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Reefs from Space: Satellite Imagery, Marine Ecology, and Ethnography in the Dominican Republic

Richard W. Stoffle,[1] David B. Halmo,[1] Thomas W. Wagner,[2] and Joseph J. Luczkovich[3]

Coral reef bleaching is an obvious indication that coastal marine ecosystems are being stressed. However, bleached reefs alone are poor indicators because they reflect the final stages of stress. This research project used multidate satellite imagery to look for coral reef changes as indicators of stress. Findings suggest that (1) satellite imagery can be used to identify small-scale changes in coastal marine ecosystems, including coral reefs; (2) remote sensing, marine ecology, and ethnographic data can be integrated to suggest potential causes of coral reef stress; and (3) changes in reef, seagrass, and mangrove ecozones are more closely tied to fishing, tourism, and land use practices than to global warming.

KEY WORDS: remote sensing; marine ecology; ethnography; fisheries; Dominican Republic.

INTRODUCTION

Once again anthropologists are sharing their professional expertise about the role of humans in changing the face of the earth (Thomas, 1956; Turner, 1990), or as it is now termed, the human dimensions of global environmental change (CIESIN, 1992; Stern et al., 1992). To face this new challenge, anthropologists are reframing old issues and insights; but the current framework seems to be on a scale that requires new ways of thinking about problems and new types of research methodology. Current global change issues include seasonal thinning in the ozone layer, massive removal of tropical forests, and worldwide declines in biodiversity, including coral reefs.

[1] Bureau of Applied Research in Anthropology, University of Arizona, Tucson, Arizona 85721.
[2] Environmental Research Institute of Michigan, Ann Arbor, Michigan 48113.
[3] Institute for Coastal and Marine Resources, East Carolina University, Greenville, North Carolina 27858.

Complex and highly productive coastal ecosystems are an important component of the earth's biosphere. These coastal ecosystems are interfaces for complex energy and material exchanges between the land and the oceans. Exchanges across this land-sea boundary are fundamental to the global circulation of elements and energy within the biosphere. Recent studies suggest that the health and abundance of coral reefs may hold a key to prehistoric changes of carbon dioxide levels in the atmosphere and accumulations of carbon compounds in the deep ocean (Opdyke and Walker, 1992). It is important to obtain scientific information about this interaction so that these ecosystems can be sustainably used and preserved. The International Geosphere Biosphere Programme (IGBP) initiative entitled "Land-Ocean Interactions in the Coastal Zone," which is focused on physical and biological processes in the coastal zone, is a step in that direction. This article addresses these processes as well as the human dimensions of coastal change.

HUMAN DIMENSIONS OF GLOBAL CHANGE

Theory

Much of the knowledge that has been offered to explain global change or predict its consequences has been developed with information collected for other purposes. This is true for the physical as well as the human sciences. As a result, most global change theories are based on data and theory generated by research focused on other, usually more local issues. The challenge for scientists, then, is to derive the greatest explanatory utility out of existing theories while applied global change research is being designed and conducted to verify or disprove such theories.

A guiding structure for global change research has been modeled by the *Bretherton Wiring Diagram* (NASA, 1986), which includes a single category termed *human activities*. But the diagram fails to specify the key human parameters. The specific human dimensions of global change need to be added to this diagram. Various conferences are being held to identify key issues and parameters associated with global change (CIESIN, 1991). In 1992, the Aspen Global Change Institute brought together several noted physical and social scientists to produce the *Social Process Diagram*, which was intended as a preliminary model of the human dimensions of global change (CIESIN, 1992). As applied global change research projects produce findings, this social process diagram will be increasingly grounded in observed data and be refined to provide testable hypotheses.

Research

Satellites routinely collect basic data from extensive geographic areas. These repetitive data can be used to understand and monitor physical changes. One limitation of satellites is that they can neither fully interpret what is observed nor explain the causes for the observed changes. *Ground truth* is a general term that refers to the surface-based activities of scientists who conduct studies to obtain data necessary in interpreting what the satellite sees and the causes of the observed phenomena. Ground truthing provides the linkage between the satellite observed phenomena and the processes on the ground that are attributed to the phenomena. It connects the activities of discipline-specific scientists to satellite scientists who produce earth images from space.

Global environmental change problems are complex, so research teams should also be complex, reflecting the range of variables that may be influencing the global problem under study. There have been very few cases in which human dimensions of global change have been studied by interdisciplinary research teams using both satellite images and traditional social science research techniques (Guyer and Lambin, 1993). Therefore, applied research projects are required in order to ascertain whether or not certain types of global change issues can be effectively studied by interdisciplinary research teams. These questions begin to be answered by analysis of single locations where changes are occurring. Such analysis permits the multidimensional research that is needed to take the first step. The second step is to move from the successful study of one locale to the analysis of other locales that are similar in most respects to the first pilot area (Moran, 1990), but contrast in ways that permit hypotheses emerging from the first study to be tested. A third step is a national or international study where smaller samples are taken from a much larger area and used to determine whether the initial methods or findings have scale limitations. The ultimate goal would be to monitor from space representative, ecologically threatened regions of the entire planet, using comprehensive satellite data with limited ground truthing in widely separate locales to test specific hypotheses.

CIESIN AND PILOT RESEARCH

In 1990, NASA funded the creation of an organization known as the Consortium for International Earth Science Information Network (CIESIN) (Kuhn et al., 1991). The purpose of CIESIN is to understand the human dimensions of global change by increasing access to and use of human science and earth science datasets by international scientific and decision making communities. CIESIN has created a facility known as the CIESIN Socioeconomic Data Archive Center (SEDAC) which is located in Michigan. The SEDAC uses global change models to develop, archive, and distribute special research products to public users as well as global change scientists. Based on these global change models, the SEDAC collects selected Earth Observing System (EOS) satellite data, as well as datasets from the physical, biological, and social sciences.

