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# EARTH SYSTEM MONITOR

A guide to NOAA's data and information services

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration


# Mapping and monitoring of U.S. coral reef ecosystems

## *The coupling of ecology, remote sensing, and GIS technology*


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Coral reef management is a challenging and complex balancing act between ecosystem protection and enabling humans to enjoy and use these wonderful natural resources. The cumulative pressures on coral reef ecosystems, such as climate change, pollution, overfishing, coastal development, and other human activities threaten their existence. The Global Coral Reef Monitoring Network (*GCRMN 2000*) reported that by 1998, 11 percent of the world's coral reefs had already been destroyed. If man-made and natural destructive activities affecting coral reefs continue, it is estimated that up to 60 percent of the ocean's reefs could be gone within the next 30 years (*GCRMN 2000*).

This year, the National Academy of Science released several studies that, for the first time, demonstrate that the Earth's climate is changing, and that global warming is real. Global warming is considered by researchers to be a major cause of El Nino weather patterns. These El Nino weather patterns and their associated alterations in typical ocean water temperatures in tropical areas around the world are considered to be the primary cause of coral reef bleaching. Bleaching has killed as much as 50-70 percent of coral reefs in some areas. Once the corals die, the ecosystem begins to change. Other organisms take advantage of the situation and move in, and fish population structure begins to change. If the coral reefs fail to recover from bleaching, it may take hundreds of years for the ecosystem to recover.

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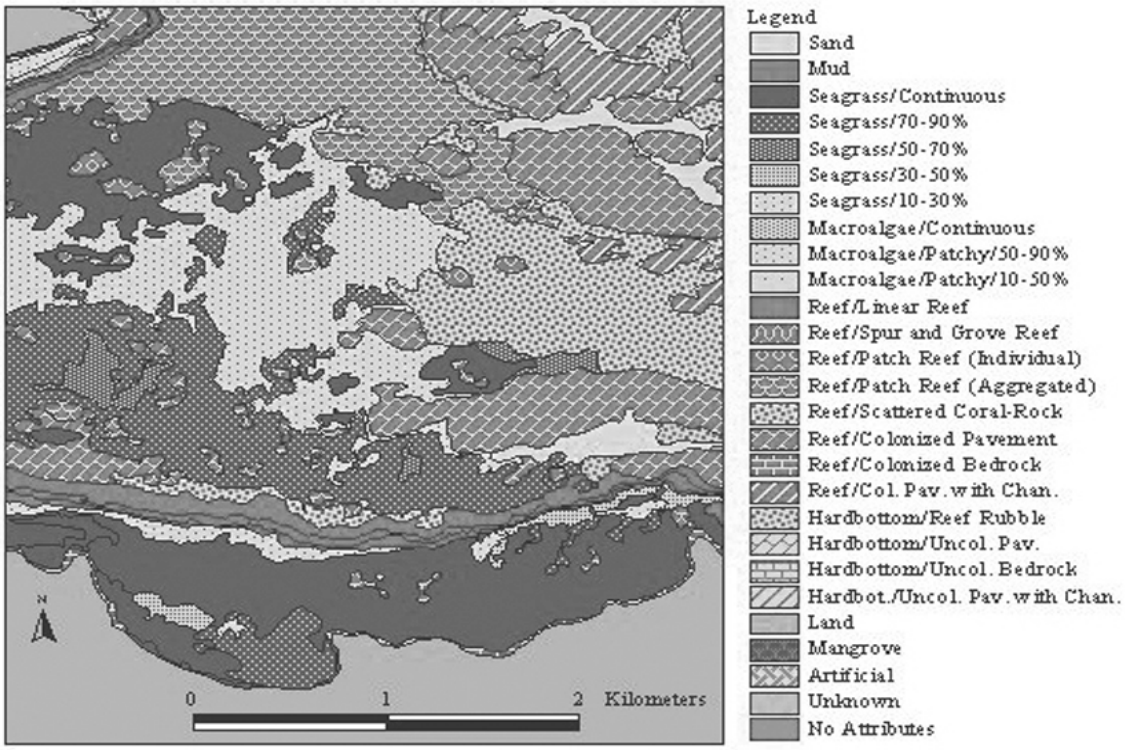


▲ **Figure 1**. Benthic features of Buck Island Channel, St. Croix, US Virgin Islands. Twenty six benthic habitat types were mapped by visually interpreting features in orthorectified aerial photographs.

***Coral reef ecosystems,*** *from page 1*

In response to the continued decline of US coral reefs, President William Clinton, signed the Coral Reef Protection Executive Order 13089 to conserve and protect the health, biodiversity, heritage, ecological, social, and economic values of US corals. The Order created an interagency US Coral Reef Task Force (USCRTF) which established seven working groups, including coral reef mapping and monitoring teams. The Mapping Work Group is co-chaired by the National Oceanic and Atmospheric Administration (NOAA), The National Aeronautical and Space Administration (NASA), and the US Geological Survey (USGS). The Monitoring team is a subgroup of the Ecosystem Science Working Group. In addition, the Coral Reef Conservation Act of 2000 (H.R. 1653) and other Congressional support has enabled NOAA and other agencies (e.g., Dept of Interior) to aggressively initiate an integrated program of coral reef mapping and monitoring. The focus of this article is on NOAA's National Ocean Service (NOS) coral reef mapping and monitoring activities across US coral reef ecosystems.

We define coral reef ecosystems as those integrated biological and physical habitats that include the coral structures and other commonly associated habitats such as, sea grasses, mangroves, and soft sediment communities. By nature, the management of coral reef ecosystems, is in part, a spatial problem as these systems range from continuous to discrete features throughout waters surrounding islands and adjacent to continents. Of the estimated 17,000 square kilometers of coral reef areas in US waters, only about eight percent has been meticulously mapped (*Rohmann 2000*). Thus, our ability to make informed decisions on the placement of marine protected areas, optimal location for coastal development, and defining essential fish habitats, is severely limited without highly resolved and accurate digital habitat maps. The National Action Plan for US coral reef protection endorsed by USCRTF identified mapping of all US coral reefs as one of the highest priorities to be addressed to protect these important ecosystems (*USCRTF 2000*). Based on the guidance of the USCRTF's Mapping and Information Synthesis Work Group's Mapping Implementation Plan (*MISWG 1999*), NOAA/NOS was charged to coordinate and implement the synoptic mapping of all shallow-water US coral reef ecosystems using airborne remote sensing technologies.

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### Coral reef mapping

Coral reef mapping is currently underway through a series of partnerships across NOS offices and most important, with local island partners. The partnerships include territory, state, federal, academic, and private sector colleagues who have come together to develop applied map products, and simultaneously conduct coral reef monitoring and research to accelerate our collective capability to develop maps and utilize these tools for management. A suite of technologies are required to develop useful map products to meet the complex needs of the natural resource management community. Aircraft can acquire color aerial photographs and hyperspectral imagery, and minimize the problems associated with remotely sensed imagery. For example, sunglint and clouds often affect our ability to map bottom or benthic habitat features. Figure 1 (cover page) is a product of a high resolution habitat map derived from visual interpretation of NOS color aerial photography. However, aircraft-based technology is relatively expensive and often results in a single snap shot of current distribution of bottom habitats. Satellites can acquire low resolution (30-meter), moderate resolution (20-meter), and high resolution (4-meter) multispectral images, but are subject to images masked by cloud cover (Figure 2). However, they provide a tool to monitor the distribution and possible health of coral reefs over time due to their repeat data collection cycles. Thus, to

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## EARTH SYSTEM MONITOR

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### North American Climate Extremes Workshop

The National Climatic Data Center (NCDC) is working with Canada and Mexico to organize a North American Climate Extremes Workshop to be held at the NCDC, tentatively in November. The goal of this workshop is to address changes and variations in extreme weather and climate. As each country now has data sets that can be used to assemble a broad assessment of changes and variations of climate variability and extremes, the NCDC believes it would be advantageous to discuss common issues of data quality, analysis methods and trends.

