Mapping Marine Populations:
Using Surface Water GPS for Spatial Analysis

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ABSTRACT

Landscape pattern analysis of the distribution of biological populations and community types has been well developed for terrestrial mapping for some time. Global Positioning Systems (GPS) are used routinely to provide accurate maps and locations of point and polygon features that can be imported into a GIS platform. In the marine environment, mapping populations of organisms and understanding seascape patterns are considerably more difficult as a result of technical, equipment, access, depth and visibility problems.

This presentation will describe a simple new protocol for Surface Water GPS methodology for mapping shallow reefs and near coastal species distributions. A group of partner agencies in the USVI; University of the Virgin islands, U.S. Geological Survey and Virgin Islands National Park, have developed a low-tech method for geo-referenced mapping in coastal waters. This technique is presently being used to map the distribution of Acroporid

Using existing technology and adapting it to marine circumstances, highly accurate population distribution maps can be overlaid on digital imagery and benthic habitat maps creating the first maps of marine population distribution and population characteristics. This methodology opens a new approach to marine community mapping by providing position data capable of being used at the scale of the local population to track change; either loss or recovery over time.

KEY WORDS: Mapping, GPS, benthic habitats

Desarrollo de Mapas de Poblaciones Marinas

Hace algún tiempo se desarrolló en mapas terrestres, el análisis de los patrones de superficie para la distribución de poblaciones biológicas y sus comunidades. Los sistemas de posición global (GPS, por sus siglas en inglés) se utilizan de manera rutinaria para proveer mapas de alta resolución y la localización de puntos y polígonos; características que pueden ser importadas a una plataforma GIS. En el ambiente marino resulta más difícil descifrar los patrones de superficie del fondo para la creación de mapas de poblaciones de organismos debido a problemas técnicos, de equipo, acceso, profundidad y visibilidad.

Esta presentación describe un protocolo, nuevo y simple, para el uso de la metodología GPS en aguas superficiales, el cual es aplicable al desarrollo de mapas de arrecifes de poca profundidad y de distribución de especies cercanas a la costa. Un grupo de agencias de las Islas Vírgenes asociadas en este esfuerzo incluye a la Universidad de las Islas Vírgenes, al Servicio Geológico de los Estados Unidos y el Servicio de Parques Nacionales en las Islas Vírgenes; éstas han desarrollado un método de baja tecnología para el desarrollo de mapas geo-referenciados de las aguas costeras. Esta técnica se está utilizando para crear mapas de la distribución de especies de Acropóridos, incluyendo tamaño, profundidad, depredación por caracoles, incidencia de enfermedades y por ciento de cobertura viva.

Mediante el uso de tecnología existente y su adaptación a circunstancias particulares del ambiente marino, los mapas de alta resolución de distribución de poblaciones pueden ser sobrepuestos a imágenes digitales y mapas de hábitats bénticos creando así los primeros mapas de distribución de poblaciones marinas y sus características. Esta metodología presenta un nuevo enfoque al desarrollo de mapas de comunidades marinas al proveer datos de posición, capaces de ser usados a escalas de poblaciones locales para evaluar cambios; ya sea pérdida o recuperación a través del tiempo.

PALABRAS CLAVES: Mapas, GPS, hábitats bénticos

INTRODUCTION

The latest ecological observations suggest that elkhorn corals (*Acropora palmata)* have built reefs here in the Caribbean for at least the last 10,000 years (Hubbard Pers. comm.) and that populations fluctuate on small scales of time and space. In the decades of the 1960s and 1970s, widespread stands of elkhorn coral were the dominant coral of the shallow near-shore reefs around the USVI and the wider Caribbean. This keystone species, prolific and fast growing, created communities of high structural complexity that supported a broad diversity of vertebrates and invertebrates by providing food, shelter, and breeding grounds.