CIESIN initiated a series of nine human dimensions of global change pilot projects in 1991, to better understand how physical, biological, and social scientists must interact in order to address problems of importance to decision-makers. There is also a need to develop methodologies for merging datasets which differ on spatial and temporal scales, and indeed, to ascertain whether or not data are generally available to address specific, highly complex problems. Thus, interdisciplinary studies were emphasized, especially those combining earth and social sciences. Because there has been virtually no research on the use of remotely sensed data in the social sciences of global change, this was a component of each pilot project.

DOMINICAN REPUBLIC PILOT PROJECT

One of the CIESIN human dimensions of global change pilot projects is situated on the north coast of the Dominican Republic (Stoffle, 1993; Stoffle and Halmo, 1991; see Figs. 1 and 2). The study area involves a portion of 30-mile long coral reef, described by the Smithsonian Marine Systems Laboratory as one of the best remaining reefs in the Caribbean. The project was intended to examine (1) whether or not satellite images can be used to identify and monitor small scale changes in coral reefs and the associated coastal marine ecosystem, and (2) whether or not interdisciplinary research can explain how humans are affecting, and being affected by, changes in this ecosystem. The analysis derives primarily from field data collected as part of the CIESIN pilot project during 1991, but builds upon a long-term research commitment to the region that began in 1985 (Rubino and Stoffle, 1989, 1990; B. Stoffle, 1994; Stoffle, 1986; Stoffle and Halmo, 1991, 1992; Stoffle et al. 1991, 1993).

When Columbus first observed the north coast of Hispaniola he noted numerous large Indian villages associated with extensive agricultural fields. Disease, warfare, and forced relocation caused much of the coast to be abandoned by the early 1600s. Few Spaniards ever occupied the north coast of the Dominican Republic, so it is assumed that the natural environment recovered from indigenous land use patterns over a period of 300 years. The study area community was established in 1897 by a small group of

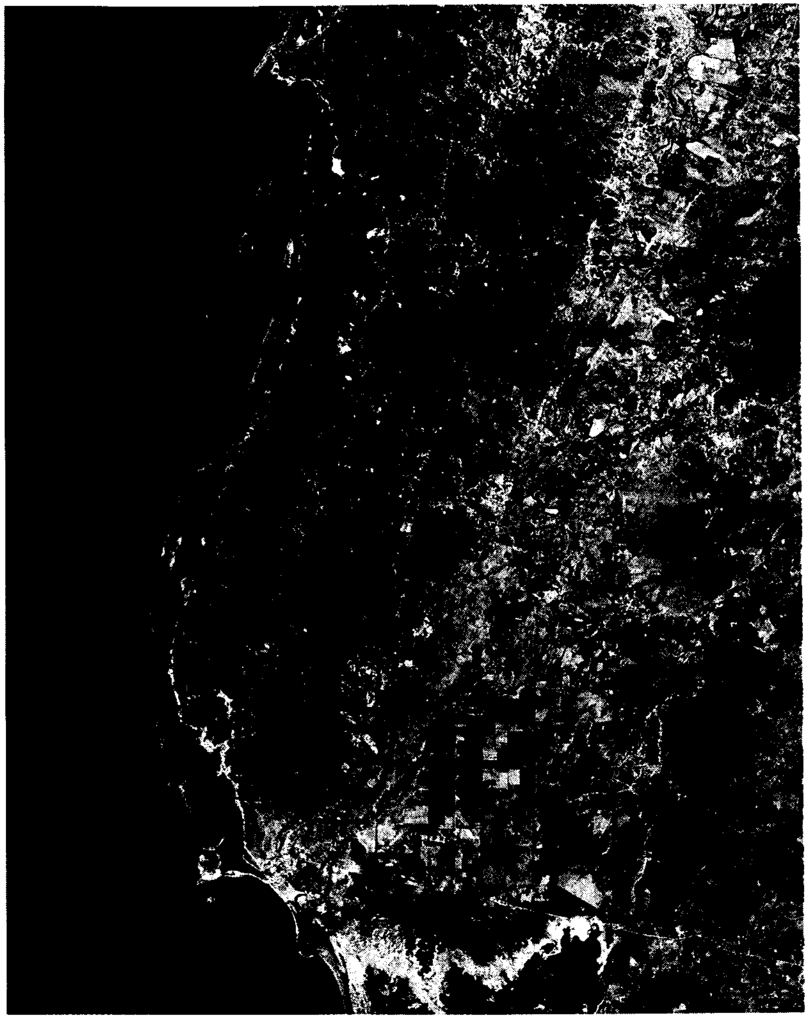


Fig. 1. Natural color image of the north coast of the Dominican Republic. Monte Cristi can be seen on the left. Buen Hombre is located just right of center, near top of image where there is a break in the reef. (Photo courtesy of Environmental Research Institute of Michigan.)

