Northwestern Hawaiian Island Shallow-water Coral Reef Ecosystem Map Development Procedures

The maps found on these CDs were derived by NOAA's Oceans and Coasts (NOS) from satellite imagery. IKONOS high-resolution satellite imagery was used to derive the draft benthic (seabed) habitat maps, estimated depth, and the color images. Landsat moderate-resolution satellite imagery was used to derive the maps of banks.

Generally, features (habitats) on the seabed to a depth of approximately 30 m can be seen in the satellite imagery. In some areas, such as portions of the southeastern part of Pearl and Hermes Atoll, turbidity in the water limited visibility to 12 m into the water column. In other areas, such as the southern part of Laysan, seabed features could be clearly identified in water 25–30 m deep.

Satellite Technologies

The IKONOS satellite provides commercially available panchromatic (black and white) and multispectral (blue/green/red/near-infrared) imagery. The panchromatic imagery has a 1-m pixel dimension (meaning features as small as 1 m square can be seen in the imagery). The multispectral imagery has a 4-m pixel dimension (meaning features as small as 16 sq. m can be seen in the imagery). IKONOS imagery is purchased under strict licensing agreement. Only licensed users can have access to the

IKONOS multispectral image of a portion of Midway Atoll.

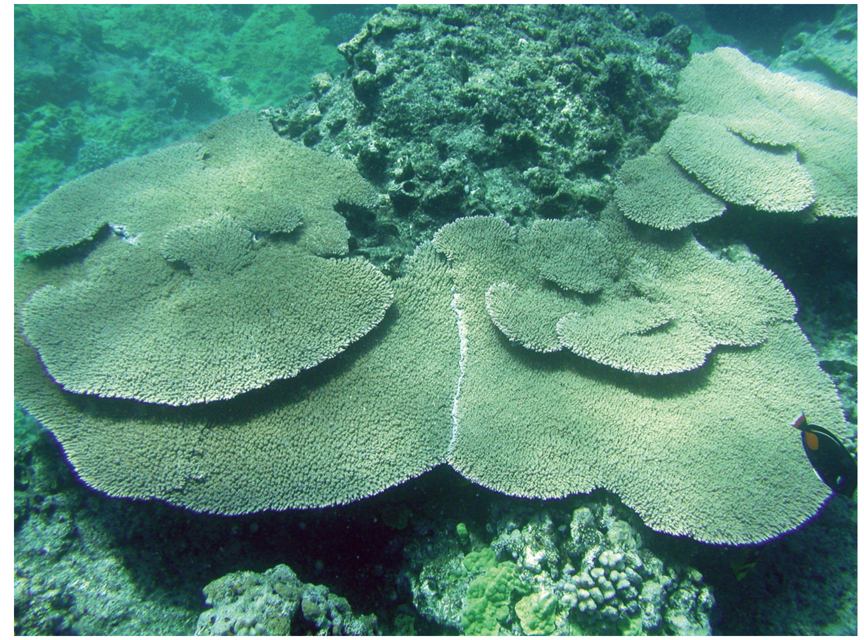


Table coral at French Frigate Shoals.

imagery. Derived products, such as the habitat maps provided on these CDs, can be openly distributed.

The Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite imagery has a 28.5 m multispectral pixel dimension (meaning features with an area of about 812 sq. m can be seen). The Landsat satellite has six color and near-infrared bands, including a red, a green, and a blue band. The spectral characteristics of the IKONOS and Landsat satellites are similar, which allows for easier analysis of the imagery to generate maps. There are no redistribution restrictions on Landsat 7 ETM+ imagery.

The IKONOS imagery is purchased in 11-km-wide swaths that are mosaicked together to produce complete images of locales. In total, the following areas of IKONOS imagery were purchased. For two areas, Kure Atoll and French Frigate Shoals, two image purchases were made. These two images were merged to reduce the amount of area obscured by cloud and cloud shadow.

