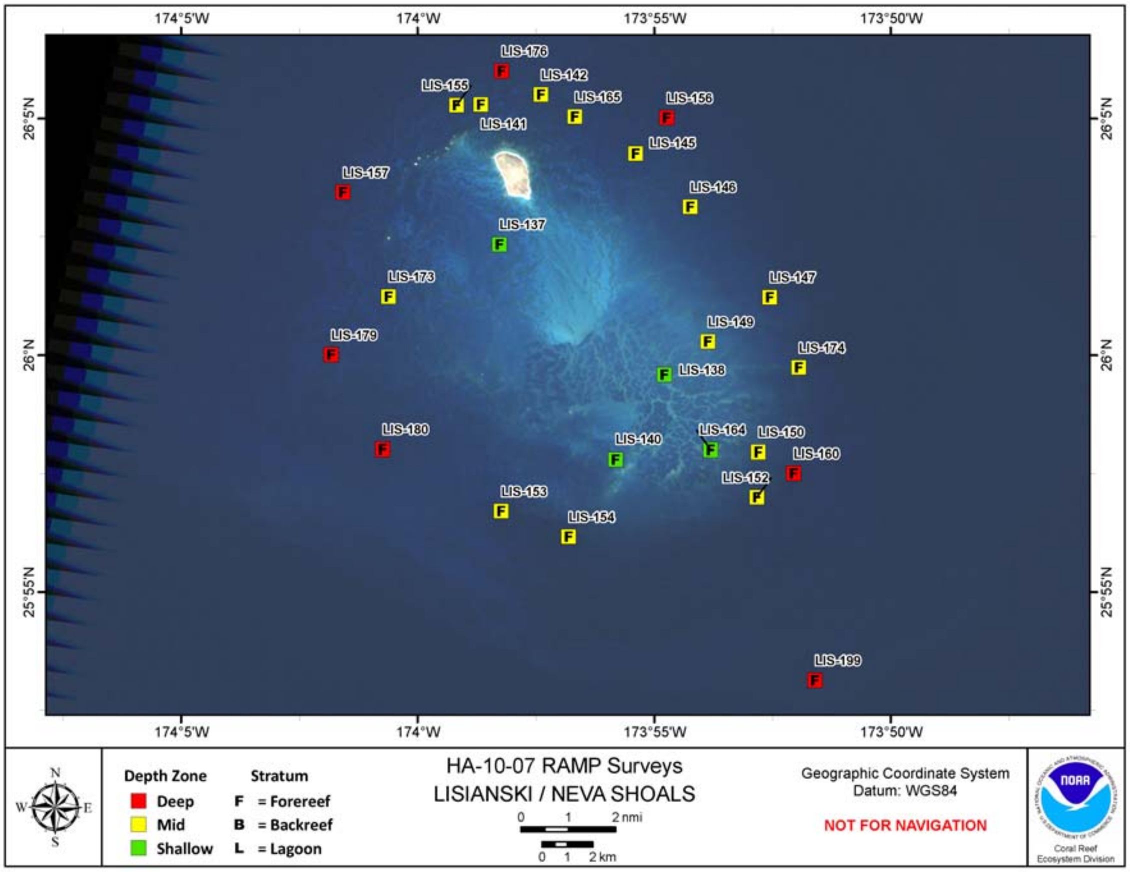

Figure E.3.1. Locations of REA fish sites surveyed at Lisianski Island and Neva Shoal during cruise HA-10-07. All of these REA sites were selected using a stratified random design. Landsat satellite imagery data used in this map figure are available from the U.S. Geological Survey.

Table E.3.1. Summary of sites where REA fish surveys were conducted at Lisianski Island and Neva Shoal during cruise HA-10-07.