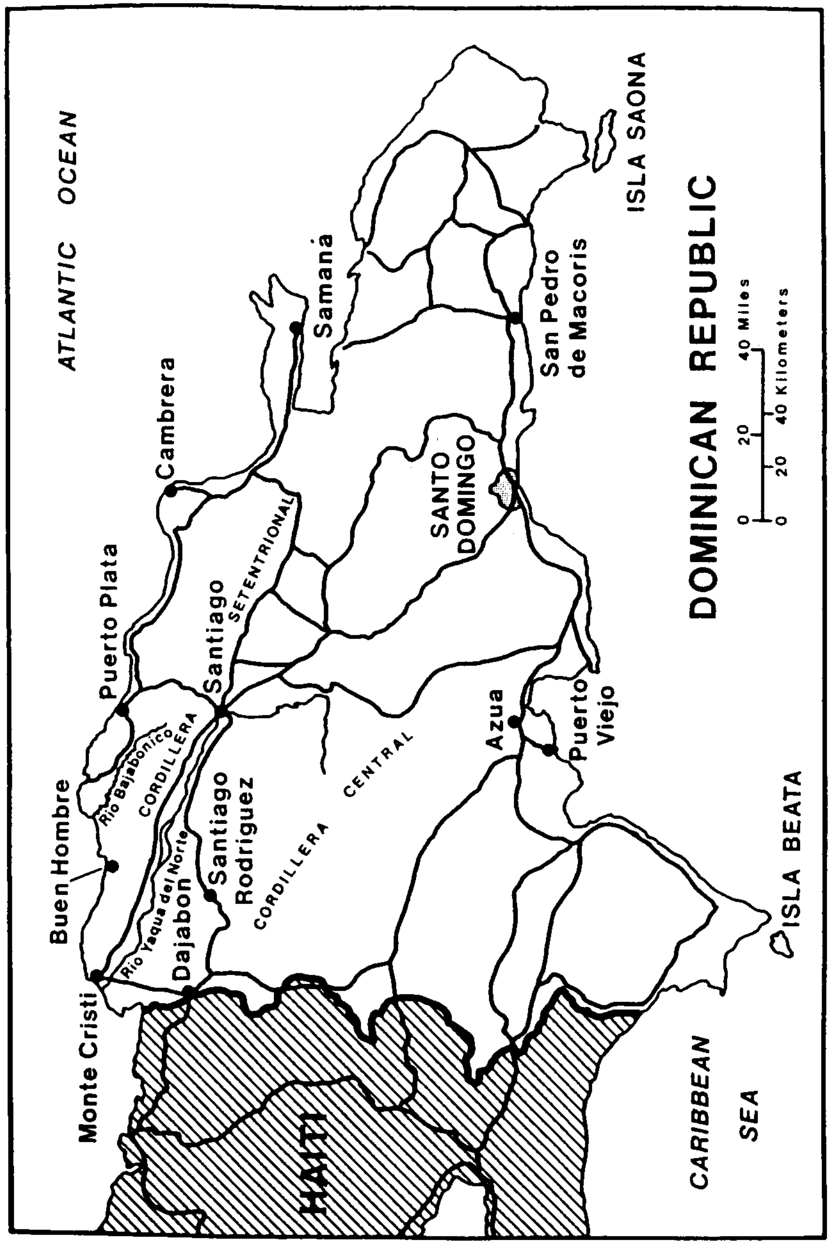


Fig. 2. The Dominican Republic, showing the north coast and the location of Buen Hombre.

settlers. Slowly the size of this coastal community, which came to be called Buen Hombre, grew until, by the late 1980s, its population was approximately 900 residents. Informal surveys of archeological sites in the Buen Hombre area suggest that today the current village residents are living exactly where and very much like the Indian people were at the time of Columbus. It can be argued that the coastal marine ecosystem and the local human population could exist in sustainable balance if pressures on this system only derived from the people of Buen Hombre and similar folks in other villages along the coast. This is not the case.

The future of this ecosystem is in doubt. This prediction is based on direct data and by analog. Fishermen in Buen Hombre report lower fish catches and smaller fish size over the past generation. A dive-shop operator at a neighboring international tourist hotel reports the need to take tourists to new reefs, because the ones close to the hotel have died during the past 5 years. Fishermen from distant towns are beginning to fish in the study area's coastal waters with large nets (*chinchorros*) that are illegal and may be highly destructive of fish populations and habitat. Local fishermen say that the manatee have disappeared from those areas where *chinchorros* have been used. Finally, analogous coral reef areas to the west in Haiti have been characterized as "dead" (Brass, 1991; personal communication) and to the east in other parts of the Dominican Republic as "fished out."

In this study, cultural anthropologists, remote sensing scientists, and a marine ecologist jointly visited specific sites to obtain data relevant to their disciplines. The common reference for organizing these detailed, location-specific observations was provided by satellite global positioning system (GPS) data (latitude and longitude). The GPS reference point data made integration of our multidisciplinary data possible, and allowed statistical analyses to be conducted. The GPS position data, collected in a coordinated fashion, were essential for allowing further insights and integration of the anthropological, remote sensing, and marine ecological data.

ETHNOGRAPHY OF FISHING

The two major economic activities in Buen Hombre are fishing and farming. Few males who identify themselves as farmers also fish. In contrast, virtually all males who identify themselves as fishermen also farm. Consequently, most fishermen belong to both the community-based fisherman's association and to the agricultural association. The fisherman's association is composed of men who have risen through the ranks of the developmental cycle of fishing, which involves four distinct stages: (1) apprentice, (2) journeyman, (3) craftsman, and (4) beached (Stoffle, 1986, pp. 95–100).

As is the case among most small-scale coastal fishermen, the task of fishing is constrained by fluctuations in weather conditions and a lack of mechanized technology such as boat motors. Buen Hombre fishermen have adapted to these constraints by forming social and economic relationships that help ensure access to resources for fishing as well as subsistence.

Buen Hombre fishermen use a variety of methods for catching fish. The most common method is the use of snorkel and speargun for diving on the coral reefs. This method involves an ability to remain submerged for substantial periods of time in order to locate, stalk, and shoot one's target. Accuracy is crucial because spears must be retrieved and refastened to the gun should a fishermen miss his target.

A 1989 inventory of fishing equipment illustrates that the 34 fisherman's association members employ multiple methods in fishing. Forty-one percent of association members use handlines (*cordeles*), which are used mainly during night fishing. Fifty percent use snorkeling gear and spearguns. Thirty-five percent of association members own and deploy *nasas*, or fish traps in deeper waters. Access to and use of boats and motors is controlled by 26% of association members, but it must be remembered that fishing crew members cooperate in boat travel to fishing locations. Twelve percent of association members use *atarrayas* or beach cast nets. Only two association fishermen use boat nets (*trasmallos*); significantly, no Buen Hombre fishermen use beach set nets (*chinchorros*) as a fishing strategy. Night fishermen also use flashlights and makeshift lamps, which are held over the water in order to attract fish. Social relationships, both kin and non-kin based, facilitate sharing or loaning of equipment among and between fishermen.

