Integrated Gap Analysis Project: Assessing Conservation of Freshwater, Estuarine, Marine, and Terrestrial Biodiversity

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ABSTRACT

The structure and function of freshwater, estuarine, and marine environments are affected by surrounding and upstream terrestrial ecosystems. Conservation areas often encompass both terrestrial and aquatic resources. Government policy makers and natural resource managers must often consider a complex landscape matrix and need accurate, fine-scale information on the distribution of species and habitats in order to develop conservation management plans. An integrated terrestrial and aquatic GAP analysis project is addressing this need. The goal is to develop a comprehensive set of databases on Puerto Rico and the US Virgin Islands' freshwater and marine resources – including habitat description and mapping, species distributions and conservation status, and protected areas and conservation priorities – combined with existing Puerto Rico and USVI terrestrial GAP databases, to conduct integrated analyses of gaps in conservation protection. As a start to this project we have complied an annotated list of over 1200 animal species associated with terrestrial and aquatic habitats in Puerto Rico and the US Virgin Islands. We have modeled the distributions of over 200 of the terrestrial species and are working on 200 aquatic species and their habitat distributions. This will be used to develop species range maps and predicted distributions, which will then be assessed in terms of the degree to which species and habitats are protected for conservation by reserves and other protected areas.

KEY WORDS: Marine Protected Areas, conservatioon, Biodiversity, GAP analysis

Análisis Integrado del Proyecto Gap: Determinación de la Conservación de la Biodiversidad de las Ecosistemas Agua Dulce, Estuario, Marina, y Terrestre

PALABRAS CLAVE: APMs, conservación, biodiversidad, análisis integrado Gap

Analyse Intégré de Projet Gap: L'Evaluation de la Conservation de la Biodiversité des Écosystèmes d'Eau Douce, d'Estuaire, Marine, et Terrestre

MOTS CLÉS: Conservation, biodiversité, analyse intégré Gap

INTRODUCTION

The GAP analysis program (Scott et al. 1993, Jennings 2000) was initiated in the early 1980s as a landscape approach to conservation planning with the following objectives:

i) To map distributions of animal species and habitats,
ii) To map conservation areas, and
iii) To assess the relationships of animal and habitat distributions with respect to protected areas.

The program was initiated as state-wide assessments and has progressed to regional and national scales over the last two decades. It is administered by the U.S. Geological Survey and is an open, collaborative program. The mission of the National Gap Analysis Program is to conduct regional assessments of the conservation status of native animal species and natural land cover types in order to determine "gaps" in the conservation of species and habitats, and to assist in conservation planning and management. The Caribbean has been recently included with implementation of the Puerto Rico and U.S. Virgin Islands projects (Gould et al. 2007, Gould et al. 2010) which focused on terrestrial species and habitats, and this has been expanded with the initiation of the Integrated Terrestrial-Aquatic Gap Analysis Project (Integrated Gap) described here.

The coastal zones are perhaps the earth's most complex landscapes physiographically, ecologically and socially. They harbor biologically diverse reef, estuarine, and wetland systems, they exchange materials and energy with deep ocean and terrestrial systems, they are home to perhaps 60% of humanity (Sloan et al. 2007) and have always been a culturally important landscape. The structure and function of freshwater, estuarine, and marine environments are affected by surrounding and upstream terrestrial ecosystems. Conservation areas often encompass both terrestrial and aquatic resources but integrated land-sea conservation planning efforts are rare (Stoms et al. 2005). With increasing demands on ecosystem services and open space - and the structural and ecological links between aquatic and terrestrial systems - conservation management plans and environmental laws may be more effective when considering these as an integrated system rather than separate systems. As such there is a need for research in conservation biology that includes both of these systems. The Integrated Gap described here is addressing this need. The goal is to develop a comprehensive set of databases and carry out an assessment on the conservation status of the terrestrial, freshwater and marine resources of Puerto Rico and the US Virgin Islands.