REA Site	Date	Depth Zone	Stratum	Depth (m)	Latitude	Longitude
LIS-138	22-Sept	Shallow	Forereef	5	25.99311079	–173.9130338
LIS-140	22-Sept	Shallow	Forereef	4	25.96347950	–173.9302710
LIS-147	22-Sept	Moderate	Forereef	15	26.02048474	–173.8759265
LIS-149	22-Sept	Moderate	Forereef	9	26.00485149	–173.8977095
LIS-150	22-Sept	Moderate	Forereef	12	25.96597664	–173.8799546
LIS-152	22-Sept	Moderate	Forereef	14	25.95009813	–173.8803839
LIS-160	22-Sept	Deep	Forereef	23	25.95852119	–173.8674763
LIS-164	22-Sept	Shallow	Forereef	2	25.96677032	–173.8967245
LIS-174	22-Sept	Moderate	Forereef	14	25.99569786	–173.8657271
LIS-141	23-Sept	Moderate	Forereef	14	26.08844421	–173.9777830
LIS-142	23-Sept	Moderate	Forereef	14	26.09191541	–173.9565957
LIS-145	23-Sept	Moderate	Forereef	13	26.07116994	–173.9231853
LIS-146	23-Sept	Moderate	Forereef	18	26.05233723	–173.9039747
LIS-155	23-Sept	Moderate	Forereef	15	26.08821698	–173.9862654
LIS-156	23-Sept	Deep	Forereef	25	26.08378856	–173.9122009
LIS-165	23-Sept	Moderate	Forereef	14	26.08411672	–173.9446185
LIS-176	23-Sept	Deep	Forereef	22	26.10029966	–173.9704480
LIS-137	24-Sept	Shallow	Forereef	5	26.03912677	–173.9712633
LIS-153	24-Sept	Moderate	Forereef	15	25.94523344	–173.9705902
LIS-154	24-Sept	Moderate	Forereef	14	25.93626782	–173.9468795
LIS-157	24-Sept	Deep	Forereef	24	26.05743787	–174.0264062
LIS-173	24-Sept	Moderate	Forereef	14	26.02071583	–174.0103305
LIS-179	24-Sept	Deep	Forereef	20	26.00018210	–174.0304875
LIS-180	24-Sept	Deep	Forereef	20	25.96691323	–174.0123502
LIS-199	24-Sept	Deep	Forereef	26	25.88560693	–173.8599445

APPENDIX F: FIVE FATHOM PINNACLE

Five Fathom Pinnacle is located at 21.70° N, 160.60° W in the north Pacific ~ 35 km west-southwest of the island of Ni`ihau in the main Hawaiian Islands. For information about the methods used to perform the activities discussed below, please see Appendix A: "Methods."

F.1. Oceanography and Water Quality

Oceanographic operations at Five Fathom Pinnacle during HA-10-07 entailed the retrieval and replacement of one ecological acoustic recorder (EAR) and the subsurface temperature recorder (STR) that was moored with it.

Table F.1.1.--Geographic coordinates and sensor depths of the EARs and STRs that were retrieved and deployed at Five Fathom Pinnacle during cruise HA-10-07.

Mooring Site	Instrument Type	Latitude	Longitude	Depth (m)	Retrieval	Deployment
FFP-001	EAR	21.68675423	–160.6031605	18.9	1	1
FFP-001	STR	21.68675423	–160.6031605	18.9	1	1

APPENDIX G: NORTHWESTERN HAWAIIAN ISLANDS

G.1. Oceanography and Water Quality

Oceanographic operations conducted on board the NOAA Ship *Hi`ialakai* during cruise HA-10-07 include the following activities that were not directly associated with island operations: conductivity, temperature, and depth (CTD) casts and water sampling for nutrient and chlorophyll-*a* analysis at permanent NWHI CTD locations, continuous measurement of temperature, salinity, and partial pressure of carbon dioxide (pCO_2) at the upper surface, continuous collection of acoustic Doppler current profiler (ADCP) data in up to a depth of 600 m, water sampling for analyses of dissolved inorganic carbon (DIC), total alkalinity (TA), and salinity at select locations for calibration of the $pC0_2$ measurements. See Figure G.1.1 for locations of CTD data collected.