### *Synoptic and Dynamic Climatology*

A new climate book titled "Synoptic and Dynamic Climatology," by National Snow and Ice Data Center Director Roger G. Barry, and Andrew M. Carleton of Pennsylvania State University, has been published by Routledge of London. The 620-page work, available in hardcover and paperback, is an advanced-level text for students and climate researchers. It addresses methods of analysis of conventional and remotely-sensed meteorological data, the general circulation, planetary waves and blocking patterns, teleconnections, synoptic-scale circulation tropical and mid-high latitude systems, and synoptic climatological methods. Each chapter has a comprehensive bibliography.

### Ocean Drilling panel meeting

Dr. David Divins of the National Geophysical Data Center (NGDC) attended a meeting of the Ocean Drilling Program's (ODP) Scientific Measurements Panel (SCIMP) in Montpellier, France, in June. Dr. Divins is a member of this panel that provides advice on ODP information related to scientific measurements made onboard the scientific research vessel JOIDES *Resolution*.

Specific responsibilities of the panel are publications, databases, curation, computers, shipboard equipment usage, and needs. As ODP prepares to end in 2003, there are many discussions regarding what to archive and in what format. NGDC will provide long-term maintenance and archival of all ODP-generated data.

## News briefs

### Enhanced security for NNDC Online Store

While researching statistics for subscription orders, it was discovered that two domains were placing an overwhelming load on the National Climatic Data Center (NCDC) web resource by running scripts that continually accessed the NOAA National Data Center's (NNDC) Online Store searching for updates. As a security measure, these IP addresses have been excluded from the firewall so that they will not have access to the NCDC web site. NCDC will continue to monitor the situation and will take similar action against any scripts that continually access their servers for a prolonged period of time with the possible malicious intent of bringing the site down.

### Asian monsoon system

Dr. Anil K. Gupta, National Research Councill Senior Resident Research Associate from the Indian Institute of Technology in Kharagpur, India, is currently a visiting scientist at NGDC's Paleoclimatology Program. During his visit, Dr. Gupta will be collaborating with NGDC's David Anderson on a project entitled "Century to Millenial Scale Changes in the Asian Monsoon System during the Last Twenty Thousand Years: Results from the ODP Site 723." Dr. Gupta will also be analyzing samples from adjacent cores RC2730 and RC2735 to comprehend the impact of the Little Ice Age on the Asian monsoons. The Asian monsoon is believed to have undergone short-term as well as long-term changes over the last few million years. The proposed study is expected to retrieve new information about changes in monsoonal seasonality and its link with both internal and external processes. The studies will include micropaleontological (foraminiferal) faunal and isotopic examinations of deep-sea core samples from the Arabian Sea.

### Upper air proposal funded

The National Climatic Data Center has received funding to begin work on a project which allows radiosonde records in the Comprehensive Aerological Reference Data Set database to be used in climate monitoring applications.

### GOES satellite data used to study aerosol distribution

Each year a large amount of dust aerosols are transported from the Sahara to the Eastern United States. During July 2000, an experiment called the Puerto Rico Dust Experiment (PRIDE), was conducted in Puerto Rico. Researchers from the National Centers for Environmental Prediction (NCEP) have acquired GOES-8 data from the National Climatic Data Center to help map aerosol distributions from space, to retrieve aerosol optical thickness, and to estimate radiative forcing. Since *in situ* observations are available during last summer, this will allow NCEP to refine and develop new algorithms to study the effects of aerosols on regional climate patterns. The aerosol properties retrieved from the GOES-8 Imager will be used to compare against ground-based sun photometer measurements.

### Freezing rain and ice storm climatology

The National Climatic Data Center was notified that the Office of Global Programs (OGP) proposal, to assess long-term fluctuations of freezing rain and ice storms in the U.S., was approved for funding. This two-year project begins in September 2001 and will be a joint effort with Dr. Stan Changnon of Illinois. The NCDC will develop the hourly data set that will be used to analyze the long-term temporal and spatial variability of freezing rain events. A climatology of severe ice storms will be developed and will include statistics such as intensity of rainfall, ice accumulation, duration of event and return interval of indices. Products derived from this project will be included in NCDC's Climate Atlas.

### NOAA/Singapore cooperation

David Hastings of the National Geophysical Data Center presented three approaches of regional data to the National University of Singapore and Defense Science Organization. He gave an overview of Global Land One-Km Base Elevation (single layer) data fusion, coastal relief model development, and Global Ecosystems Database multi-layer database integration. The LIDAR-based elevation model, developed by the National Geodetic Survey and the Coastal Services Center, was also presented.

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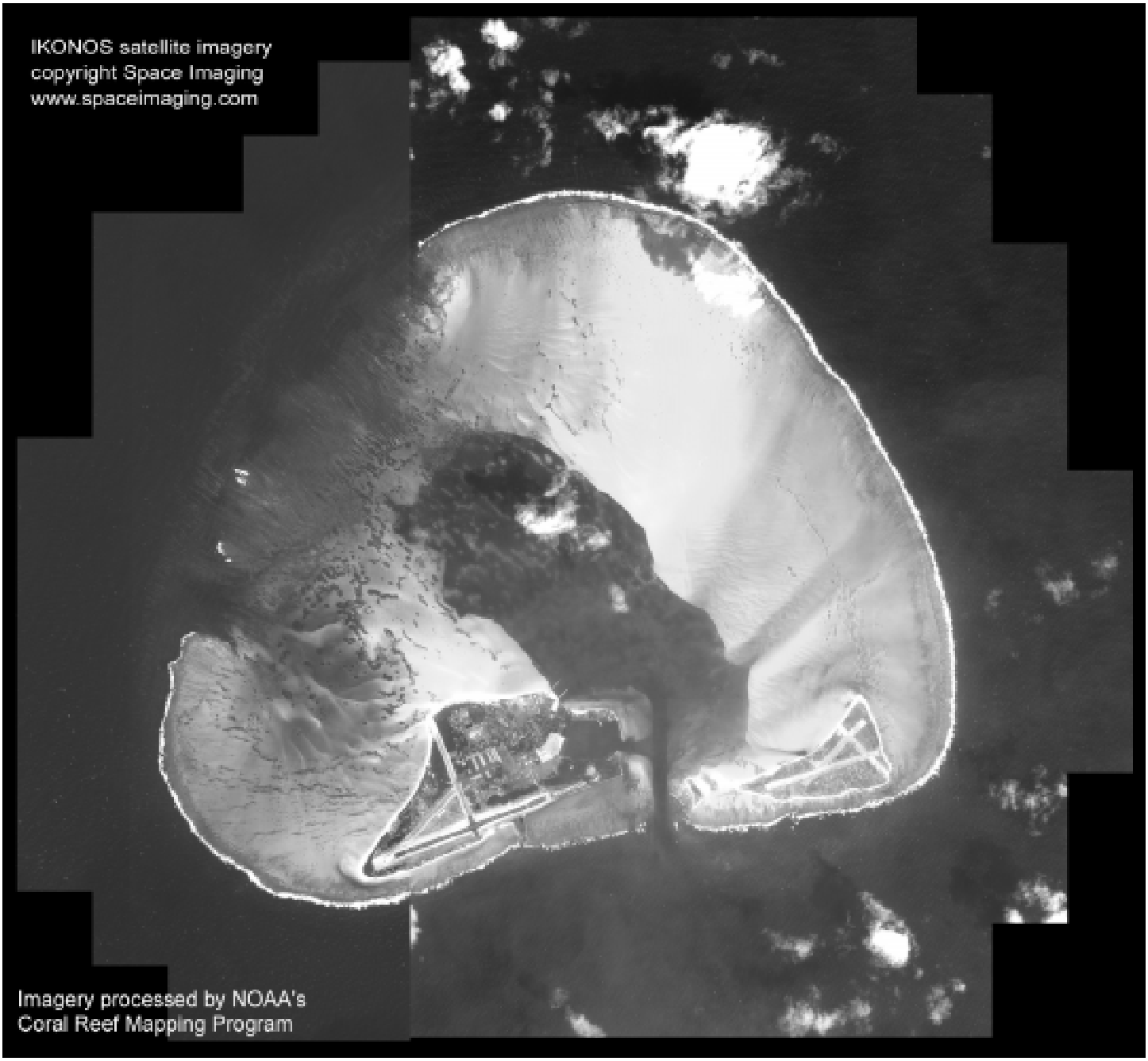
map coral reef ecosystems adequately and cost-effectively requires a combination of integrated technologies.