Imagery Positioning

All of the IKONOS imagery was purchased in National Imagery Transmission Format with the associated Rational Polynomial Coefficients (RPCs or satellite ephemeris data). When using image analysis software capable of reading NITF files with associated RPCs, the horizontal positioning error never exceeded 15 m (for locations where there is little or no vertical relief to affect image pixel displacement).

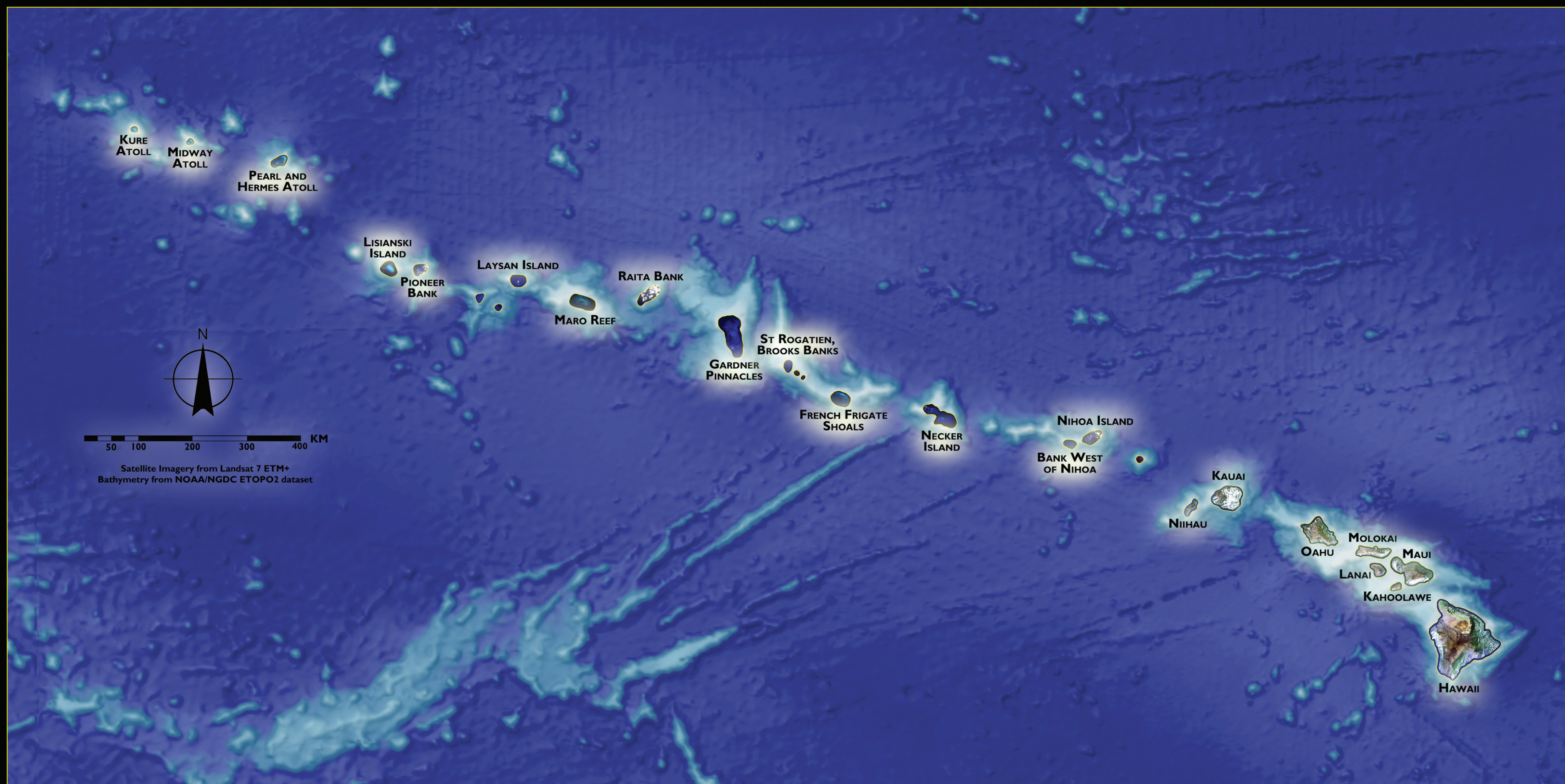
NOS mosaicked the IKONOS imagery swaths, both panchromatic and multispectral, to within one pixel. In the case of the 1-m panchromatic imagery, the swaths overlap to within 1 m. For the 4-meter multispectral imagery, the swaths overlap to within 4 m.