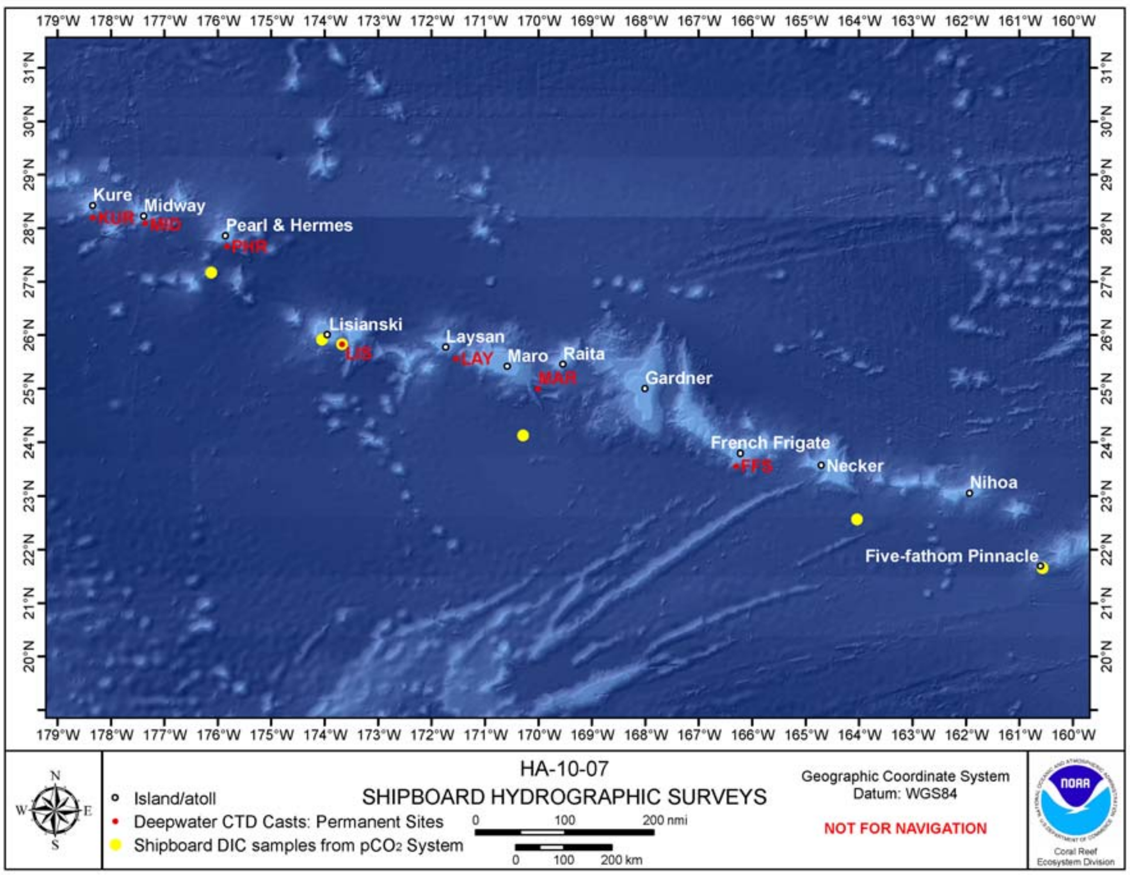

Figure G.1.1.--Location of deepwater CTD casts performed at permanent CTD sites in the NWHI and DIC water samples collected from the shipboard pCO_2 system during cruise HA-10-07. Satellite image SIO, NOAA, U.S. Navy, NGA, GEBCO (Becker, 2009; Smith and Sandwell, 1997) © 2008 The Regents of the University of California.

APPENDIX H: BIOLOGICAL COLLECTIONS

Biological samples were collected at French Frigate Shoals, Pearl and Hermes Atoll, Kure Atoll, and Lisianski Island and Neva Shoal, and their surrounding waters for multiple research purposes. A complete listing of these collections is presented here in Table H.1.

Table H.1. Biological samples collected at French Frigate Shoals (FFS), Pearl and Hermes Atoll (PHR), Kure Atoll (KUR), and Lisianski Island and Neva Shoal (LIS) during cruise HA-10-07.