Although mapping of US coral reef ecosystems is a difficult challenge, NOS and its partners have been aggressively implementing the mandate of the USCRTF (see *http://biogeo.nos.noaa.gov*). To date, NOS has led partnership efforts to map the Florida Keys (*FMRI/NOAA 1998*), the US Virgin Islands, and Puerto Rico (*Kendall et al. 2000*). In year 2000, NOS and its Hawaii partners initiated mapping in the eight major Hawaiian Islands and the very remote Northwest Hawaiian Islands (*Coyne et al. 2001a,b*). NOS conducted an applied (aerial photography) and research (airborne hyperspectral) mapping mission in the spring of 2000. The mission was conducted jointly with several private sector companies, the University of Hawaii, Hawaii Division of Lands and Natural Resources, and was coordinated with NASA's high altitude hyperspectral data collection. In addition, in partnership with the University of Hawaii, NOS's National Centers for Coastal Ocean Science (NCCOS) has been conducting research using low-altitude hyperspectral imagery and multispectral satellite technology to determine if




▲ **Figure 2.** Midway Islands, Northwestern Hawaiian Islands. The Midway Islands lie approximately 2000 kilometers WNW of Honolulu, Hawaii. The islands and surrounding waters are a national wildlife refuge.

these remote sensing tools can increase our accuracy and efficiency in mapping benthic habitats. Results of this research show that hyperspectral data enables image interpreters to visually delineate more acreage of reef habitats, as the high spectral resolution enables delineation of shallow and deep reef habitats (*ALH 2001*). By using up to 6-10 bands, specific shallow-water reef and relatively deep (down to 30 nominally meters) benthic habitats were able to be delineated when compared to classifying features from the digital color aerial photography (nominally limited to 20 m or less). In addition, the University of Hawaii published the results of their studies that used multispectral imagery to map benthic habitat using spectral analyses (*Hochberg and Atkinson 2000*). This work uses a spectral library to automate classification of several benthic habitats (e.g., coral hard bottom, algae, sand) based upon the spectral signature of a specific habitat. Currently, NOS and the University of Hawaii are determining if spectral analysis classification efforts can be moved from the research community to an applied technology that is accurate in classifying benthic habitats, can be adequately georefer-enced with minimal post processing, and is cost efficient.

Complementary satellite technologies are being used to develop maps of U.S. shallow-water coral reef ecosystems. Maps will be produced by analyzing the spatial and spectral characteristics of high-resolution (4-meter multispectral and 1-meter panchromatic) IKONOS satellite imagery (Figure 2). These maps will represent the first georeferenced, classified maps of the many remote U.S. shallow-water coral reef ecosystems. Due to the remoteness of many of these locales, satellite imagery appears to be the most cost-effective technology for acquiring imagery for mapping. Also, the imagery can be used to more accurately locate these places on the earth.

Acquiring standard bathymetric data in remote locations is logistically challenging and expensive. However, detailed bathymetric data are critical for mapping and characterizing shallow-water benthic habitats. As part of its satellite-based coral reef mapping program, NOS will be generating "pseudo-bathymetry" from the high resolution satellite imagery. The pseudo-bathymetry computed by analyzing the spectral characteristics of the satellite imagery is being considered as a surrogate until comprehensive bathymetry surveys can be completed.

Any effort to characterize coral reef ecosystems requires a scheme for classifying the benthic habitats found, or expected, in the area to be mapped. Such schemes should be developed taking into consideration both the anticipated uses of the resulting maps and the capacity of the imaging technology to provide sufficient spatial and spectral discrimination in identifying benthic features. NOS/NCOSS has led in the development of several peer-reviewed classification systems for the coral reef mapping studies and will continue to develop schemes as the mapping efforts continue in the far Pacific (*Kendall et al. 2001, Coyne et al. 2001a, b*).

### Coral reef monitoring

To complement the mapping efforts NOS/NCOSS and its partners have initiated a national coral reef monitoring program (*NOAA/NOS 2000*). This effort is in response to the USCRTF's National Action Plan, that called for a nationally coordinated, long-term program to assess, inventory, and monitor US coral reef ecosystems (Action Plan 2000). To date, the modestly funded grant program has been implemented in the state of Hawaii, US Virgin Islands, Puerto Rico, Guam, American Samoa, and Commonwealth of the Northern Marianas (CNMI). The objective of this partnership-based program is to develop relatively compatible information across all US coral reefs to assess the status and health of coral reef ecosystems. The results are to be published every two years as a national report that summarizes the health of US coral reef ecosystems.

To enable development of this report, the NOS coral monitoring grant program is currently focused on providing funds to support gaps in local capability to assess, inventory, and monitor coral reef ecosystems. Long-term plans include filling information gaps, while simultaneously implementing similar monitoring methodologies across all US states, commonwealths, and territories. Plans are to develop the information over time that will enable a national coral reef health report to be designed around a "scorecard" approach. This approach will enable the health and quality of coral reefs by island area to be ranked using a qualitative scale, such as high, medium, or low, that would be derived from quantitative information obtained through coral ecosystem grant monitoring program.

The national monitoring program is complemented by NOS/ NCCOS reef fish monitoring and habitat characterization studies conducted by NCCOS's Biogeography Program (*Christensen et al. in prep*). The reef fish work is done in collaboration with many state, territory, and Federal partners. Currently reef fish ecology studies are focused in La Parguera, Puerto Rico and are done in cooperation with NCCOS's Center for Coastal Fisheries Habitat Research and the University of Puerto Rico. This particular investigation is determining cross-shelf species habitat utilization patterns based on the digital habitat maps. Two additional sites in the US Virgin Islands are being studied in cooperation with the National Park Service and the US Geological Survey in Buck Island National Monument, St. Croix, and the National Park and Monument located at St. John. These studies are designed to evaluate the effectiveness of management strategies, such as, areas closed to fishing, and to define biologically relevant boundaries of marine protected areas (MPAs). In addition, these studies are addressing the level of fish monitoring efforts necessary to detect change in fish populations.