The objectives are to develop databases on Puerto Rico and the US Virgin Islands' freshwater, estuarine, and marine resources – including habitat description and mapping, species distributions and conservation status, and protected areas and conservation priorities — combined with existing Puerto Rico and USVI terrestrial GAP databases — to conduct integrated analyses of gaps in conservation protection for the U.S. Territories in the Caribbean. The project includes the compilation of existing information, creation of new information, and analyses of landscape patterns in biodiversity and conservation management.

APPROACH AND COMPONENTS

Four main tasks related to compilation include:

i) Gathering information on the *natural history* of selected species, including taxonomic information, conservation status, global and local range information, habitat affinities, and a species bibliography;
ii) Compiling information on *species occurrences* – including point data, published range maps, and site species lists that can be documented with a date, observer, and source;
iii) Compiling all geospatial data related to habitat characteristics - and often manipulating these data and creating new data to develop a hierarchical geospatial data set that relates to the scales at which organisms respond to the environment, at which local management occurs, and can be used for regional and global assessments; and 4. Compiling information on protected areas boundaries, management, and priorities – including parks, reserves, regulated areas, and traditional uses.

The primary modeling task is to develop predicted species distribution maps based on species-habitat relationships. We will use both deductive and inductive modeling techniques. Deductive methods were used in the PRGAP terrestrial project and involve species habitat models derived from the literature and expert opinion based on the occurrence of habitat within the predicted range (based on our occurrence data) of each species. Inductive modeling will be used for species where appropriate data is available and will be based on the statistical relationships between species occurrence and geospatial layers of habitat characteristics. The statistical relationships will then be used top extrapolate species distribution to areas for which we do not have occurrence information.

The predicted species distributions and habitat mapping layers will be used in a "Gap" analysis to determine the relationship of species and habitats with protected areas. We will address the questions: " To what extent do protected areas overlap with species distributions, biodiversity hotspots, and habitats of interest?" and "Where are there gaps in conservation protection?"

To initiate this project we have compiled an annotated list of 1,250 animal species associated with terrestrial and aquatic habitats in Puerto Rico and the US Virgin Islands.

We have modeled species distributions and assessed the conservation status of 200 terrestrial species and we have selected an additional 200+ aquatic species - including fish, mammals, reptiles, birds, corals and other invertebrates - as components of the Integrated Gap.

Expected products and outcomes will be individual maps of species range (coarse scale) and species distribution (fine scale) for over 400 species, assessments of biodiversity (species richness) patterns and controls at fine and coarse scales, geospatial information on aquatic habitats, reports on species natural history, and information in biodiversity databases useful locally for research and management and integrated in the GAP National Protected Areas Database and the Gap National Landcover Database.

Developing Species Lists

The first step in assessing the conservation status and mapping the distribution of species in a region is to define the species of interest. The GAP motto is "keeping common species common" and typically GAP projects select species based on occurrence and breeding status, the main concern being regularly occurring species that breed in the study area and that might become threatened or endangered in the future if no proactive steps are taken to promote their conservation. During the terrestrial component of our project we selected endemic, threatened or endangered, common breeding residents, breeding migratory species, ad the most common non breeding migrants. We also mapped established exotic species of importance to natural resources management. This resulted in the development of a taxonomic database of 437 terrestrial vertebrates occurring in the area, a subset of 177 species for gap analysis, and a subsequent addition of additional important migratory species. Aquatic environments represent a challenge in part because of the greater number of species. Fish, for instance, represent 714 species of all the species listed in our database for Puerto Rico and the US Virgin Islands. In addition, there is no standard reference of classification of aquatic species by occurrence status. In other words, we have no reference that we could use to discriminate between common or rare species. From the total number of species we made a selection of a little over 200 species based on the concerns of the Integrated Gap project and the concerns of our collaborating agency the DNER. The main criteria were to include all freshwater and marine recreational fish, commercial fish, endemic and endangered species, and the most common species. Additionally we included all marine mammals, sea turtles, two corals, and important invertebrate species. The list has gone through expert review and already some fisheries experts and researchers have recommended that we add species to the list that are of importance commercially and some species that play an important role in reef ecosystems.