REA Site	Date	Latitude	Longitude	Specimen Collected	Number of Samples	Depth (m)
Algal Collections: Calcification Studies						
FFS-21	7-Sept	23.8469537	–166.3269575	*Halimeda opuntia*	10	7.6
FFS-21	7-Sept	23.8469537	–166.3269575	*Halimeda velasquezii*	10	7.6
FFS-21	7-Sept	23.8469537	–166.3269575	*Halimeda discoidea*	10	7.6
FFS-30	7-Sept	23.8498866	–166.2973491	*Halimeda velasquezii*	10	5.2
FFS-30	7-Sept	23.8498866	–166.2973491	*Halimeda discoidea*	10	5.2
FFS-12	9-Sept	23.6383500	–166.1800500	*Halimeda opuntia*	10	6.7
FFS-12	9-Sept	23.6383500	–166.1800500	*Halimeda discoidea*	10	6.7
FFS-12	9-Sept	23.6383500	–166.1800500	*Halimeda gracilis*	1	6.7
FFS-12	9-Sept	23.6383500	–166.1800500	*Halimeda velasquezii*	10	6.7
FFS-R29	9-Sept	23.6786508	–166.1463565	*Halimeda discoidea*	4	6.1
FFS-R29	9-Sept	23.6786508	–166.1463565	*Halimeda velasquezii*	10	6.1
FFS-10	10-Sept	23.7448102	–166.1728963	*Halimeda opuntia*	10	6.1
FFS-10	10-Sept	23.7448102	–166.1728963	*Halimeda discoidea*	10	6.1
FFS-10	10-Sept	23.7448102	–166.1728963	*Halimeda velasquezii*	10	6.1
PHR-26	15-Sept	27.9579890	–175.8021820	*Halimeda velasquezii*	18	2.4
PHR-26	15-Sept	27.9579890	–175.8021820	*Halimeda discoidea*	20	2.4
PHR-R39	15-Sept	27.9404600	–175.8613100	*Halimeda velasquezii*	10	13.4
PHR-24	16-Sept	27.9195830	–175.8615830	*Halimeda discoidea*	10	6.1
PHR-24	16-Sept	27.9195830	–175.8615830	*Halimeda opuntia*	10	6.1
PHR-R44	16-Sept	27.9106170	–175.9048330	*Halimeda discoidea*	10	12.2
PHR-R44	16-Sept	27.9106170	–175.9048330	*Halimeda velasquezii*	10	12.2
PHR-34	17-Sept	27.7558327	–175.9615825	*Halimeda discoidea*	10	13.7
PHR-34	17-Sept	27.7558327	–175.9615825	*Halimeda velasquezii*	10	13.7
KUR-R36	19-Sept	28.4203500	–178.3714170	*Halimeda discoidea*	10	1.5
KUR-14	20-Sept	28.4535104	–178.3286369	*Halimeda discoidea*	10	1.5
LIS-17	22-Sept	25.9692500	–173.9629000	*Halimeda velasquezii*	10	12.2
LIS-12	23-Sept	26.0659634	–174.0017516	*Halimeda velasquezii*	10	10.7
LIS-R9	23-Sept	26.0394079	–174.0125452	*Halimeda velasquezii*	10	10.7
LIS-R9	23-Sept	26.0394079	–174.0125452	*Halimeda opuntia*	10	10.7
LIS-10	24-Sept	25.9410005	–173.9223797	*Halimeda opuntia*	10	10.7
LIS-10	24-Sept	25.9410005	–173.9223797	*Halimeda velasquezii*	10	10.7
Algal Collections: Voucher Specimens						
FFS-21	7-Sept	23.8469537	–166.3269575	unknown algae	1	7.6
FFS-R46	8-Sept	23.7692800	–166.2617300	*Kallymenia sessilis*	1	9.1
FFS-R46	8-Sept	23.7692800	–166.2617300	*Halichrysis irregularis*	1	9.1
FFS-R46	8-Sept	23.7692800	–166.2617300	*Predaea weldii*	1	9.1
FFS-R46	8-Sept	23.7692800	–166.2617300	*Amansia* sp	1	9.1
FFS-10	10-Sept	23.7448102	–166.1728963	*Laurencia* sp	1	6.4