Fishing crews usually operate in three "shifts" because of frequent equipment failure, access to boats, or other economic commitments in the system of occupational multiplicity. The first shift is usually worked by the majority of fishermen, who begin about 8:00 a.m. and return around noon, depending on weather conditions. In the early morning hours, the sea is at its calmest, allowing easier boat travel to the reefs and beyond. Returning is also easy because fishermen have the prevailing northeast wind at their backs. The second shift begins after 12 noon. Rowing out to the reefs can be difficult against the strong afternoon winds and rough waters. After 4 or 5 hours of fishing, the return trip home is facilitated by the same winds. Several individuals and some crews fish at night. Their shift begins around 8:00 p.m. and lasts throughout the night. Equipped with containers of coffee and rum, a flashlight hooked up to an automobile battery, handlines and hooks, night fishermen have the advantage of calm waters. Fish are attracted to the light and thus some of the largest catches occur at night. Night fishing is, however, the most dangerous because of the risks of running into coral heads, damaging boats and motors, and the possibility of being attacked by barracudas or sharks, should the fisherman decide to snorkel dive. The night shift is the longest because fishermen must wait until morning to bring their catch to the market, when someone is there to weigh the fish and put them on ice. Each of the shifts, then, has advantages and disadvantages. Some fishermen will occasionally fish more than one shift, going out in the morning and then making another all-night trip (Stoffle, 1986, pp. 101–102).

Conservation Strategies

Buen Hombre fishermen traditionally have employed sustainable methods of fishing that appear to derive from a conservation ethic (B. Stoffle, 1994; Stoffle et al., 1994). Interviews with key experts indicate that fishermen recognize the potential adverse effects of indiscriminate fishing practices on reef fish populations. Small fish are not targeted by fishermen; only rarely are they captured in fish pots. Expert fishermen explain that small fish are avoided in order to allow them to grow to an appropriate size. Small fish are not ideal for consumption or sale because of the low proportion of flesh. Large fish provide high returns in terms of the amount of protein-rich food compared to the amount of energy expended to catch them. This fishing behavior may suggest an energy maximization strategy on the part of "optimal foraging" fishermen (Begossi, 1992). Avoidance of small fish and other seafood species also implies that fishermen are cognizant of the effects of overfishing on population reproduction.

Fishing entails the dual goals of providing food and income. Consequently, fishermen harvest a diversified supply of seafood. Daily individual catches usually include an array of parrotfish (*Sparisoma* and *Scarus*), grouper (*Epinephalis* sp.), snapper (*Lutjanus* sp.), crab (*Mithrax* sp.), lobster (*Panulirus argus*), conch (*Strombus gigas*), and other reef fish. A comparison was made between the species reported to be harvested by Buen Hombre fishermen and those observed during diver ecological surveys at 17 stations (Figs. 3a,3b). Grunts (*Haemulon* sp.), Nassau grouper (*Epinephelus striatus*), and spiny lobster were the most frequently harvested species, being mentioned by fishermen at 17, 15, and 13 stations, respectively. However, divers listed these species rarely: bluestriped grunt (*Haemulon sciurus*) and Nassau grouper were observed at four stations, ranking 19th and 20th out of 78 species, and spiny lobster at none. More commonly, divers observed striped parrotfish (*Scarus croicensis*), blue tang (*Acanthurus coerulus*), and bluehead wrasse (*Thalassoma bifasciatum*) as the top three species, occurring at 13, 12, and 10 stations. Some of the difference between fishes present at the stations and those harvested by fishermen can be attributed to the short sampling period (February 15–March 4, 1991) used in the SCUBA obser-

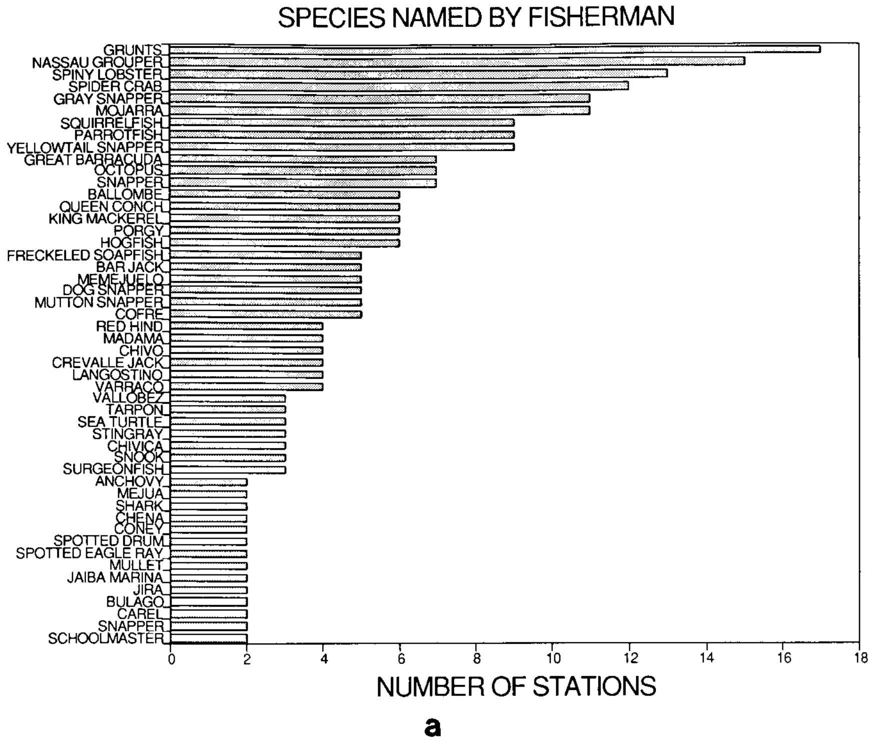
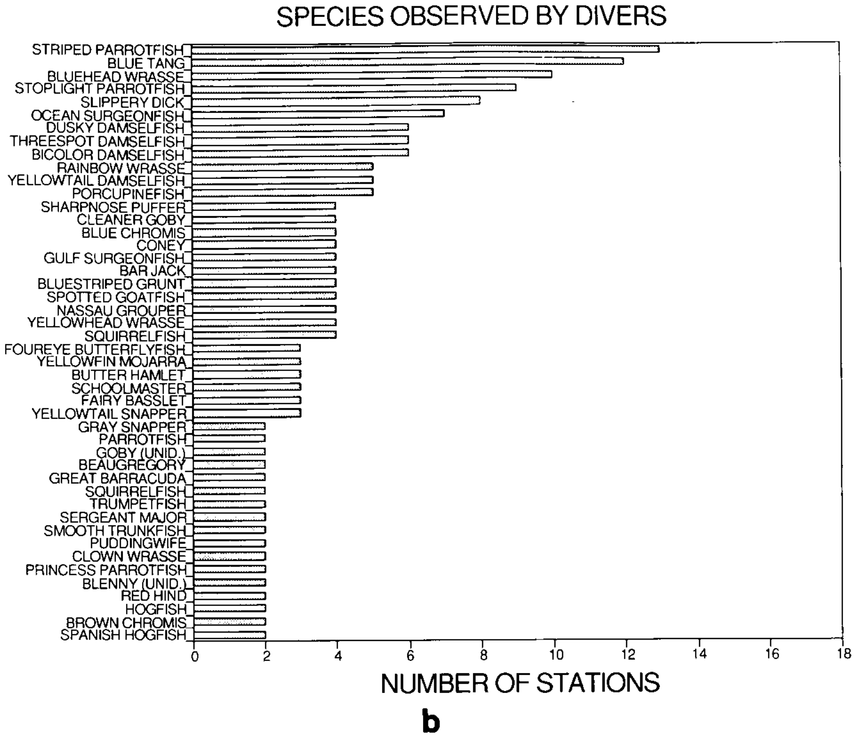