All of these research and monitoring studies are dependent on the NOS high-resolution benthic habitat maps. For the island areas where the benthic habitat maps have been developed, NOS and its partners now have the capability to select monitoring stations stratified by detailed habitat information. The remotely sensed digital habitat maps can be used to develop statistically robust monitoring pro-

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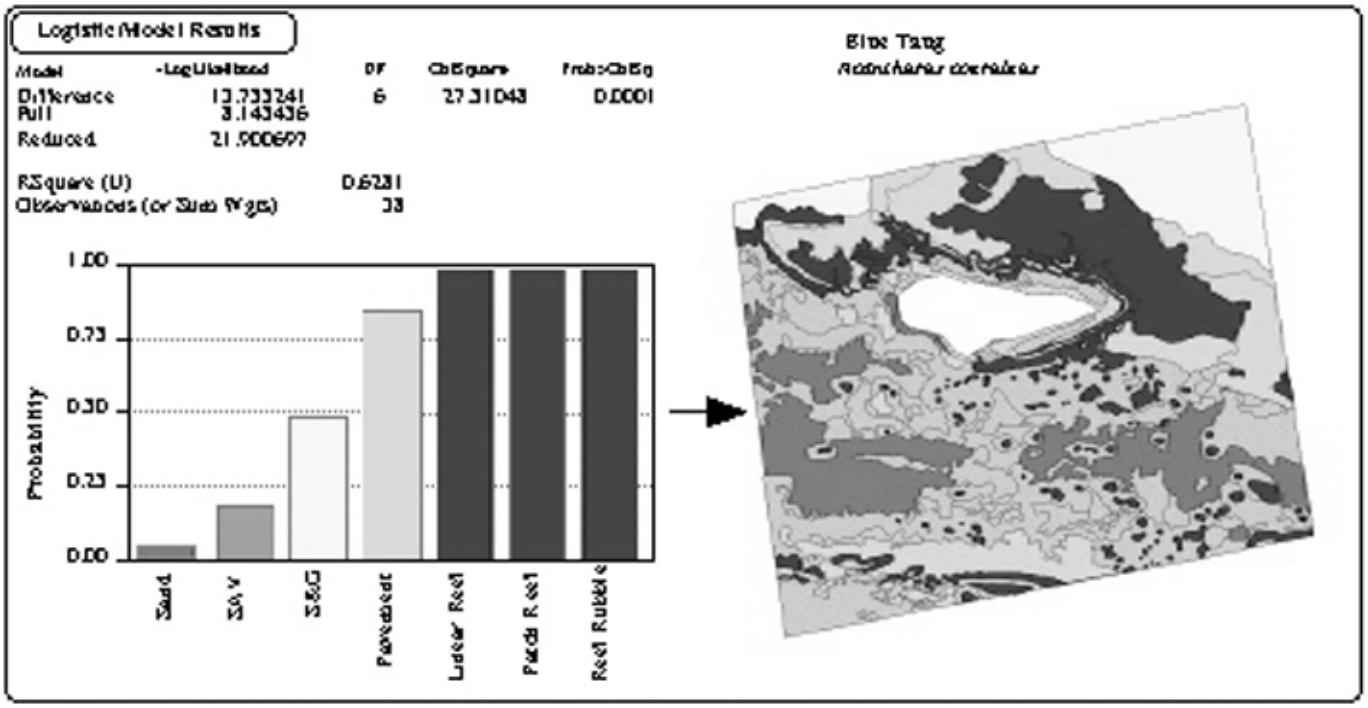
***Coral reef ecosystems,*** *from page 5*
grams to elucidate ecological relationships. Plans are to build similar capabilities in the US Pacific as the habitat maps are developed for Hawaii, Guam, American Samoa, and CNMI.

**Coupling ecology and habitat maps**

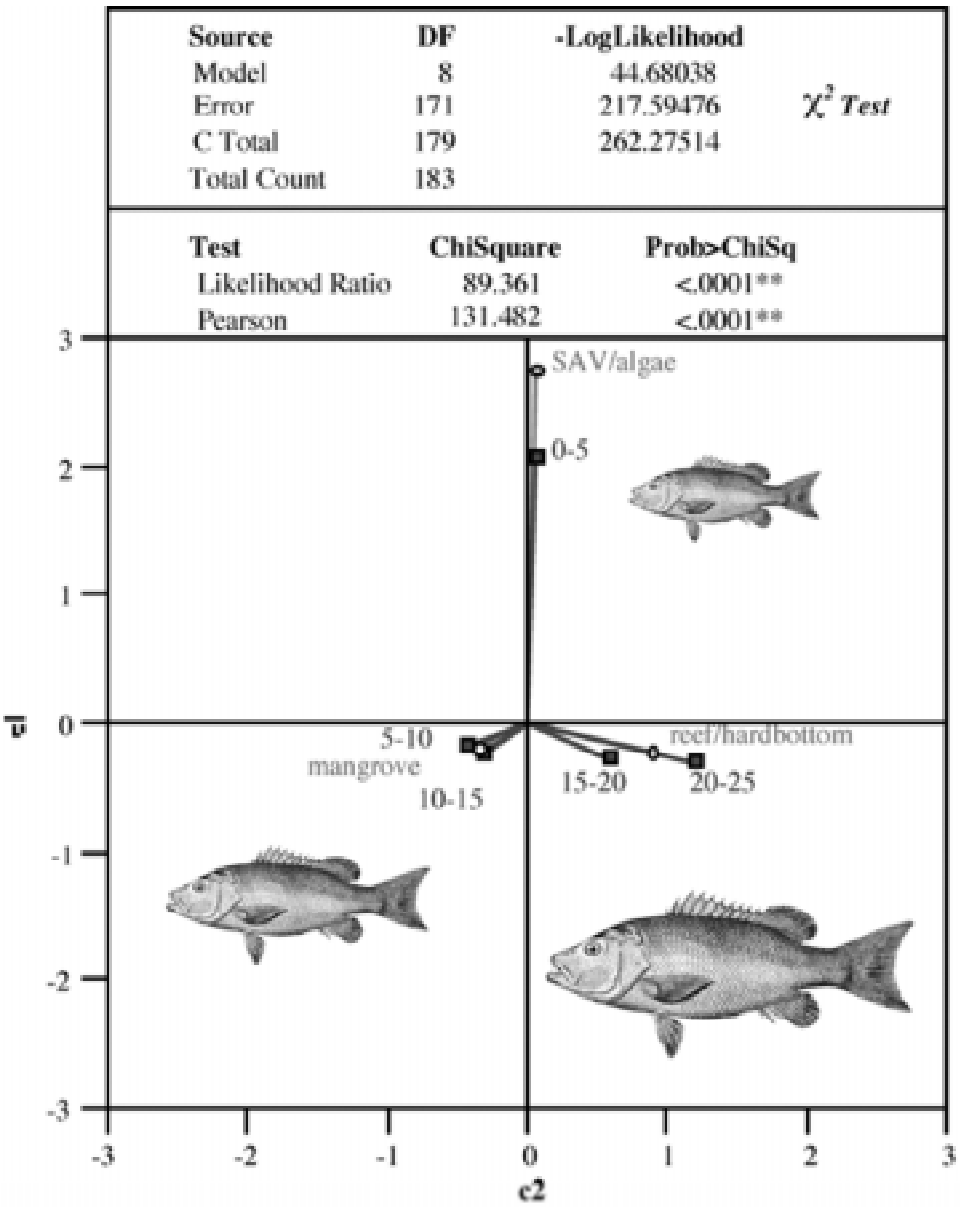
The production of high-resolution and digital benthic habitat maps is a critical step in the development of tools for managers to implement coral reef conservation strategies. However, the maps are only an initial product required to conduct spatial analyses to support management decisions. Two important additional steps required for the management of coral reef ecosystems and their associated living marine resources are: 1) defining the spatial and temporal distribution by life stage of fishes and invertebrates, and 2) determining species habitat affinities (*Monaco et al. 1998*). The integrated approach of mapping habitats, identifying species distributions, and determining the strength of association between the mapped habitats and species habitat affinities enables the development of management tools (*Monaco and Christensen 1997, Gill et al. 2001*). These include quantitatively defining the distribution of essential fish habitats (*Clark et al. in review*) and defining biologically relevant boundaries of marine protected areas MPAs (*Christensen et al. in prep*). Coupling the distribution of habitats and species habitat affinities using GIS technology, enables the elucidation of species habitat utilization patterns for a single species and/or assemblages of animals (*Brown et al. 2000, Kendall et al. in review*). Figure 3a shows the probability of encountering a blue tang (*Acanthurus coeruleus*) across benthic habitats. In turn, these probabilities can be displayed geographically based on the distribution of the benthic habitats (Figure 3b). This type of analysis provides managers a "biological weather map" that predicts the probability of encountering a species, a group species, or indices of relative ecological value ( e.g., species diversity) to aid in determining biological "hotspots" requiring protection.