NOAA's National Geodetic Survey (NGS) recently gathered very accurate ground control data (horizontally accurate to within 15 cm of its location on the earth) on nine locales in the NWHI. The only locale that was not successfully "occupied" was Maro Reef, where no permanent site could be found above sea level. Where available, NOS used these ground control data in its efforts to improve the geopositioning of IKONOS imagery.

Working with NGS, NOAA's Office of the Coast Survey will be publishing revised nautical charts for the NWHI. The revision of these charts included obtaining satellite imagery from sources not available to the public. NGS compiled vector shoreline for all but one NWHI locale (Maro Reef) using a combination of IKONOS and restricted-access imagery. Where available, NOS used this vector shoreline in its efforts to improve the geopositioning of IKONOS imagery. However, because the restricted-access imagery used to compile vector shoreline for some areas has a different resolution and was acquired at different times from the IKONOS imagery, complete superimposition is not possible.

For Kure Atoll, Midway Atoll, Pearl and Hermes Atoll, Laysan Island, Lisianski Island, and French Frigate Shoals, NOS used a combination of ground control data and vector shoreline data to further geoposition the IKONOS panchromatic and multispectral imagery. As a result, the mean horizontal positioning error at sea level of this imagery is less than 4 m (one pixel).

Endangered Hawaiian monk seal at Necker Island.



Northwestern Islands and Banks of the Hawaiian Archipelago

NGS successfully gathered ground control data and compiled vector shoreline for Necker Island, Nihoa Island and Gardner Pinnacles. However, the islands have considerable vertical relief. As a result, both the restricted access imagery and IKONOS imagery for these islands are affected by parallax (the displacement of an object as seen from two different points not on a straight line from the object). This parallax results in less accurate positioning of the imagery. NOS used a combination of ground control data and vector shoreline data to improve the geopositioning of IKONOS panchromatic and multispectral imagery. NOS believes the IKONOS imagery of Necker Island, Nihoa Island, and Gardner Pinnacles to be within 15 m of their actual locations at sea level.

For Maro Reef, neither supplemental ground control data nor vector shoreline data are available. However, trackline bathymetry with accurate GPS data was recently gathered at Maro Reef. These data were used to correct the position of the imagery. Using these data, the mean horizontal error at sea level for Maro Reef was 11 m.

The IKONOS satellite is capable of collecting imagery of features on the earth's surface at angles as much as 45 degrees from nadir (when the feature is directly below the satellite). All of the IKONOS images of the NWHI were collected with collection angles of less than 20 degrees from nadir. Constraining the collection angle is important because positioning features on the seabed using satellite imagery is affected by refraction of light through the water column. When the collection angle is limited to less than 20 degrees, the maximum offset of seabed features would be less than 4 m (one IKONOS multispectral pixel) in water less than 15 m deep and less than 8 m in water less than 30 m deep. The combination of horizontal positioning error and light refraction error adds up to a maximum positioning error of approximately 12 m in water 30 m deep.

Algae at Laysan Island.

Two procedures were used to georeference the Landsat satellite imagery used to derive the maps on these CDs. For Landsat imagery where contemporary IKONOS imagery was available, the Landsat imagery was positioned using the IKONOS imagery. As a result, these Landsat data are positioned to within 28.5 m (one Landsat pixel) of the IKONOS imagery. For Landsat imagery where contemporary IKONOS imagery was not available, several contemporary Landsat images were used to compute a least-squares fit of two or more images. As a result, these Landsat data are positioned to within 57 m (two Landsat pixels).