Species Natural History

Scientific literature is the cumulative, published experience of specialists in the field (Csuti and Crist 1998, Jennings 2000) and for the GAP Analysis Projects it represents a major source of information. We are developing an Access database with information on species natural history, taxonomy, conservation and occurrence status and habitat associations. On the one hand, this database represents and library of information that will be useful for future reference. However, the primary purpose fore compiling the information is that the habitat information gathered therein allows us to identify important habitat characteristics for each species and develop appropriate geospatial information on habitats required for species habitat distribution modeling. We develop deductive models based on the assumption that particular biophysical and historical characteristics (*e.g.* temperature, soil characteristics, elevation, land use history, surrounding terrain) influence the species presence in a particular area and can be mapped (Csuti and Crist 1998). The database is developed using extensive literature including peer reviewed journals, reference books, theses, government reports and authoritative internet databases. We prioritize information derived from studies developed in Puerto Rico and US Virgin Islands as habitat affinities may vary geographically, but include studies in the Caribbean or across the range of any species. More specifically, we are gathering information on species requirements including benthic cover, water temperature, depth, salinity, and water current speed, among others. In addition, we take into account habitat use throughout species life stages (eggs, larvae and hatchlings, juvenile, and adults) and habitat use for different activities (migration, reproduction, foraging, and resting). Finally, individual species accounts are developed which summarize all the compiled information. These are reviewed through an expert review process and form the basis of deductive species-habitat models developed for each species.

Habitat Modeling

Freshwater habitats — Freshwater bodies of Puerto Rico and US Virgin Islands are classified by international organizations as subtropical or tropical coastal rivers (Abell et al. 2008, WWF/TNC 2008, WWF 2001). However we need a more detailed classification of freshwater habitats for the purposes of this project. Characterization of habitats within a watershed's environment will be conducted by using a modification of the hierarchical spatial nested framework proposed by Frissell (1986). In PR and USVI, watersheds are used as conservation and management units by government agencies. We decided to characterize freshwater habitats using watersheds as the highest level in the framework so as not to duplicate work efforts and to add to the existing knowledge base.

In our hierarchical framework, the watershed level is followed by a lower level represented by a stream network (10^3 m), and finally, at the lowest level by stream segments (10^2 m). In order to characterize levels, we look for landscape features that control the processes of formation and development of habitats at different temporal and spatial scales (Frissell 1986). For example, at the watershed level, stream channel slope changes according to climate, geology, and initial relief, but, as time goes by, the slope becomes more stable and is considered an independent variable that controls channel morphology and sedimentation (Frissell 1986). This framework offers the advantage of measuring the human footprint at the stream segment level by including other landscape features that play a role in modifying riverine areas, such as land cover and land use. Characterization at watershed levels will be based on geology, climate, soil, and land cover classes; at stream network level we will follow Strahler's (1964) guidelines of stream order, elevation, and slope gradient; and at the stream segment level by the slope gradient per segment, landform, land use, and vegetation type (land cover) associated to adjacent riverine areas defined by a buffer zone. Characterization and classification of freshwater habitats will be based on units with relative homogeneous landscape features by using ordination analysis (Figure 1).