NCCOS Biogeography Program scientists are characterizing reef fish community structure associated with reef, seagrass, and unconsolidated sediment sites. Simple to complex statistical techniques are used to develop probability-based estimates of species habitat utilization patterns. These data can be used to identify deviations from expected levels of abundance and distribution at varying locations that may differ in the quality of benthic habitats, as well as provide a comprehensive analysis of fish community structure within MPAs. As the use of MPAs continues to increase, we must ensure that all ecosystem components are protected as reef species often use different habitats across life history stages (*Christensen et al. in prep)*, Figure 4.

Censusing fishes found on habitats other than coral reefs (e.g., seagrass beds) in Puerto Rico and St. Croix, USVI has revealed ontogenetic shifts in habitat utilization. By utilizing the digital habitat maps the ontogenetic ecology of the snappers and grunts can be quantitatively determined in space and time (*Kendall et al. in review*). This has profound implications on the management and maintenance of species populations within specific areas.




▲ **Figures 3 a,b**. Results of a logstic habitat selection model for Blue Tang (*Acanthurus coeruleus*); (a) mapped into the landscape, (b) near Buck Island Reef National Monument, St. Croix. Results express the probability of encountering this species at any given location.




▲ **Figure 4**. Correspondence analysis of snapper (family *Lutjanidae*) census data indicate that younger fishes disproportionately select seagrass habitats, move to mangroves as sub-adults, then ultimately move onto the reef as they reach maturity. This has profound implications on the management of such species, and supports the concept of protecting a mosaic of habitat types critical to population maintenance.

For example, in Puerto Rico, ordination techniques indicate that snappers between 0-5 cm fork-length were disproportionately abundant in seagrasses, than selected mangrove habitat between 5-15 cm. Larger (>15 cm) snappers redistribute themselves among reef habitats (Figure 4).

**Future plans**

The integrated coral mapping and monitoring studies provide a unique opportunity to couple ecology, remote sensing, and GIS technology to better understand and manage US coral reef ecosystems. The integrated coral reef mapping and monitoring studies will continue in FY 2002 with refined mapping studies in the USVI, completion of maps for Puerto Rico, and continued Caribbean reef fish ecology studies. In the US Pacific, NOS and private sector partners will focus on developing high resolution and digital habitat maps for 37 levels of habitat type in the main 8 Hawaiian Islands. In addition, in partnership with the Hawaii Division of Lands and Natural Resources, the Oceanic Institute, Analytical Laboratories of Hawaii, Inc, and the University of Hawaii, NOS/NCCOS has initiated reef fish ecology and habitat characterization and quality studies that are linked to the developing benthic habitat maps. In the Northwestern Hawaiian Islands, NOS will continue to conduct mapping experiments to determine how best to map the shallow water reef habitats using IKONOS satellite imagery. In addition, NOS will determine with its American Samoa, Guam, and CNMI partners the best mix of technology to map the coral reef ecosystems of these island areas.

**Acknowledgements**

The NOS coral mapping and monitoring studies can only be conducted through a suite of federal, state, local, territory, commonwealth, academic, and private sector partners. We thank all of these entities and especially our colleagues in the NOS/NCCOS Biogeography Program and the NOS Coastal Services Center in development of technical mapping approaches. We especially thank our colleagues in the National Geodetic Survey who conducted the aerial photography and hyperspectral remote sensing missions in the Caribbean and Hawaii. In addition, we thank our colleagues at the University of Puerto Rico, the National Park Service, and USGS in St. Croix and St. John, USVI for aiding us in developing approaches to integrate coral reef ecosystem monitoring into the mapping program. Special thanks to Dr. James Beets of the University of Jacksonville and Dr. Alan Friedlander of the Hawaii Oceanic Institute for their guidance and direction in development of reef fish census techniques and sampling strategies.

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# Submerged Aquatic Vegetation

## *An information resource for those charged with protecting what can't always be seen*

*Lori Cary-Kothera*
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Eelgrass, widgeon grass, turtle grass, and many other types of submerged vegetation (SAV) grow in the nation's coastal zone. While numerous state and federal laws protect this important resource, it is often hard to protect what you can't see.

The NOAA Coastal Services Center has combined years of expertise in this area into a CD-ROM, *Submerged Aquatic Vegetation: Data Development and Applied Uses*. Coastal managers throughout the nation were introduced to this information resource during an innovative session held during Coastal Zone '01 in Cleveland, Ohio. The Coastal Zone conference series is the largest international conference for coastal managers.

During the SAV session, members of the audience were given a question that could be answered with information found on the CD-ROM. Participants seemed to enjoy themselves as they dove into the CD-ROM and the search. At the end of the exercise, participants reported back to the group on what they learned regarding the question and the CD-ROM itself. Participants got an in-depth look at the contents, learned from each other, and the CD-ROM developers got some important feedback on their product.

Participants found information coastal resource managers can use to start or improve their state seagrass mapping efforts.

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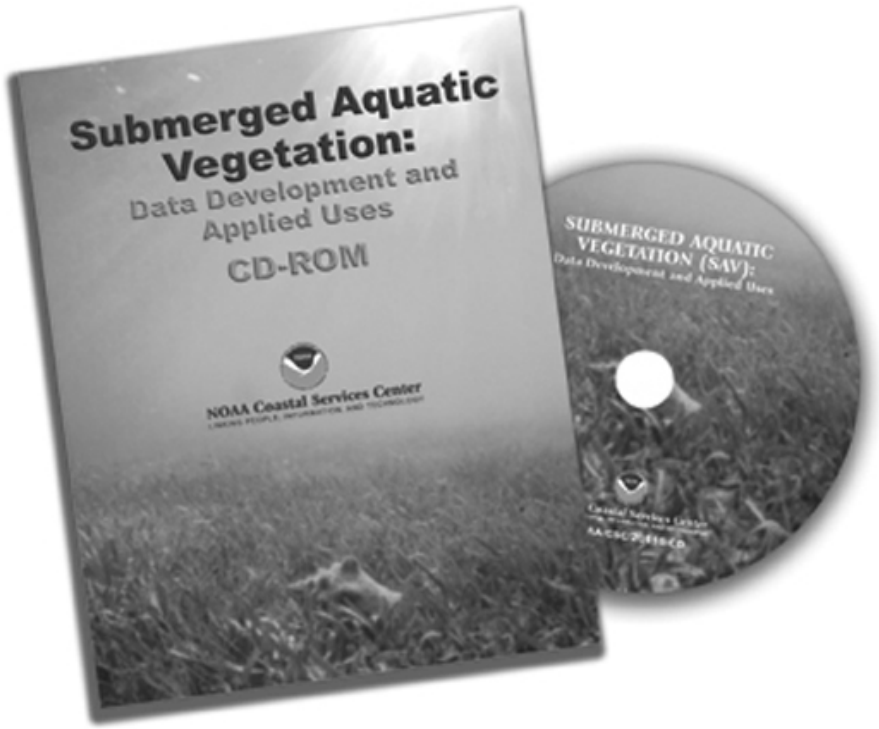


*Submerged Aquatic Vegetation: Data Development and Applied Uses* can help coastal managers:

- Keep costs down
- Educate constituents about seagrasses
- Find new ways to use seagrass data

For many coastal programs, SAV maps are a cornerstone data information resource. Examples from Massachusetts, Virginia, Florida, and Washington are included. These states use SAV data and maps for a variety of uses, including water quality indicators, permitting and planning programs, and documenting changes in habitat.