Image Analysis

Several intermediate, derived products were produced as the satellite imagery was processed to generate the benthic habitat maps. First, the raw satellite images were converted from Digital Numbers (DNs) to normalized reflectance. Normalized reflectance (or at-satellite reflectance) converts DNs into standardized, satellite-independent, comparable values. First developed for Landsat satellite imagery, the algorithm used to perform this conversion was modified for IKONOS image processing. As part of the conversion from DNs to at-satellite reflectance, the following equation is used (Green et al., 2000):

R = pi * L/ (Eo cos(theta0) 1/r^2)

L = radiance (from calibration provided by Space Imaging).
theta0 = the solar zenith angle.
r = earth-sun distance in Astronomical Units.
Eo = the mean solar exo-atmospheric irradiance in each band. (A convolution of the spectral response and solar radiation from Neckel and Labs (1984) was used to get Eo.)

The acquisition angles (ephemeris data) of the satellite relative to the ground at the time of image acquisition were also used. Calibration coefficients for the satellite, provided by Space Imaging, were used to calculate at-satellite radiance, which was then transformed to reflectance.

The normalized reflectance imagery was then transformed into water reflectance (or the signal < 10 cm above the water surface). Water reflectance uses the near-infrared band to remove radiance attributable to atmospheric and surface effects (Stumpf et al., in press). Water reflectance estimates how the signal (photons) received by the satellite is diminished as it passes through the atmosphere on the way down to the water-atmosphere boundary and on the way back up to the satellite after the signal leaves the water-atmosphere boundary. Water reflectance also estimates how the signal at the satellite is diminished by water vapor, clouds, specular effects at the water surface (wave surface glint), and other signal-absorbing and diffusing materials in the air and at the water surface (Green et al., 2000).

Spectacled parrotfish at Kure Atoll.

Estimating Depth

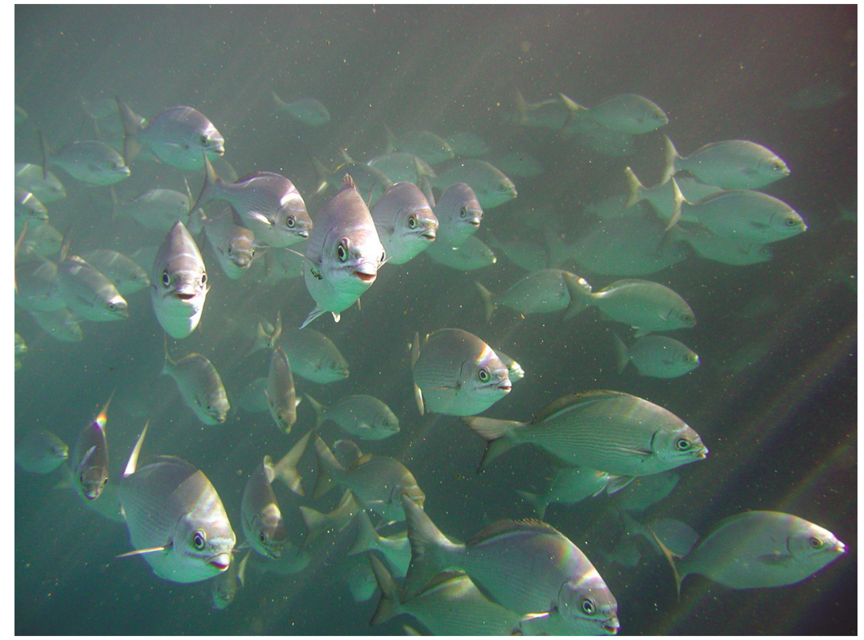
Water depth, in the form of estimated depth, is derived from the satellite imagery following the procedure of Stumpf et al. (in press). Knowing the depth of the water is important because water attenuates (absorbs) light. As the water depth increases, less and less light reaches the bottom and even less light is reflected off the bottom back up through the water column. Mapping relies on identifying and characterizing seabed features based on their spectral and morphologic characteristics. Due to water attenuation, the spectral characteristics of a seabed feature in 2 m of water is different than that same seabed feature in 10 m or 15 m of water. The estimated depth is used to compensate for the attenuation of light by the water column during analysis of satellite imagery. It also is used in the analysis to help determine seabed features such as patch reefs, linear reefs, and micro-atolls.