Marine habitats — We are identifying classification frameworks for marine habitats using the influence that seascape features have on the distribution of species in marine environments as a main criterion. For example, habitat rugosity and structural complexity influence shelter capacity for fish species determining the number of species present in different marine habitats at the 10 -100 m scale. However, their effect is not relevant at bigger scales of

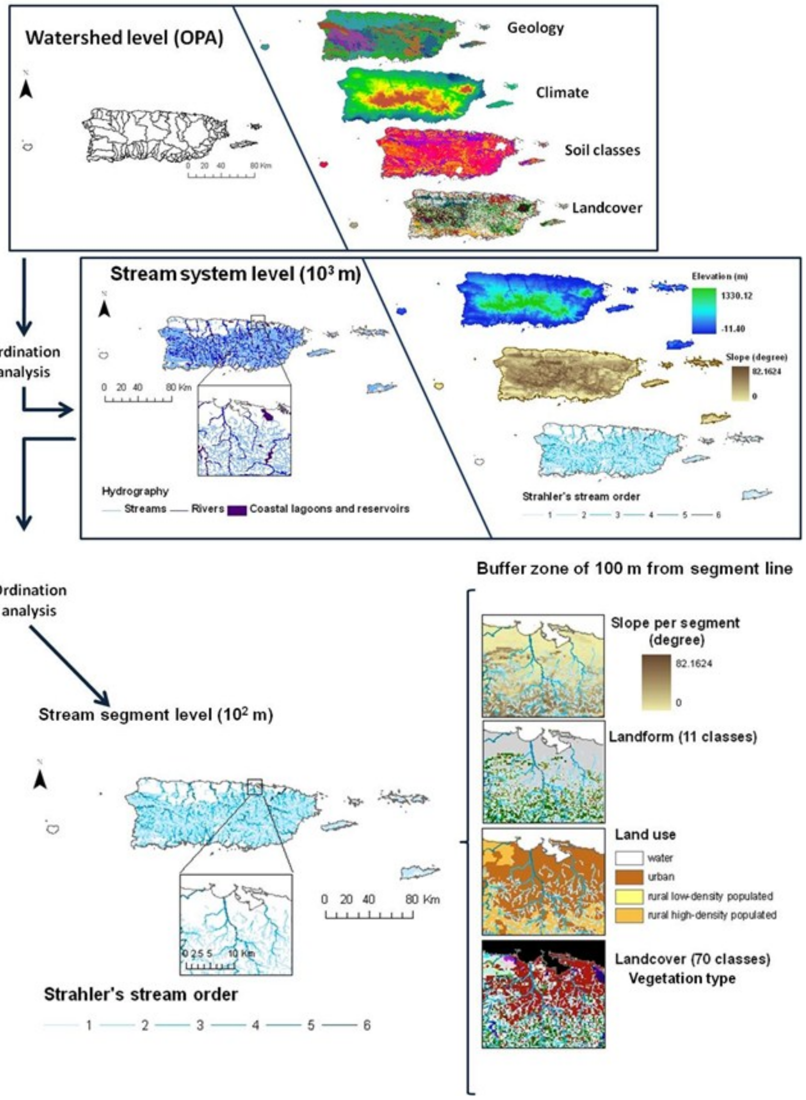

Figure 1. A hierarchical spatial nested framework that include all habitats within the watersheds environment by following the framework proposed by Frissell (1986): Watershed level, stream system and stream segment systems. Freshwater habitats are classified by establishing units with relative homogeneous landscape features by using ordination analysis.

more than 100 m. Other variables that influence the number of species at the 10 -100 m spatial scale are depth, live coral cover, and microhabitat availability (Mellin et al. 2009).

We are identifying existing thematic layers or developing derivates of existing ones based on the seascape features that are known to influence the presence and distribution of fish, mammals, reptile and invertebrate species in marine environments. We are also standardizing these layers with the best resolution possible to map potential habitats and modeling distribution of species listed in the project.

In our preliminary search we have found bathymetric data for Puerto Rico at different resolutions such as 90 m^2, 10 m^2, and 4 m^2. We have derived sea bottom rugosity and slope layers at the same resolution of the bathymetric layers by using the Benthic Terrain Modeler (BTM) and the Spatial Analysis tools of Arc Map. We expect to have high resolution bathymetry for coastal areas and a coarse resolution for areas located more than 3 miles away from the coast.