The CD-ROM contains technical guidance and standardized methodology recommendations for states embarking upon SAV mapping programs. This section was written using the cumulative lessons learned from over a decade of seagrass mapping work. This document, which is on the Web at *www.csc.noaa.gov/crs/bhm/*, also helps data developers keep abreast of new trends and technology.

This comprehensive resource guide also contains a field guide, a PowerPoint presentation, information about funding sources, seagrass related laws and policies, reference materials, an image gallery, and tips for working with mapping contractors.

*Submerged Aquatic Vegetation: Data Development and Applied Uses* is available free of charge from the NOAA Coastal Services Center. To obtain a copy, go to *www.csc.noaa.gov/clearinghouse*. To learn more about the NOAA Coastal Services Center's other benthic mapping products, please visit *www.csc.noaa.gov/crs/bhm/*. ■

# Integrating the science of habitat-maintaining processes into natural resource policy

## *The need to preserve and restore natural processes in marine and freshwater habitats*

*Doug Myers*
*Puget Sound Water Quality Action Team*

Recent scientific investigations signal a departure from traditional natural resource management assumptions that the function of a habitat is guaranteed if the structure of that habitat appears natural. These investigations point to the central need to preserve and restore natural processes that create and maintain marine and freshwater habitats. This presentation will summarize some of the scientific findings from various projects in the Pacific Northwest and the challenge of creating new policy goals and objectives that incorporate this concept.

### Process-based scientific investigations

New trends emerged in the 1990s in resource management. These include regulatory streamlining, considering the link between water quality and habitat and the advent of incentive-based habitat restoration as part of larger comprehensive planning processes. In September 1995, a conference sponsored by the Northwest Chapter of the Society for Ecological Restoration entitled "Wetland and Riparian Restoration: Taking a Broader View" was held in Seattle. The conference highlighted research from around the region that considered the success of restoration sites over a watershed or larger regional context and often over longer than normal time scales (*Macdonald and Weinmann, 1997*).

King County (*Mockler, et al, 1998*) and Washington Department of Ecology (*Johnson and Mock, et al, 2000*) studied the success of permitted wetland mitigation sites. Most of these sites were created with the goal of restoring functions that were lost through permitted alteration of wetlands. Performance measures detailed a certain cover of certain plant types within a certain time period. Results of monitoring studies revealed a very low level (33 - 41percent) of compliance with the permit performance standards. Discussions from both of these studies suggested that natural hydrologic connections be established as a way to improve success. This could be done by establishing performance measures on the level of natural wetland-forming processes restored to the site. The state began investing technical resources in the nationally growing concept of using Hydrogeomorphic (HGM) characteristics as measures of wetland function rather than plant composition.

The most convincing investigation comes from a multi-disciplinary team of scientists that worked on a river basin scale characterization of the Snohomish River in northern Puget Sound (*Gersib and Grigsby, 2000*). The method synthesized the technical disciplines of hydrogeology, geomorphology, water quality, fish biology, ecology and GIS to develop a new conceptual model for understanding ecosystem processes that could lead to more effective habitat restoration. The team evaluated changes to the delivery and routing of surface and groundwater, nutrients, sediment, wood and heat throughout the system and ranked each sub-basin as to its chance for successful preservation and restoration. The

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▲ **Figure 1.** Volunteers do a beach habitat assessment to identify the condition of nearshore habitats.

▲ **Figure 2.** Bulkhead-induced erosion, a result of failing to take natural processes of shoreline erosion and sedimentation into effect.

***Habitat processes,*** *from page 9*
project used GIS projections of land use, assuming present growth trends, and analyzed the resulting process alterations. Those sub-basins with the fewest natural process alterations over time were more likely to be successfully protected and restored.

**Policy analysis**

While the findings of these scientific investigations were becoming known, several stocks of Pacific salmon were declining throughout the Pacific Northwest. In 1999, a number of Pacific salmon stocks throughout the region were listed as threatened under the Endangered Species Act. State policies that affect salmon began addressing salmon protection and recovery incorporating the scientific framework of habitat forming and maintaining processes.

The first policy framework to incorporate the concept of protecting natural processes was the Washington State Watershed Analysis Manual in 1995 (*Macdonald and Weinmann, 1997*). This manual was developed by state agencies, Native American tribes, environmental and timber industry groups to guide forest practices under an agreement called Timber, Fish and Wildlife. The manual included a multi-disciplinary resource assessment, prescriptions for operating in sensitive areas, a public review process, and a monitoring plan to track changes throughout the watershed.

In 1998, the state legislature enacted the Salmon Recovery Planning Act that included the concept of alternative mitigation. Throughout the next year, representatives of the Departments of Transportation, Ecology and Fish and Wildlife developed mitigation policy guidance that expanded on the sequence of avoidance, minimization and compensation typically reserved for wetland impacts. The policy guidance applied to all kinds of aquatic resource impacts that could be mitigated and required that mitigation projects be chosen for their overall net benefit in the watershed. Many of the wetlands being mitigated had limited functions in the landscape due to invasive species, proximity to urban areas and isolation from surface and groundwater sources. Projects that restore ecological processes, such as reconnecting tidal influence and reducing barriers to fish passage, may be of greater benefit to fish and watershed health overall than replacing the limited functions of

the impacted wetland (*Washington Departments of Ecology, Fish and Wildlife and Transportation, 2000*).

Washington's Shoreline Management Act has been implemented since 1973. Under the Act, coastal cities and counties must prepare shoreline master programs designating various uses of shoreline properties within 200 feet of the shoreline and associated wetlands. Each shoreline use designation is assigned appropriate use policies. The Department of Ecology develops guidelines for preparing the master programs. The 2000 update of these guidelines requires that shoreline jurisdictions protect properly functioning conditions for threatened and endangered species. These include protection of the channel migration zone, discouraging the armoring of shorelines and maintaining hydrologic connections throughout the watershed. Implementation of these guidelines will require each jurisdiction to perform the necessary resource inventories and analysis to understand the natural processes that occur on their unique shorelines within larger watersheds often shared across jurisdictions (*Washington Department of Ecology, 2000*).

Probably the most wide-ranging use of the "process" concept is in the 2000 Puget Sound Management Plan. During the preparation of this edition, staff of the Puget Sound Water Quality Action Team met with researchers and agency staff involved in the efforts described above. The concepts were shared with stakeholder groups and a general agreement to include the "process" concept in the management plan was recommended by the Puget Sound Council. The stormwater management program and the marine and freshwater habitat program of the management plan included protection of natural hydrology, and habitat forming and maintaining processes, as a central theme. Specific programs for local comprehensive land use planning, state and federal agency permitting, and even education focused on this concept.