REA Site	Date	Latitude	Longitude	Specimen Collected	Number of Samples	Depth (m)
PHR-R32	13-Sept	27.8391670	–175.7530330	*Ganonema pinnatum*	1	1.5
PHR-R39	15-Sept	27.9404600	–175.8613100	*Caulerpa serrulata*	1	12.8
PHR-R39	15-Sept	27.9404600	–175.8613100	*Peyssonnelia inamoena*	1	12.8
PHR-R39	15-Sept	27.9404600	–175.8613100	*Kallymenia sessilis*	1	12.8
PHR-23	16-Sept	27.8813149	–175.9327325	*Chrysymenia* sp	2	9.8
PHR-23	16-Sept	27.8813149	–175.9327325	*Coelarthrum* sp	1	2.4
PHR-R44	16-Sept	27.9106170	–175.9048330	Red algae	1	12.2
PHR-R42	17-Sept	27.7531330	–175.9487670	*Dasya atropurpurea*	1	13.7
KUR-18	18-Sept	28.4185354	–178.3445748	*Halimeda discoidea*	1	6.1
KUR-18	18-Sept	28.4185354	–178.3445748	*Dictyosphaeria cavernosa*	1	6.1
KUR-R35	18-Sept	28.3931330	–178.3493330	*Caulerpa* sp	1	1.8
KUR-R35	18-Sept	28.3931330	–178.3493330	*Sargassum* sp	1	1.8
LIS-17	22-Sept	25.9692500	–173.9629000	*Gibsmithia dotyi*	1	12.2
LIS-17	22-Sept	25.9692500	–173.9629000	*Kallymenia sessilis*	1	12.2
LIS-12	23-Sept	26.0659634	–174.0017516	Red algae	1	10.7
LIS-10	24-Sept	25.9410005	–173.9223797	*Liagora* sp	1	12.8
Coral Collections: Histology						
KUR-09	20-Sept	28.4057670	–178.3422830	*Pocillopora meandrina*	3	6.1
Microbial Collections: Sea Water						
FFS-H6	7-Sept	23.8804552	–166.2730599	2 L	4	9.8
FFS-33	8-Sept	23.8365143	–166.2666948	2 L	4	7.9
FFS-12	9-Sept	23.6383500	–166.1800500	2 L	4	9.8
FFS-34	10-Sept	23.6279200	–166.1353800	2 L	4	9.8
FFS-34	10-Sept	23.6279200	–166.1353800	20 L	3	9.8
PHR-R26	13-Sept	27.7858330	–175.7802830	2 L	4	13.1
PHR-33	14-Sept	27.7854375	–175.8235427	2 L	4	9.8
PHR-R31	15-Sept	27.8266416	–175.7915369	2 L	4	10.7
PHR-23	16-Sept	27.8813149	–175.9327325	2 L	4	9.8
PHR-R42	17-Sept	27.7531330	–175.9487670	20 L	3	14.6
PHR-R42	17-Sept	27.7531330	–175.9487670	2 L	4	13.7
KUR-12	18-Sept	28.3823076	–178.3244794	20 L	3	10.7
KUR-12	18-Sept	28.3823076	–178.3244794	2 L	4	9.8
KUR-R33	19-Sept	28.4167670	–178.3784330	2 L	4	13.1
KUR-02	20-Sept	28.4536330	–178.3440170	2 L	4	10.7
LIS-18	22-Sept	26.0042830	–173.9940280	2 L	4	6.7
LIS-R14	23-Sept	26.0784151	–173.9970114	20 L	3	12.8
LIS-R14	23-Sept	26.0784151	–173.9970114	2 L	4	12.8
LIS-R10	24-Sept	25.9446200	–173.9536100	2 L	4	12.2