Bathymetry provides valuable information for organism habitat use, where both structure and water depth affect distribution patterns. Estimated depth is being examined for use in vessel navigation, and these CDs include estimated depth for many areas in the NWHI. Estimated depth can be determined in clear water to between 20 m and 35 m, depending on the bottom type and absolute water clarity. The absolute accuracy of estimated depth varies with water depth. The error is generally 0.3 m for water less than 1 m deep. In water up to 15 m, deep the error is plus or minus 15 percent. In water 15 or more meters deep, the error is plus or minus 30 percent. The estimated depth maps on these CDs depict structural features larger than 8 m in diameter.

Using the estimated depth and water reflectance, bottom albedo (bottom reflectance) is computed. The image analysis to identify and characterize seabed features (i.e., map) is performed on the bottom reflectance. Bottom reflectance is the approximate reflectance of bottom features when the water column is removed. Approximations of light attenuation are computed, based on real or estimated water depth, and "added" to the actual reflectance signal received from the bottom. The result is a "normalized" bottom feature reflectance.

The seabed habitat maps are generated using digital image analysis of the color and depth information. The analysis uses methods originally developed for land classification. The computer-based image identifies seabed features in the imagery based on spectral and spatial characteristics of seabed features that are of similar type, but in different water depths. For example, sand has a much brighter appearance in water 5 m deep than in water 20 m deep. The analysis starts by incorporating numerous examples of the spectral and spatial characteristics of various habitats. In total, 1,130 of these site-specific examples were available for mapping the NWHI. These and other data (e.g., the estimated depth) are used to analyze the spectral and spatial characteristics of the image. The habitat maps have a minimum mapping unit of about 100 sq. m (six

Jacks (Ulua) at French Frigate Shoals.



Chubs at Midway Atoll.

IKONOS pixels). Through a series of iterative steps, a final draft map is generated that depicts as many as 25 separate seabed habitats. The analysis also requires that a habitat classification scheme be developed.

Classification Scheme

The habitat classification scheme, developed with extensive input from locally-knowledgeable, shallow-water coral reef experts, describes the characteristics of each seabed habitat identified in the imagery. The scheme is designed to separate structure (e.g., unconsolidated or hard bottom) from cover (e.g., coral or macroalgae). The classification scheme for mapping the NWHI is presented on page 14. The classification scheme separates habitat on the basis of substrate, structure and cover. A total of 23 habitat types have been mapped in the NWHI. Indeterminate cover is identified on the maps, but is not considered a unique class.

In addition to the 1,130 site-specific characterizations used, several other sources of information were used as part of the mapping activity. Information gathered during several research cruises, including videotapes and Rapid Ecological Assessments by the NMFS Coral Reef Ecosystem Investigation program, the 2000 NOW-RAMP cruise, and information collected from personal communication also were used for the mapping effort.