Fig. 3. (a) The number of stations at which species were harvested, based upon fishermen interviews. (b) Number of stations at which SCUBA divers observed fishes at same sites, February 15–March 4, 1991. Interview and dive stations are indicated by highlighted boxes in Fig. 1.

vation relative to the longer interval over which the fishermen remember their catches, but these data indicate clearly that fishermen harvested grunts, Nassau groupers, spiny lobsters, and other species in a selective manner. This selectivity is due to the preferences of the fishermen, or their targeting behavior. The species that were the most frequently observed by divers were among the smallest species and of the lowest market value. It appears that the fishermen were targeting large, high-value species.

The diversity of catch clearly indicates that multiple species are deliberately and commonly sought. Buen Hombre fishermen thus employ deliberate fishing strategies for both subsistence and cash. While fishermen prefer certain species for home consumption, these species are usually part of a diversified catch. It can be argued that diversifying the catch reduces the risk of overfishing certain species.



Data suggest that these fishing strategies can and do change, based on such factors as weather condition and stress in other sectors of the local economy. These changes can be either short-term (day, week, month) or longer-term (seasonal). Under conditions of environmental (drought) and economic (crop failure) stress, Buen Hombre fishermen appear to be intensifying their fishing efforts in terms of (1) length of fishing trip, (2) more intensive exploitation of certain locations along the coral reef, and (3) a concentrated effort to capture species that are in high demand in the market economy.

Fishing Dynamics

Wind and rain play significant roles in decisions regarding whether or not one goes out to fish. If the weather is favorable, the pressure of having to fish long hours and exert great amounts of effort is reduced. On the other hand, when weather conditions are adverse, the lack of larger boats and outboard motors mitigate against going out to the reefs to fish.

Boats and motors are too small to be safely handled in strong winds and rough waters. Consequently, fishermen may be more likely to walk along the shore to the point of the lagoon and swim out to fishing spots well inside the inner reef. To compensate for lost subsistence and income on those days when weather conditions are not favorable, fishermen may exert more effort while fishing or target specific species of high-value seafood on those days when the weather is favorable.

A statistical analysis of fishermen catch records (Stoffle et al., 1993, pp. 273–279) documents that fishermen sold roughly the same amount of seafood overall but made more money during the spring season. This was accomplished by targeting high-value species and improving efficiency of fishing effort. These data show that the Buen Hombre fishermen can and do engage in fishing practices that increase the amount of high-value seafood removed from the coral reef ecozone when it becomes necessary to do so. The question remains as to why they do not do so all the time. The answer provided by the fishermen is that they realize that fishing for only high-value species will eventually destroy the coral reef.

Despite a general desire to be economically better off, the fishermen of Buen Hombre have weighed this desire for short-term economic benefit against an even stronger concern for the long-term sustainability of the coral reef ecozone. Fishermen resolve conflicting desires for economic betterment and conservation by fishing for a mix of species and at lower daily levels whenever they can in order to protect the coral reef for themselves and future generations. When they do engage in nonsustainable fishing practices, they do so only on a short-term basis in order to compensate for (1) fishing income lost due to the effects of adverse weather conditions on the ability to fish, (2) competing labor demands, such as peak seasonal commitments to agricultural activities, (3) crop losses due to drought, and (4) the purchase of basic essentials such as water and other staple foods.

The local adaptive strategy of engaging in multiple occupations (fishing and farming), based on mixed production of diverse commodities (varieties of seafood and crops), serves to reduce the risk of economic failure. Perhaps an under-recognized adaptive function of occupational multiplicity is that such a system potentially serves to reduce the risk of environmental degradation in terms of overuse of terrestrial and marine ecozone components of coastal ecosystems.

Threats to the Coral Reef Ecozone

Local resource use and management practices of Buen Hombre fishermen-farmers are currently being threatened by the destructive practices of outsiders. Like most small-scale fishermen (Cordell, 1989), the people of Buen Hombre perceive the coastal waters as part of their community territory. Small-scale fishermen from interior villages and port city commercial fishermen compete for access to reef and sea resources with the fishermen of the coastal village of Buen Hombre.

The burgeoning tourism industry also affects the coral reef ecozone. Even in small-scale resorts near Buen Hombre, there already appears to have been an increase in coral harvesting, collected by tourists as souvenirs. As the industry continues to grow and expand beyond the boundaries of port towns, increasing numbers of tourists will intensify their search for "wilderness" areas, thus subjecting the Buen Hombre coral reefs to higher levels of disruption. Together, tourists and growing numbers of small-scale fishermen have the capability to destroy one of the largest living reef zones in the world.