Throughout the Caribbean, the extensive populations of these colonies have been decimated in the last two decades by White Band Disease (WBD) and hurricane storm damage from David (1979) and Hugo (1989) and several others in the recent past. As a result, the area of these stands and the number of live colonies and live coral cover has been reduced catastrophically, as much as 80 % in some locations. The complex structural community, which supported an extremely diverse flora and fauna, has been destroyed. Few extensive stands exist today anywhere in the Caribbean region. Specific data suggest the current population decline is unprecedented in the past 2500 years, at least at certain sites (Aronson and Precht 2001).

In the genus *Acropora*, reef builder and thicket corals, only three species are found in Atlantic-Caribbean waters; elkhorn coral (*Acropora palmata)*, staghorn coral (*A. cervicornis)* and fused staghorn coral (*A. prolifera)*, a suspected hybrid or intermediate growth form between the others. This alone makes the *Acroporids* rare to begin. Their dominance and abundance on shallow coastal shelves with high wave energy created large, complex habitat patches that are home for millions of marine creatures. These thickets often contain a higher diversity of fish species than in other reefs in comparable areas (Gladfelter and Gladfelter 1978). *A. palmata* also helps create islands, boulder ramparts, and coral cays in exposed locations that provide essential fish habitat (Williams et al. 1999).

SPECIES IN RECOVERY?

On a broad regional scale, very little is known about the present status and trends of surviving *Acroporid* populations. With respect to their biology, the life history strategies are not supportive of rapid recovery from any type of mass mortality (Aronson and Precht 2002). During the past decade however, some small colonies have recruited to former locations and new population centers are developing. In addition, fragmentation, which is the primary means of reproduction for this species, has helped to begin new colonies from broken pieces. Most of these elkhorn colonies seem to be in good condition despite subsequent storms and predation by corallivorous snails. Disease incidence seems very low at present. At least in some locations, this keystone reef-building species appear to be recovering through increasing numbers and size but may still be at risk from sediment deposition. Some data indicate that storm generated fragments grow and cement the reef, creating a strong connection between storm disturbance, survivorship, and persistence of this species (Lirman Pers. com. 2002).

During the past half century, many coral reef communities around the Caribbean and the world have been experiencing increasingly stressful conditions due to a combination of natural and anthropogenic factors (Epstein et al. 1998). The Caribbean is considered a disease "hot spot" as a result of the increase in frequency and the fast emergence of "new " diseases associated with corals (Weil et al. 2000). There is a growing consensus that coral diseases have proliferated in the 1990s (Santavy and Peters 1997, Goreau et al. 1998, Harvell et al. 2000). There are some 30+ coral diseases and syndromes that have been identified. Many may be the same pathogen causing different syndromes or effects. Of these 30+ diseases, only four have their causative agent identified. There is a great inability to explain the source and sudden emergence of the majority of these diseases (Richardson and Aronson 2001).

Current threats to the remaining populations of *Acropora* consist of many factors acting in combination and include hurricanes, disease, corallivory, hyper- and hypothermic stress, sea level rise and pollution (Aronson and Precht 2001). Many of these factors are beyond the reach of management and conservation strategies, but may result from an anthropogenic factor — human impacts. Sedimentation inputs to marine systems from poor or inappropriate land use practices have been shown to have a significant impact on survival and reproduction of many coral species. *Acropora palmata* colonies have been shown to be quite sensitive to the effect of sediment deposition that smothers coral polyps (Rogers 1983). Additionally, Maragos (1974) described an effect whereby coral recruitment is inhibited by sedimentation.

These diseases and the mass mortality of the sea urchin *(Diadema antillarum)* in the 1980s from an unknown pathogen are biological mysteries that may have anthropogenic origins. What is the chemical and biological make-up of the soup of inputs from non-point source pollution.? Could this terrestrial soup coming from our lands and rivers be contributing to the stress and decline of near-shore coral reefs and other community types? Additional research is needed.