**Challenges of implementation**

Fully implementing the "process" concept, however, poses certain challenges. Natural resource managers are unfamiliar with how the policy will work on the ground. The Alternative Mitigation policy guidance has been in effect for nearly a year but few mitigation projects have been negotiated that support the concept. Many other policies in the state give a strong preference for on-site, in-kind mitigation. A strict interpretation of that convention often polarizes managers against considering a more process-based approach. The new shoreline management guidelines are being appealed by a number of local jurisdictions and associations on the grounds that the state overstepped its authority by attempting to protect salmon through shoreline management. Salmon restoration managers struggle with the physical inability to restore certain processes in highly urbanized or otherwise altered watersheds. However, local groups are completing watershed analyses for water supply, water quality, habitat and salmon recovery. The clearest way to affect holistic natural resource recovery, and at the same time, do more with less, will be to consider the restoration of natural processes.

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# Unraveling the mystery of underwater volcanoes

According to government and university scientists, a device placed by the National Oceanic and Atmospheric Administration's (NOAA) Pacific Marine Environmental Laboratory has provided an eyewitness account of what happens when an underwater volcano erupts. The device survived after being engulfed by a lava flow during an active eruption in 1998.

The site of the 1998 eruption was Axial volcano, along the Juan de Fuca Ridge seafloor, located about 300 miles off of Cannon Beach, Oregon. This volcano has been the focus of a long-term NOAA research effort called the Vents Program, that seeks to understand the mechanisms by which the earth's interior exchanges heat and chemicals with the earth's surface through seafloor spreading centers.

In an article in the August 16 issue of *Nature*, Christopher G. Fox and Robert W. Embley from the Commerce Department's NOAA facility in Newport, Oregon, and William W. Chadwick, Jr. of Oregon State University's Cooperative Institute for Marine Resources Studies, describe in detail the results obtained from this serendipitous occurrence.

"We began monitoring Axial in 1987, using simple bottom pressure recorders to measure the long-term vertical movements of the seafloor associated with magma transport within the volcano," reports Fox. "We never expected to get this close a look at the eruptive process."

The seafloor instrument, a Volcanic System Monitor (VSM), had been installed on the summit of Axial in October 1997 to continue the decade-long research effort begun by scientists in 1987. The precise location of the VSM was based on geological and geophysical measurements and was thought to overlie the magma center. Following the eruption, NOAA vessels visited the site and attempted to recover the instrument. Although the VSM responded, it would not release to the surface. Later investigations using a Remotely Operated Vehicle (ROV) showed the instrument to be trapped in the lava flow. A plan was formulated to recover the instrument in 1999.

Surprisingly, the instrument was recovered with very little damage. According to Chadwick, "the maximum temperature recorded inside the instrument during the eruption was only 7.5 degrees Celsius. This was remarkably low considering that the instrument was sitting atop basaltic lava that had probably erupted at around 1,190 degrees Celsius." Scientists believe this was due to the thermal insulation provided by the surface crust that forms and thickens when submarine lava flows come into contact with frigid sea water.

"Much of the data were intact, in particular the pressure and temperature data," said Fox. The data give a detailed view of the dynamics of a deep ocean volcanic eruption. In addition to the information on the flow itself, the long-term pressure record, in conjunction with other instruments deployed around the volcano by NOAA's Vents Program, provided a picture of what happened to the magma in the subsurface, making the 1998 Axial event the first deep submarine eruption ever recorded.

According to Fox, little is known about deep-sea eruptions because only in the last decade have we been able to detect them, and none has ever been witnessed. "The data we report here, recorded by the VSM instrument caught in the 1998 lava flow at Axial volcano, were obtained by fortuitous circumstance. The instrument was simply in the right place at the right time, with the right sensors and happened to survive the eruption," said Fox.

"It is doubtful that we will ever be clever enough to intentionally place an instrument in an active submarine lava flow, so this serendipitous recording becomes a benchmark in our understanding of submarine volcanism," Fox concludes.

The Commerce Department's National Oceanic and Atmospheric Administration (NOAA) is dedicated to enhancing economic security and national safety through the prediction and research of weather and climate-related events and providing environmental stewardship of our nation's coastal and marine resources.

For more information about the Pacific Marine Environmental Laboratory and the Vents Program, visit *http://www.pmel.noaa.gov/vents*.

— Barbara McGehan
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▲ **Figure 1.** In April 2001, NOAA scientists monitored this underwater eruption about 100 miles off the coast of southern Oregon and northern California.

# NOAA's Community-based Restoration Program

## *Implementing a national strategy for coastal and estuarine habitat restoration*

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The NOAA Community-based Restoration Program (CRP) began in 1996 to inspire local efforts to conduct meaningful, on-the-ground restoration of marine, estuarine and riparian habitat. The CRP is a systematic effort to catalyze partnerships at the national, regional and local level to contribute funding, technical assistance, land, volunteer support or other in-kind services to help citizens carry out restoration projects that promote stewardship and a conservation ethic for living marine resources. The CRP links funding and technical expertise to citizen-driven restoration projects, and emphasizes collaborative strategies built around improving NOAA trust resources and the quality of the communities they sustain.

The CRP is administered by the NOAA Fisheries Office of Habitat Conservation, through the NOAA Restoration Center. Until recently, the program has operated on a shoe-string budget of between $250K and $450K per year to support habitat restoration in coastal communities. In 2000, Congress gave the program a much needed boost and provided $2 million in funds that were distributed for grass-roots habitat restoration projects around the country, significantly expanding this highly successful program. In 2001, $8 million was made available to support community-based habitat restoration efforts.

An underlying principle of the program, and a primary reason for its success, is the development of national and regional partnerships that match NOAA funds at least 1:1, enabling a greater number of projects to be jointly selected and implemented. Between 2000 and 2001, partnerships were established with nationally recognized conservation and fishery groups such as the American Sportfishing Association (Fish America Foundation), the National Fisheries Institute (through their affiliated research and education organization, Ocean Trust), and Restore America's Estuaries, to name a few. In most cases, these partners contribute project funds that are matched again at the local level.

▲ **Figure 1.** Volunteers planting saltmarsh grass to restore a valuable wetland habitat.

Typically, past projects have leveraged on average $3 to $5 for every NOAA dollar invested, but some projects leverage up to 10 times the initial investment. Technical assistance, land donations or conservation easements, workforce support, and volunteer labor for project implementation and monitoring are all ways partners may contribute. This significant leverage translates into a conservative estimate of between 24 to 40 million of community-based habitat restoration work that will be implemented in 2001 under this program.

The role of the NOAA Restoration Center is to help identify sound projects, strengthen their development and implementation with help from

*— continued on page 14*

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***NOAA's CRP,*** *from page 13*
the community and local interest groups, and generate long-term national and regional partnerships to provide funds and other support for community-based restoration efforts around the country. Proposals for projects are requested several times each year, either directly by the RC or through its numerous partners. NOAA Fisheries field staff make site visits and meet with potential grantees to answer questions and guide them through the restoration process. Proposals undergo a competitive review, and projects are selected based on their technical merit, level of community involvement, ecological benefits to marine and anadromous fish habitat, and partnership opportunities.

By the end of 2000, NOAA funding had supported 180 community-based projects in 25 states, and hundreds more projects are expected to receive awards and begin in 2001. While individually small, these projects are beginning to have a cumulative impact on improving the health of the nation's marine, estuarine, coastal and riparian habitats. Support for individual projects in 2001 will range from $1,000 to up to $100,000, and national and regional partnerships will range from $100,000 to almost $2,000,000.

Partnerships allow communities to reach significant milestones faster, and the cooperative nature of the community-based restoration process fosters a sense of collective stewardship and respect for the environment. Projects funded through existing partnerships include fish ladder installations and small dam removals in New Hampshire; fish passage improvements in Massachusetts; seagrass restorations in Virginia and Maryland; oyster reef restoration in South Carolina; coral reef and mangrove restorations in Florida; marsh habitat restorations in Texas; kelp forest and salmon stream restorations in California; the reconnection of historic wetlands to tidal bays in Oregon; opening of impounded sloughs in Washington; invasive species removal in Florida and Washington; and streambank stabilization and revegetation in Alaska, to name a few.