SATELLITE IMAGERY

Satellites collect data from extensive geographical areas in very short periods. These data consist primarily of electronic records of the intensities of electromagnetic radiation reflected or emitted from the earth's surface through the atmosphere to the satellite. Taken repetitively, these data may help identify and monitor changes in the average amount of radiation recorded from analytical units called pixels. However, the satellites can neither interpret what is observed in ecological terms nor explain what has caused the observed changes. For this study, *sea-truthing* is the term that describes the ancillary information required to interpret the satellite data and establish what is causing the radiation changes. Sea truthing was conducted at specific locations.

A hand-held GPS unit was used to obtain precise locational information for the sites. GPS involves a new system of polar-orbiting satellites operated by the U.S. Navy to provide direct information to receivers on the ground. At the time of the fieldwork, 14 GPS satellites with very precise orbits were broadcasting signals that were received on the ground. When three or more simultaneous signals were received from the GPS satellites, the ground receiver calculates and displays the precise latitude and longitude of its location. A Magellan NAV 1000 PRO unit was used to determine all position fixes during the marine survey. This lightweight, hand-held, weatherproof portable receiver provided autonomous positioning accuracies of 15 meters or less within several seconds of acquiring signals from three GPS satellites.

Several remote sensing technologies were used during this study—Landsat satellite imagery, aerial photography, GPS, and hand-held sonar. These data-gathering tools were combined with marine biology and ethno-

Fig. 4. Natural color image of La Costa de Buen Hombre, showing sea-truth sites highlighted as yellow boxes.

graphic field data to map the coastal land use practices and water depths (bathymetry) and to identify areas of coastal ecosystem change. Some 52 marine sites were selected as the research sample for study (see Fig. 4). Conclusions were derived from marine and ethnographic data sea-truthed at these sites. The sites also will serve as baseline points from which to measure future changes in the ecosystem.

Multidate Landsat imagery, GPS readings, and sonar data were used to record and identify the locations of marine observations and measurements. Historical (1983) panchromatic aerial photography was used to map land use along the coast. The project area extended for approximately 20 kilometers on either side of the village of Buen Hombre.

Three dates of Landsat imagery were used for this study: February 1975, February 1985, and January 1989. The Landsat data were resampled and registered to a Universal Transverse Mercator (UTM) projection with a 25-meter grid. ERIM's (Environmental Research Institute of Michigan) "restoration" resampling was applied to correct for geometric distortions that occur when satellite data is collected. This deconvolution technique also helps recover losses (blurring) of pixels and produces a clearer, sharper image than that produced by other resampling methods. Matching the three datasets to the same projection and common 25-meter grid size allowed their analysis and comparison. These geometrically corrected datasets provided the basis for the land use, bathymetric, and change images. The TM data have greater spectral and spatial resolutions than the MSS data. The Landsat visible bands (MSS4, TM1, TM2, and TM3) were used to produce single band and natural color images at working scales of 1:50,000 and 1:25,000. These visible bands have the greatest marine water penetration capabilities and, therefore, were used to observe and map underwater features and calculate water depths.

The 1985 Landsat Thematic Mapper data were used to estimate and map water depth along the Buen Hombre coast because of cloud cover in the 1989 data. A single band algorithm of TM1 generated a depth map for this study. This single band method required the least ancillary information and works where the bottom reflectances and attenuation coefficient are fairly constant throughout the scene. The main advantage of this method over multiband methods is its simplicity and lower sensitivity to random noise.

Differences between the reflectivity of identical pixels indicate changes. Two types of Landsat change images were created (Luczkovich et al., 1993; Michalek et al., 1993). One type showed relative amounts of physical change in continuous black and white tones (ratio image). The other types showed the locations of only a certain type of change that had exceeded a threshold value (vector-change image). Bright colors are assigned to pixels that experience degrees of radiation changes that are deemed to be significant, while the remainder of the image remains grey. Sea truthing these pixels provides marine biology and ethnographic data for interpreting the significant changes.

Analysis of the 1975–1985 ratio images and the 1985–1989 ratio images showed several types of changes (see Fig. 5). Some changes were ecologically significant; some were ephemeral. The ephemeral changes were identified with cloud cover, sea state, surf-zone, and turbidity differences between the two dates. The changes that were ecologically significant were characterized by changes from darker tones on the earlier images to lighter tones on the later images, that is, pixels with increased radiances. Increased radiances within a pixel appeared to relate to decreases in both terrestrial and marine vegetation, including losses of highly productive and biologically diverse seagrasses (*Thalassia testudinum* and *Syringodium filiforme*) and corals (*Montastrea annularis*) in the water or mangrove (*Rhizophora mangle*, *Avicennia racemosa*) along the coast (Luczkovich et al., 1993). Submerged coral reefs and seagrass meadows always had less reflectivity than sand bottom, so change from dark to light indicated a decline in marine productivity and loss of biodiversity (Luczkovich et al., 1993).

Not all changes showed up well in the Landsat ratio images and these images were often difficult to relate to terrain patterns. Consequently, change vector analysis was used to detect radiometric differences that were from dark to light in two of three of the TM bands for 1985 and 1989 (Michalek et al., 1993). This approach computed pixel change direction and magnitude for the visible TM1, TM2, and TM3 bands. Using this procedure, the different types and degrees of changes that were observed in the Landsat ratio images were selectively recorded. Then areas of those

Fig. 5. Vector change image of Sand Key and Nearby Reefs. Change between 1985 and 1989 indicated by red pixels.

changes that were considered to be permanent were selected and printed out. Only those vector changes that exceeded a certain threshold were color-coded as red on a binary image. The change-vector image was then overlaid onto a single-date black and white Landsat image for locational reference. Areas of coral, algae, seagrass, and mangrove that had been badly damaged or were destroyed between the two dates were indicated by the red pixels on these images (Fig. 5).