In order to facilitate the development of species habitat distribution models, the benthic habitats, zones and biological cover classifications established by NOAA

(Kendall et al. 2001, Costa 2009, Zitello 2009) for Puerto Rico and the USVI, and worldwide by the IUCN, were included in the species accounts database. Therefore, when the information is available we will be able produce potential habitat and species distribution maps for each life stage.

Currently, we are exploring methodologies to identify benthic zones for areas that were not included in benthic habitat mapping, i.e., over 150 m deep, identifying layers for moderate to deep habitats, and remote sensing information such as sea surface temperature (SST), chlorophyll, light, wind speed, direction, and currents to improve our work on species habitat modeling.

Species Occurrence and Distribution

One of the key steps to achieve our goal of mapping species distributions across the region is to compile and manage information on aquatic species occurrence in order to model their distribution. This data comes from a variety of sources and in a variety of formats. Sources include local and federal agencies such as the Puerto Rico Department of Natural and Environmental Resources (DNER), U.S. Fish & Wildlife Service (USFWS), and the National Oceanographic and Atmospheric Administration (NOAA) departments including the National Marine Fishery Service (NMFS), the Biogeography Branch (CCMA), and the Caribbean Fishery Council. In addition, non-governmental organizations such as the Puerto Rico Conservation Trust, the Puerto Rican Ornithological Society, and other groups related to conservation are collaborating with the Gap Project, providing occurrence records data, and reviewing distribution maps. Scientific researchers in marine science, limnology, or related fields of study are valuable collaborators, adding field occurrence records to the project from their own research projects. Species occurrence records and other sensitive information are managed in a confidential manner.

The most valuable sources of records are established in natural resource databases which have been compiled and maintained by government agencies. These databases sometimes contain geographically referenced data and provide information about each record such as scientific names of the species, observers, dates, geographic coordinates, abundances, habitat descriptions, and other factors. Peer reviewed articles on aquatic sciences, fisheries, and environmental issues represent another major source of data. Some of the published articles provide occurrence maps that can be easily geo-rectified and digitized with Geographic Information System (GIS) software and later incorporated into the main project database. Research groups in universities and individual researches are another important data source. Additional sources of information are found on internet databases associated with studies on aquatic species and conservation that are sometimes kept by non-government organizations. Seamap.org, Fishbase.org, and Reef.org are some examples. These databases obtain the records from local and regional collaborators and volunteers, who are the principal experts on particular species and are therefore considered reliable information sources for our analysis.

Unfortunately, spatially referenced species occurrence data is sometimes hard to obtain, and in most cases it is quite localized, which means that some areas in the region have been given more attention over others. Regional surveys of aquatic species are rare and sometimes incomplete. In addition, some species get more attention from researchers and natural resources agencies than others (*e.g.*, threatened species). These are some of the reasons why great effort goes into identifying data sources, compiling species occurrence records, extracting the pertinent information, and documenting the process in order to make the best use of it.

All occurrence records are spatially referenced in a geospatial database in order to attribute a hexagon grid for each individual species, which is the foundation of the species range maps (Figure 2). The hexagons in the grid are classified confirmed, probable, predicted, excluded, historic – depending on the context of the occurrence record and subject to expert review.

Modeling Species Distributions

To predict species distributions we combine occurrence data with geospatial environmental data. Environmental variables have been employed in terrestrial species distribution modeling (Gould et al. 2008, Pearson 2007) and most recently in cnidarian species (Elkhorn coral) models in Puerto Rico (Schärer et al. 2009). Generally, the variables tend to describe abiotic conditions related to the species habitat (Pearson 2007), but biotic conditions such as land covers describing the major habitat types, have also been considered. Schärer (2009) combined parameters such as bathymetry, benthic habitat, and species presence data by colony density/area to delineate the potential habitat for coral species. For larval stages of species included in the Gap analysis, other parameters, such as water temperature and water current dynamics, can be incorporated into the model to identify the important characteristics of fish aggregation areas or coral spawning areas. Salinity range measurements are imperative for modeling estuarine species distributions because many of the species that are sustained by this habitat type are known to be affected by this parameter. Rincón (2009) integrated rugosity, bathymetry, and benthic habitat characteristics to describe the distribution of Hawksbill Sea Turtles in canal Luis Peña Marine Reserve on Culebra Island, PR. Also, biotic interactions have been used in terrestrial species modeling to determine distributions (Pearson 2007). As an example, we could model biotic interactions between *Acropora* species, some fishes and invertebrates. The use of environmental or habitat associations along with occurrence data to model and map species habitat distribution is limited to the availability of digital GIS datasets that describe environmental parameters and natural habitats. Obtaining, or when possible, generating these datasets is crucial to accomplish this goal.