ENDANGERED SPECIES CANDIDATE

A 1998 review by the National Marine Fisheries Service (NMFS) began an initial analysis of the major reef-building coral species to determine whether environmental or anthropogenic factors were threatening the survival of certain species and reefs in U.S. waters of the western Atlantic. Corals selected were analyzed for their role in coral reef structure and function. The project identified two Caribbean species, *A. palmata* and *A. cervicornis,* that are of immediate concern based on life history, habitat and distribution, historical abundance, extent of decline, and threats (Bruckner 2002). As a result, these two coral species were added to the candidate species list of the Endangered Species Act (ESA) in 1999 (Federal Register Vol. 64, No. 120, June 23, 1999 pp. 33466-33467).

Large gaps exist in available information about these two species. Much of the information on the decline of these corals is anecdotal. As a result, listing the species on the ESA has been hindered since marine invertebrate listing has more stringent information requirements. Only one other invertebrate has ever been listed, a California species of abalone.

Recently, data from the Atlantic and Gulf Rapid Reef Assessment (AGGRA) has been compiled on the regional status of these species. The "Caribbean *Acropora* Workshop: Potential Application of the U.S. Endangered Species Act as a Conservation Strategy" – brought contributions from coral reef ecologists, biologists, and resource managers with expertise in corals. The authors of this paper were invited to present information on the status and trends of *Acropora* in the Virgin Islands and on a simple new technique for mapping marine populations to gather data to fill these information gaps.

METHODS AND MATERIALS

The spatially referenced mapping of marine populations is in its infancy. Problems of visibility, wave surge, geographic extent, field time and technical needs exist. Using Geographic Information Systems (GPS) and ocean surface Global Positioning Systems (GPS), a new field approach to mapping *Acropora,* assessing present populations and their potential recovery is offered. These data are being collected at two scales; a rapid assessment approach to locate existing population centers with general information on abundance, condition and size, and a finer scale approach that accurately maps all of the colonies within a geographical population. The latter methods collect specific data about each colony in addition to providing a spatial picture of distribution pattern and other characteristics.

Procedures for Monitoring and Mapping Marine Populations

Project Goal — To chart the distribution and status of living elkhorn coral (*Acropora palmata*) in the US Virgin Islands [and perhaps the British Virgin Islands] and, over time, to determine if the amount of elkhorn coral is increasing. "Recovery" of this species would be indicated by an increase in the number and size of colonies (although "condition" of the colonies is also a factor). Although our project focuses on elkhorn coral, the protocol we are using is applicable to *Acropora cervicornis* and *Acropora prolifera.*

Basic Protocol

Scale one — Rapid Ecological Assessment of Acroporid Populations in the VI.

Rapid ecological assessment of the populations of *Acropora palmata* and *Acropora cervicornis* need to be undertaken to understand the size, distribution and health of Acropora in the VI. This protocol is developed to complete a broad survey of shoreline areas throughout the VI, to pinpoint by GPS, known locations of *Acropora* populations, gather preliminary information and provide guidance for more intensive work on selected sites in the future.

1. Shoreline survey of coast of St. Croix, St. Thomas, St. John and the offshore cays using rapid a technique of GPS positioning to the middle of existing populations. Data collected on these trips will be limited to:
Secondary source interviews as to location on map, size, abundance and condition.

Where:		GPS location of existing populations.
Abundance:	High	75 colonies of more in area
	Medium	30 colonies or more in area
	Low	Under 30 colonies in area
Condition:	Healthy (H)	Little disease, predation or dead coral present
	Average (A)	Modest amount of disease, predation and dead coral
	Poor (P)	Unhealthy, large amount disease, predation and dead coral
Size:	Large	1m and larger length, width or height
	Medium	30cm and larger length, width or height

Small: Small crusts, recruits or branches up to 30cm.