MARINE ECOLOGY

Marine ecological studies indicated that there are highly diverse and productive mangrove forests, seagrass meadows, and coral reefs present near Buen Hombre. Two hundred and forty species were observed, including hard corals (22 species), soft corals (15 species), plants and macroalgae (59 species), invertebrates (66 species), fishes (78 species), and their distribution mapped onto specific pixels of the Landsat image (Stoffle and Halmo, 1991). A qualitative characterization of the coastal zone was made in the field by dividing the area into five "ecozones:" (1) the mangroves (intertidal < 1 m water depth); (2) the first lagoon seagrass meadow and

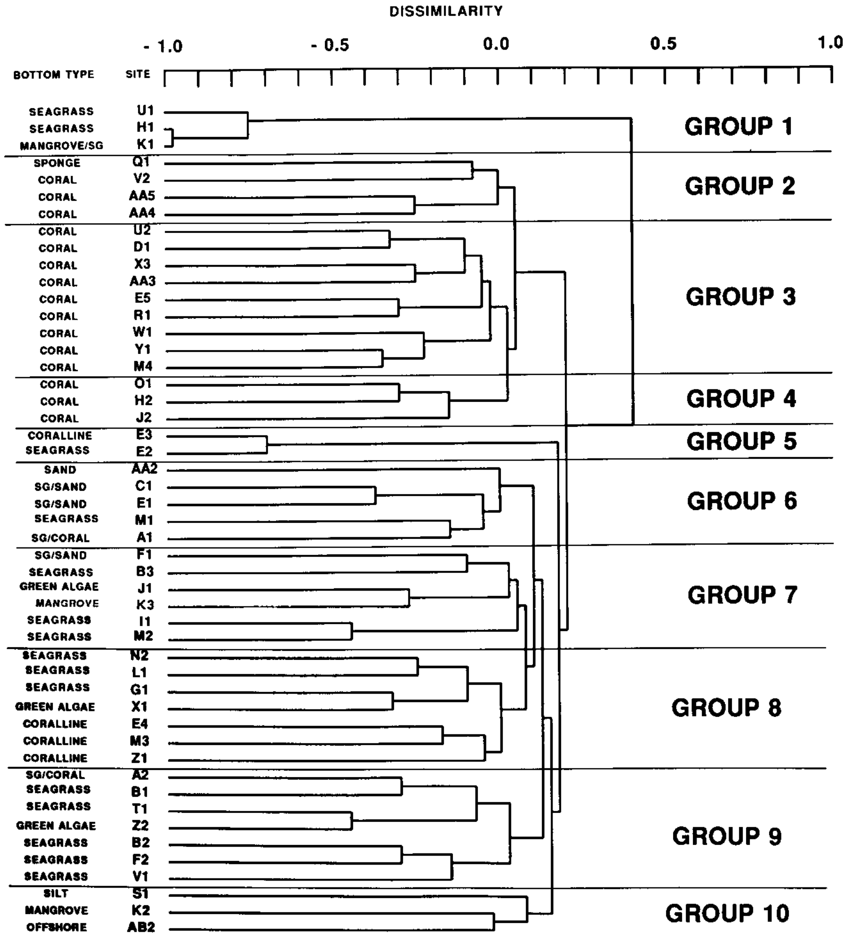


Fig. 6. A dendogram representing the Jaccard's index (dissimilarity) for a cluster analysis of the stations (sites) visited during ecological surveys. The data set used was a species-by-station matrix of presence/absence records for all species observed (plants, algae, invertebrates, fishes).

patch reefs (mean depth = 2.8 m, range 0.3–10.7 m); (3) the first barrier coral reef (mean depth = 2.9 m, range 0.3–9.0 m), which was often exposed at low tide; (4) the second lagoon seagrass and macroalgae meadow (mean depth 12.0 m, range 9.0–15.2 m); and (5) the second barrier coral reef (mean depth 9.7 m, range 0.6–16.0 m). Species of corals, fishes, invertebrates, and plants were distributed differentially in the different ecozones, so that suites of species (or ecological communities) were apparent within each zone. A cluster analysis, which was derived from a species-by-station matrix of Jaccard's index of similarity for all species (plants, invertebrates, and fishes) present or absent at 52 stations sampled suring ecological surveys, produced a dendogram shown in Fig. 6.

It is clear from the dendogram that particular stations formed natural groups with similar suites of species: there was a coral reef group (groups 2, 3, and 4), a reef flat group (groups 5 and 6), a seagrass/mangrove transitional group (group 7), and a seagrass/macroalgae group (groups 8 and 9). Such quantitative characterization of the coastal plant and animal communities resulted in site-specific species lists, which are available elsewhere (Luczkovich, 1991).

This variation in ecological communities provided a spatially diverse ecosystem that required the fishermen to travel long distances by boat to harvest particular species. This available array of harvestable species made the second barrier reef ecozone accessible only in good weather. The valuable and preferred species of fishes, snappers, groupers, and grunts, were very abundant at the offshore reefs. The inshore reefs had much lower abundance of the fishes, and apparently were heavily fished, especially during poor weather conditions, such as during the winter. Although fishes were available at all stations, the fishermen appeared to target the coral reefs, either barrier reefs or patch reefs.

Water depth is an important variable, influencing primary productivity, disturbance rate, benthic community structure, and fish abundance patterns. Remote sensing experts realize that bathymetry will influence radiance measurements, and hence can be mapped with remote sensors after sufficient ground control points are obtained. This project was successful because both the marine ecology data and remote sensing data contained depth measurements.

In addition, the Landsat data prepared for the project resulted in a bathymetric map of the Dominican north coast, facilitating future research in marine ecology and anthropology. Remote sensing of bottom depth was hampered by variations in bottom type unrelated to bottom depth. Another article (Luczkovich et al., 1993) illustrates a further refinement of the radiance values so that both bottom type and depth can be mapped in the future. Bottom-type mapping has important uses for marine ecologists and coastal resource managers. Integration of marine ecology data and remote sensing data will continue to be pursued at ever finer scales of spectral and spatial resolution. To some extent, difficulties in integration of the marine ecology and remote sensing data are due to differences in the spatial scale of previous studies; marine ecologists have focused on small areas (<10 meter square) and made detailed surveys, whereas remote sensing experts examine areas greater than 10 ha with sensors having pixel resolutions of 10–30 meters on a side (100–900/m^2). Thus, the upper limit of a study area for marine ecologists is often smaller than the lower limit of resolution for a remote sensing device such as Landsat. This disparity created some difficulties as remote sensors and marine ecologists prepared integrated datasets. New techniques and sampling protocols will have to be developed and new sensors with lower limits of resolution will eventually be deployed.