Every model will be based on species occurrence, local and regional literature, professional judgment, and peer reviewers. Factors that are positively associated and negatively associated with probable occurrence of a species can be considered (as in Myers *et al*. 2000). A group of experts will also provide suggestions for changes in occurrences or range distributions and model parameters.

PROTECTED AREAS AND GAP ANALYSIS

We have developed geospatial information on the terrestrial and marine protected areas for Puerto Rico and the US Virgin Islands but our challenge is to better understand the role of protected areas, laws, regulation, and historic and current use of aquatic resources in the conservation of species and protection of habitats. To this end, we are compiling information that will lead to a summary of not only protected areas but of the state of conservation as it relates to protected area boundaries and the distribution of species and habitats.

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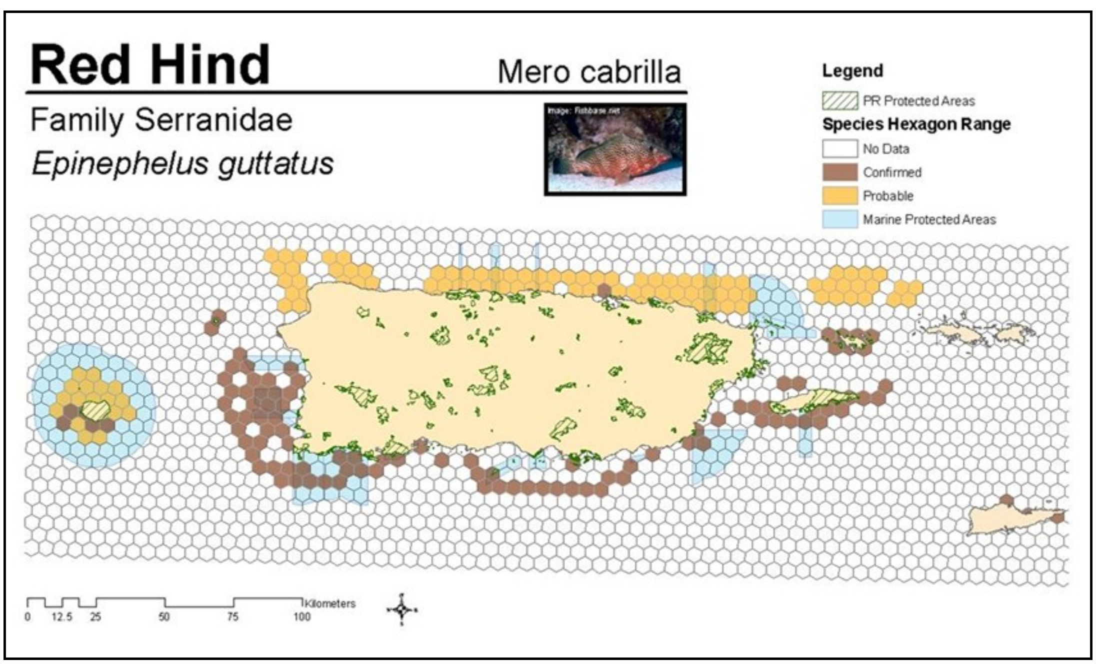

Figure 2. Example of occurrence map for the red hind (*Epinephelus guttatus*).

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