Map Validation

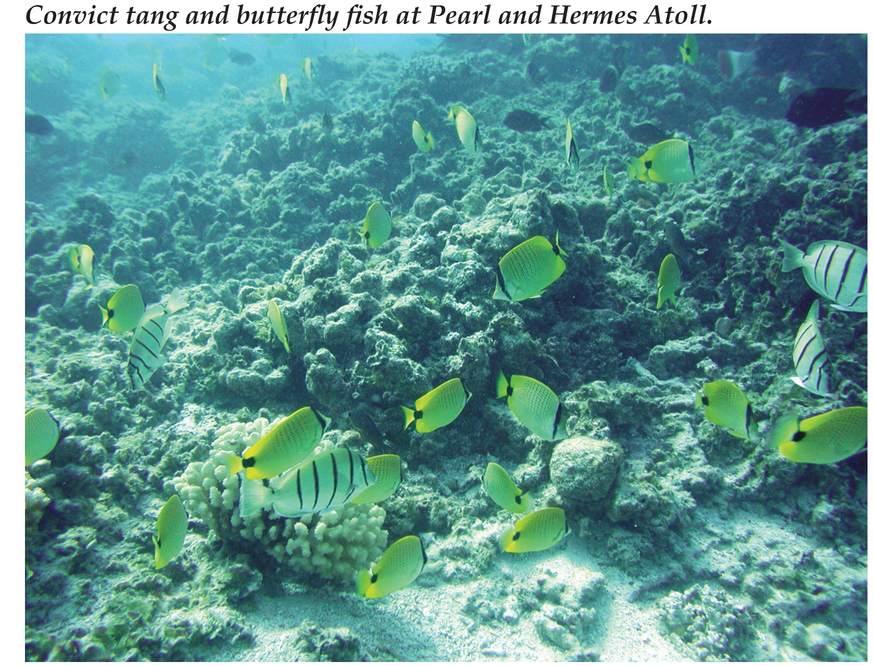
Once generated, the draft benthic habitat maps were evaluated for accuracy. Two types of validation were employed to validate the maps on these CDs. First, two workshops were held in Hawai`i to enable locally-knowledgeable, shallow-water coral reef experts to review the draft maps and provide comments. The comments from these workshops were incorporated into the draft benthic habitat maps on these CDs.

Participants in the draft habitat map review workshops include:

Alan Friedlander, Oceanic Institute
Ed Carlson, NOS, NGS
Rusty Brainard, NMFS, CREI
Jean Kenyon, NMFS, CREI
Joyce Miller, NMFS, CREI
Stephanie Holzworth, NMFS, CREI
Frank Parrish, NMFS-Honolulu Laboratory
Ray Boland, NMFS-Honolulu Laboratory
Michael Parke, NMFS-Honolulu Laboratory
Dave Foley, NMFS-Honolulu Laboratory
Jim Maragos, FWS
Ron Salz, FWS
Miles Anderson, Analytical Laboratories of Hawai`i
Dave Gulko, DLNR
Dave Smith, DLNR
Will Smith, University of Hawai`i
Paul Jokiel, University of Hawai`i
Eric Brown, University of Hawai`i
Isabelle Abbott, University of Hawai`i
Fenny Cox, University of Hawai`i
Celia Smith, University of Hawai`i
Jennifer Smith, University of Hawai`i
Eric Hochberg, University of Hawai`i

Second, statistical analysis to compute a "user" and "producer"

Convict tang and butterfly fish at Pearl and Hermes Atoll.



error was performed using a subset of the 1,100 site-specific habitat characterization data available for the NWHI. This analysis quantified the differences, i.e., the error, between what a habitat was in reality and what it was interpreted to be using rule-based image analysis. "User" accuracy is the probability that a habitat polygon interpreted from the image actually represents that habitat in the field. "Producer" accuracy is the probability that any polygon of a particular habitat is correctly classified (Green et al., 2000). The major habitat categories depicted on the draft maps will be evaluated for both "User" and "Producer" error.

A Kappa Statistic is computed as part of the accuracy assessment. A Kappa Statistic of 0.59 (59 percent) implies that the classification process is avoiding 59 percent of the errors that a completely random classification would generate (Congalton, 1991; Green et al., 2000).

In addition, a Tau Coefficient is computed. The Tau Coefficient measures the accuracy of the entire map across all major categories. The Tau Coefficient is valuable because it indicates how many more habitat polygons (groups of pixels) were correctly classified than would be expected by chance alone (Ma and Redmond, 1995).

Literature Cited

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Green, E. P., P. J. Mumby, A. J. Edwards, and C. D. Clark. (Ed. A. J. Edwards). 2000. Remote Sensing Handbook for Tropical Coastal Management. Coastal Management Sourcebooks 3, UNESCO, Paris. 316 pp.

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Staghorn coral at French Frigate Shoals.