This method can be efficiently completed by five persons and a research vessel. Two teams of two field personnel each carry a waterproof GPS unit and a standardized data sheet. One person drives the boat for drop and pickup of the teams. After reviewing existing information sources, digital images, and aerial photographs, potential survey locations are pinpointed. After reaching the potential population location, the two teams can either be dropped at each end of a survey area and swim toward one another, collecting their data or they can be dropped for survey and swim in the direction of the current until they reach the point where the other team is dropped. This would continue in a leap-frog approach along the coast. Both methods are able to cover a significant amount of shoreline in a short space of field time and provide good data on locations. During the swim period, GPS points are taken in clusters of colonies along with data on abundance, condition and size. Any additional comments can be collected. Surveys should last 10 - 15 minutes. Photos can be taken which aid in identification for re-survey. After re-boarding, the teams move on to survey other possible locations and determine where additional fine scale work is done.

Rapid Assessment Tracking Sheet

Acropora palmata, A. cervicornis

- Date ____________
- Time ____________
- Weather ____________
- Island: St. John, St.Thomas, St. Croix Diver 1 ____________
- Site: ____________ Diver 2 ____________
- GPS:Y / N Photo ____________
- Abundance: High (75 col or more)
- Med (30 col or more) ____ Estimated number ____
- Low (Under 30)
- Condition: Healthy (H): Little disease, predation or dead coral
- Average: (A): Modest amount of disease, predation, dead
- Poor (P): Unhealthy, disease dominant, predation, dead
- Size: Large (L): 1m or larger length, width, height
- Medium (M): 30cm and larger length, width, height
- Small (S): Small crusts, recruits or fragments up to 30cm.

Scale two —Fine scale mapping of population patterns and distribution

This can be done efficiently with 4 people, one person taking the GPS waypoints, one taking digital or video images kept in order for identification and two others completing the field sheet for each colony or group of colonies—in general, observers can alternate with each other (it takes much less time to get the waypoint than to fill out the info. in the field sheet).

i) Select the reef zone or area to be studied,
ii) Use Garmin to get a waypoint at the anchor site or mooring,
iii) Locate an elkhorn colony or group of colonies,
iv) Use Garmin to get GPS waypoint,
v) Take digital photo of colony (colonies),
vi) Fill out information in field data sheet (see helpful hints below) on depth, "approximate" measurements {for broad size categories},
vii) Return to office and download waypoints using Ozi Explorer software (available at OziExplorer.com) and ArcView, and
viii) Generate a map (on benthic maps or on geo-referenced aerial photos) with coral distribution, and, if you want, the track of your snorkel survey

Field Sheet for Tracking Elkhorn Corals

Long Term Monitoring

- **Observer** = the person making the observations
- **Location** = the bay or reef where the observations are being made
- **Point or polygon #** = GPS coordinates
- **Number of colonies** = here you indicate if the waypoint refers to one or more colonies; information is listed separately for each colony
- **Depth** = the depth of the colony in feet
- **Height, width, length** = these are approximate maximum measurements (perhaps should be rounded to the nearest 5- 10 cm) [see discussion of *Colony Size Estimates*]
- **Total percent dead** = a rough estimate of the portion of the colony that is dead (old and new mortality). All dead areas on the colonies will generally be covered by algae unless the mortality is recent (usually less than one month old).
- **Recent dead** = areas that are still white and have little or no algal cover indicating that they were killed within the last month or so
- **Snails**= indicate the number of snails on the colony
- **White Band Disease** = record "present" or "absent" = the presence of white band disease should be indicated only if the observer is certain that it is wbd, i.e., if there is a distinct white band separating living from dead coral
- **Photo #** = record the frame number here if a photo is taken
- **Comments** = any additional comments on coral condition or location can be made here. For example, if it is clear that the colony developed from a sexual recruit (a coral larva) then "R" for "recruit" should be indicated; "F" will indicate that the colony is now clearly a fragment (e.g., a broken branch). It is usually not possible to tell if larger colonies are from fragments or sexual recruits. Under comments, you can also note if there has been recent physical damage from storm swells, boats, snorkelers, etc. Here you can also indicate if fireworms were present on the colony.