ISSUES IN DATA INTEGRATION

Marine ecology and anthropological data integration may prove to be more difficult than the remote sensing-marine ecology data, but will ultimately provide the greatest insights to the causes of global and local changes in coastal systems. Anthropologists understand the importance of site-specific data collection, and thus integration with site-specific marine ecology data will be possible using the GPS "Rosetta Stone." One example from this case study that illustrates the integration of anthropological and marine ecological data is the data on fisherman site-selection in various weather conditions and their influence on fish abundance and fish community structure. When weather is good, fishermen venture far offshore to distant barrier reefs to obtain catches of grouper, jacks, snappers, and lobsters. However, these trips are less common because the fishermen must row a boat for up to 10 km and need to have good weather for safety. More frequently there is harsh weather and fishermen select sites closer to shore, such as on the first reef, which are easier to get to (Stoffle and Halmo, 1991, pp. 179–181).

Marine fish surveys conducted by SCUBA divers at these same GPS-positioned fishing sites indicate that different fish species are found at the inshore sites than are found at the offshore sites. In particular, the groupers and snappers are more abundant at the offshore sites, which are less frequently used by fishermen. This suggests that fishermen know where the most abundant fish populations are and will selectively fish at those locations.

Fishermen, both local and from other villages, are probably responsible for the reduced inshore populations of grouper and snapper due to intensive fishing pressure. Interestingly, remote sensing data indicate a greater amount of change in radiance (increased brightness) at the inshore stations than the offshore stations. Remotely sensed images indicate the negative effects of the intensive fishing pressure, probably due to propeller and anchor damage to coral reefs and seagrasses. This ecosystem change caused by fishermen overharvesting in an area provides an example of how anthropological, ecological, and remotely sensed data can be integrated in a meaningful way.

CONCLUSIONS

This study shows that the coastal waters and coral reefs on the north coast of the Dominican Republic are still in good condition — complex in structure and rich in marine life. But evidence of environmental stress is also evident — patches of brightening and other bottom disturbances, and for the inhabitants, decreasing fish catches and declining areas of mangroves.

Remote sensing is seen as a tool that complements direct observation and knowledge by extending them in space and time. Still, it can be concluded that remote sensing alone has little utility for scientific study and informing environmental decision making.

More specifically, as a result of this analysis it can be concluded that:

- Satellite imagery can be used to identify changes in small areas (25 m × 25 m square) of coastal marine ecosystems, including coral reefs. The ecologically significant changes were generally associated with changes from dark to light (brightening). These changes indicate losses of highly productive coral, seagrass, and mangrove that comprise diverse marine habitats from which Buen Hombre people obtain food and other resources.
- Comparisons of satellite imagery with marine and ethnographic data showed that changes in coastal bottom reflectivity from 1985 to 1989 were closely related to fishing, tourism, and land use practices. If global warming is affecting this coastal ecosystem, its effects are still masked by the effects of these other more predominant stresses.
- There are differences in the types of impacts that are being made by local people who have a sense of ownership and an inter-generational commitment to the marine resources and those impacts of outsiders such as urban fishermen and tourists. Given the option, local inhabitants seek to preserve the long-term productivity of the coastal environment, even at the expense of current harvest.

Satellite data provided a unique and comprehensive technique for studying change in this coastal marine ecosystem, and they also were effective for transferring information about those changes to policymakers at the village, regional, and national levels (Stoffle et al., 1994). Landsat TM satellite images of the north coast reef system were shown to villagers and national-level government officials at two meetings in Buen Hombre. Community fishermen were immediately able to identify familiar locations and point to named fishing locations. The imagery served as the sounding board for discussions between village fishermen and government officials regarding use conflicts between Buen Hombre fishermen and intrusive outsiders using *chinchorro* nets. The images, supplemented with sea-truth data and resource inventories, were instrumental in persuading government officials that measures were needed to help protect the coral reef system and defend the rights and interests of the local community.

As a result of these meetings, the situation in Buen Hombre became the subject of publicity campaigns, radio and television programs, and meetings with commercial fishermen from the town of Monte Cristi, designed to educate the public on existing fishery regulations and the need to protect the Buen Hombre reefs through enforcement. Much of this activity was initiated by the Vice Minister of the Department of Natural Resources and the director of a Dominican natural resource conservation foundation.

The ultimate result of the campaigns was the official recognition on the part of government officials of the rights and claims of Buen Hombre fishermen to control community waters, and the empowering of local fishermen to patrol the reefs, incarcerate intruders using illegal gear, and transfer them to the nearby coast guard station for further legal action. The Dominican government even went so far as to issue badges to local fishermen chosen by their peers to enforce local regulations governing fishing practices. Perhaps the most significant aspect of the utility of satellite imagery in this study, then, was its policy-relevant usefulness as a catalyst for government action leading to recognition of the rights of local people to defend their community territory, and formally empowering them to do so.

Are the changes documented in this case study, as well as the causes that we attribute to those changes, occurring in other regions of the world? We suspect that they are. Worldwide, population growth has led to increasing pressures on natural resources, including those of the nearshore environment. Decline in coastal biodiversity and, in turn, marine fisheries, is in large part the result of intensive use by growing numbers of small- and large-scale fishermen and international tourists, as well as effects stemming from chemical and other forms of pollution. The ultimate utility of research findings on the human dimensions of global environmental change will be the extent to which comparative findings from a number of microlevel case studies can be integrated to discern cross-cultural patterns, from which generalizations about such processes and effects can be made. Such findings should then be used to formulate and implement new policies that balance conservation with sustainable resource use.

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