A number of such projects are being implemented under a partnership first established in FY 2000 with Restore America's Estuaries (RAE) that will result in over $4.5 million in restoration with the continuation of the partnership into FY 2001. The NOAA/RAE partnership focuses on identifying, developing, and implementing estuarine habitat restoration projects in the eleven major estuaries where RAE members have established, effective, community-based conservation organizations around the coastal United States. RAE and their member organizations work closely with NOAA Fisheries staff and other partners such as state and local governments and universities to identify and develop community-based habitat restoration projects that are now being implemented under the partnership's pilot efforts. Currently, community-based restoration projects are underway at more than 35 sites in estuaries including the Gulf of Maine, Naragansett Bay, Long Island Sound, and Albermarle and Pamlico Sounds, among others. Projects funded through this partnership include oyster restoration in the Hudson-Raritan Estuary and Chesapeake Bay; anadromous fish passage improvements in Connecticut and Rhode Island; shoreline restoration and stabilization in North Carolina; salt marsh restoration in Tampa Bay, Galveston Bay, Louisiana's Mississippi delta, and Puget Sound; and wetland, estuarine, and riparian restoration in San Francisco Bay. Additional projects are under development and will begin being implemented with 2001 funds.

In addition to effectively accomplishing on-the-ground, community-based restoration projects, NOAA has been collaborating with RAE on the development of a National Strategy for Coastal and Estuarine Habitat Restoration. The purpose of the national strategy is to encourage public-private coordination and collaboration on coastal habitat restoration projects in order to ensure a more comprehensive approach to restoration. A primary goal of the national strategy is to restore one million acres of estuarine habitat by the year 2010.

The CRP has a proven track record of establishing successful public-private funds in order to accomplish on-the-ground restoration projects. Therefore, the CRP is an excellent vehicle for implementing the national strategy while getting local communities involved in restoration activities. Beyond having significant ecological and economical benefits, the community-based approach fosters a sense of stewardship and respect for coastal and marine resources within each community. Moreover, because of the unique nature of the program, community-based projects can be tailored and prioritized according to the individual restoration needs of each community.

The CRP and its partners are committed to continuing efforts to restore degraded coastal and marine resources across a wide range of geographic areas and habitats around the nation. NOAA will continue to collaborate with RAE and other interested parties on the development of a National Strategy for Coastal and Estuarine Habitat Restoration to encourage public-private coordination on habitat restoration activities as well as to meet the challenge of restoring one million acres of estuarine habitat by the year 2010 as charged by the Estuaries and Clean Waters Act of 2000. Through the cooperative efforts of local volunteers, businesses, public and non-profit organizations, government agencies, and universities, community-based restoration projects are building a base of interest and commitment for the sustainable future of our nation's marine, estuarine, and coastal resources.

Knauss Sea Grant Fellow Audra Livergood is gratefully acknowledged for her contributions to an early version of this article. More information on the Community-Based Restoration Program may be accessed at *http://www.nmfs.noaa.gov/habitat/restoration.* ■

### Paleoclimatology slides now available online

Mark McCaffrey of the Paleoclimatology Program and Dan Kowal of the Solid Earth Geophysics Division at NGDC, have recently completed an online version of nine paleoclimate slide sets which are available at *http://www.ngdc.noaa.gov/paleo/slides.html*. The slides, along with their associated narratives and background information, have been available for purchase in 35mm format, and are now also available for viewing and download through the Internet in a variety of formats including a slideshow.

The online slide collections, which cover topics such as "Tree Rings: Ancient Chronicles of Environmental Change," "Polar Ice Cores," and "Coral Paleoclimatology: Natural Record of Climate Change for High School Students," are geared for teachers and students as well as scientists and citizens interested in climate change research. These online resources include a glossary of important terms and users have the ability to search for keywords and receive a summary with thumbnails of all relevant slides.
*Contact:* NGDC

### New 1971-2000 climate normals released

The new 1971-2000 climate normals for temperature, precipitation and heating/cooling degree days are now available from the National Climatic Data Center. Monthly and daily normals were computed for nearly 8000 stations in the United States, Puerto Rico, the Virgin Islands, and the U.S. Pacific Islands. This represents an increase of over 15 percent in the number of stations from the previous 1961-1990 edition. The digital Normals files are currently available by calling, e-mailing or writing to the National Climatic Data Center. Beginning October 1, 2001, customers may order the digital Normals files online through NCDC'S "Online Store." Digital publication files (in PDF format) of the daily and monthly Normals will also be available online at that time. The new Normals will be used by NOAA's National Weather Service in the daily and monthly climate reports beginning in January 2002. Additional information on the 1971-2000 normals is available by going to *http://www/ncdc.noaa.gov/normals.html*.
*Contact:* NCDC

## Data products and services

### Online ordering of Certified Weather Data

A new E-commerce module has been added to the National Climatic Data Online Store allowing customers to purchase Certified Data online. Most states require all records that are to submitted as evidence in a court of law to be certified. To transition this requirement to the goals of E-government, certified data can now be purchased online at a price of $52.00, discounted from the usual offline rate of $60.00. The certified data includes weather observation forms, summary publications and products, and weather charts. The orders are still filled and shipped offline until such time as court approval is granted for certifying data for online delivery. This system should prove very popular for customers, resulting in a decrease in the number of telephone calls received for certification orders.
*Contact:* NCDC

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### Plankton distribution research

United Kingdom (UK) research scientists at the Southampton Oceanography Center are acquiring ten years of NOAA Level 1b data from the Advanced Very High Resolution Radiometer (AVHRR) flown on NOAA's polar orbiting satellites from the National Climatic Data Center. The intended use of the data is to support a highly-rated research project studying the distribution of 'coccolithophore' plankton in the Bering Sea. This type of plankton is highly reflecting, so it can be detected using a combination of AVHRR channels 1 and 2. These data will be used to fill the time gap between the ocean color sensors —Coastal Zone Color Scanner (CZCS) of 1978-1986, and SeaWiFS, 1997-present.
*Contact:* NCDC

### MODIS sea ice products

Three Moderate Resolution Imaging Spectrometer (MODIS) sea ice products are now being distributed by the National Snow and Ice Data Center (NSIDC). A level 2 swath product (MOD29) and level 3 gridded day and night products (MOD29P1D and MOD29P1N, respectively) contain sea ice extent at 1-km spatial resolution. The sea ice algorithm uses a Normalized Difference Sea Ice Index (NDSI) and other criteria to distinguish sea ice from open ocean, based on reflective and thermal characteristics. MODIS sea ice data, when combined with SSM/I passive microwave data and synthetic aperture radar (SAR) data, give scientists a more detailed understanding of global sea ice extent, albedo, and thickness; location of ice margins and leads; ice type, motion, and concentraton; and radiative and turbulent heat flux properties for large-scale climate studies. Users can order MODIS sea ice products from the NASA EOS Data Gateway of *http://nsidc.org/~imswelcome/*.
*Contact:* NSIDC

### Ocean Drilling Program data

The National Geophysical Data Center is releasing a new CD-ROM containing marine geological data from legs 101-129 of the Ocean Drilling Program. The new CD-ROM includes a tab-delimited version of the data, optimized for direct loading into spreadsheets and databases and features a cross-platform HTML interface.
*Contact:* NGDC

***Coral reef ecosystems,*** *from page 7*

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