RATIONALE FOR RECORDING GPS LOCATIONS

It may seem excessive and overly time-consuming to record GPS coordinates for isolated elkhorn colonies and elkhorn stands. However, I believe that we should attempt to get these fixes when possible. A primary product from this study will be a map showing the distribution of living elkhorn, and the recording of GPS fixes will facilitate the preparation of this map. Because elkhorn coral primarily reproduces via fragmentation (in most cases), it is logical to assume that groups of colonies will form the basis of new stands of live elkhorn. It is also possible that groups of colonies will be either more or less susceptible to some of the stresses (for example, predation by snails, disease) than isolated colonies. It may turn out that detailed maps showing distances and compass bearings between colonies/groups will be useful as well in some locations of particular concern. In addition, obtaining GPS coordinates around the perimeter of dense elkhorn stands will allow a calculation of the area of the stand. Density of colonies can also be obtained by recording the number of colonies observed within the surveyed area (as calculated using the GPS waypoints corresponding to the perimeter of this area).

We do not know yet how feasible it will be to return to individual colonies using the waypoints, but we should be able to get pretty close! In any case, with this GIS-based information, we should be able to look at the patterns of elkhorn distribution, and, over time, see if new patch reefs are forming in certain areas. The maps will illustrate patterns in distribution of disease, predation, size, fresh breakage or percent dead. [For example, we might learn that elkhorn colonies in certain locations are much more susceptible to predation or disease. This information can even be linked to genetic studies and other experimental research.] Much of what is currently going on in the developing field of terrestrial landscape pattern analysis will undoubtedly be adapted for marine systems in the future. This approach represents an early step in this direction.

COLONY SIZE ESTIMATES

At least initially, it is advisable to list approximate height, width, and length of individual colonies. It may turn out that the maximum dimension is a sufficient indicator of colony size and that this single measurement can be used. However, analysis of the size data should be conducted to determine this. Although the size groups will be arbitrary, colonies can be assigned to groups of specific dimensions to look at size distribution of colonies. Obviously, over time an increase in the number of colonies in the larger size categories would be an indicator of an increase in abundance. We multiply the two or three measurements to come up with a rough "volume" and then divide the colonies into five arbitrary size categories:

I. Less than or equal to 1,000 cm^3 (10cm x 10cm x 10cm);
II. More than I but less than or equal to 15,625 cm^3 (25 x 25 x25);
III. Larger than II but less than or equal to 125,000 cm^3 (50 x 50 x 50)
IV. Larger than III but less than or equal to 1 m^3 (1,000,000 cm^3) (100 x

100 x 100)

V. All colonies larger than IV

DISCUSSION

Storms, disease, predators, and damage from boats continue to cause elkhorn colony mortality. Although this species has many mechanisms for recovering from physical damage, and fragments can develop into new colonies, it is not clear that it will be successful at recovering from the overall, unprecedented combination of stresses (including predation and disease) to which it is now subjected.

Because this coral species has a relatively high growth rate (up to 10 cm per year), substantial increases could be seen within five years, increases that could be measured and tracked using the surface water GPS methodology. Evidence of a decrease in the abundance of this species could be correlated with the presence of predators, disease, storms, or other factors, although we will not necessarily be able to conclusively show causation. Even under the best of circumstances, it would take decades for elkhorn coral to fully "recover" or return to the abundance seen in the 1970s and 1980s, before its decimation by hurricanes and white band disease.

There is the possibility that the potential recovery underway in the Virgin Islands reflects a very long term trend in variation within a period of 50 - 60 years. This variation would only be detectable with careful, detailed spatial and temporal monitoring over a long period of time. The combination of GIS and GPS can be very useful in charting population trends of marine species using a simple methodology.

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