# Multiple Scale Integrated Range Maps for Modeling Predicted Distributions of Vertebrate Species in the U.S. Virgin Islands

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## Introduction

Biodiversity assessments and conservation management benefit from spatial models that predict species distributions across ranges, interpolating between known occurrences and predicting distribution where suitable habitat occurs within an expected range (Karl et al. 2000, Ferrier 2002, Scott et al. 2002). One of the first steps in a predicted distribution model usually involves development of a species range map used to constrain its distribution. Species range maps have an associated scale and resolution. Occurrences at a point often are extrapolated by attributing a polygon, for example counties, hexagons, or watersheds (Scott et al. 1993; Boykin et al. 2007) using Geographic Information Systems (GIS). Precision and bias of predicted species distributions can be affected by the minimum mapping unit (MMU) used in determining a species range (Stoms 1994, Stockwell and Peterson 2003). Species range maps and distribution models have been developed at many scales and for various uses. There is no consensus about the best range map unit and there is no scale that satisfies all scenarios. This has been described as the modifiable areal unit problem (MAUP) which recognizes a scale effect (Green and Flowerdew 1996). This scale effect is the tendency to obtain different results with the same data (i.e. species occurrence records) when it is grouped at different levels of spatial resolution. A relatively large MMU decreases the amount of information needed to systematically assess species occurrence over an area and develop a range map, but decreases the precision of information. Conversely, a small MMU increases the amount of information needed and may increase the ultimate resolution of the range map, potentially making it a more useful tool for land managers. Typically, the scale selected for an analysis is influenced by size of the area of interest, data availability, and expected use of the predicted distributions.

### The Problem

Conservation biologists do a better job of predicting species distributions at coarse scales (continental, regional) than at fine scales (subregional, within reserves or potential reserves) because at coarse scales distributions are constrained by large scale latitudinal gradients as well as other gradients such as climate, seasonality, geography, major vegetation formations, and biome limits. However, land managers and decision makers increasingly are asking researchers for detailed information about the likelihood of particular species presence or absence, species richness, and biodiversity in general for specific land areas as they make management decisions and develop conservation priorities. At fine scales, variability and uncertainty of species distributions becomes more apparent in modeling predicted species distributions and this has an impact on the utility of these predictions as a tool in conservation. Examples of this variability and uncertainty include the amount of area occupied by a species within its range, and the degree of uncertainty about where within its range a species occurs. This variability depends on the ecology of the species, whether the species is a generalist or not in terms of habitat preference, the underlying ecological heterogeneity of the landscape, and the resolution of the range map, (i.e. the size of the minimum mapping unit). The uncertainty of biodiversity assessments is compounded by the variability among species in how they perceive, occupy, and move about the landscape and in the dynamic nature of landscapes at fine scales.

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## Background

The idea behind integrating habitat maps with range maps is that the range map constrains the geographic distribution of a species while habitat maps depict landscape heterogeneity within each minimum mapped unit in the range map. This heterogeneity is ideally described by models of wildlife-habitat relations so that species distribution can be predicted at a fine scale within the known range. A species predicted distribution is often at the scale of meters (i.e. Landsat or other remotely sensed imagery) as opposed to kilometers (i.e. counties, hexagons, watersheds) for range map MMUs. The ideal range map unit is at a scale for which we can assume that where a species occurs within a mapped unit, it occurs throughout that unit, wherever there is habitat available.

As an example of mapping species ranges, most state GAP projects have used a hexagon shape based on the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP) typically used in Gap Analysis (White et al. 1992, Scott et al. 1993). These hexagons have an area of 648 km$^2$. The 50 U.S. states range in area from 4,000 km$^2$ to more than 1.7 million km$^2$ and the mean number of hexagons needed to cover a state is just over 300 (this is a low estimate as hexagons along a state boundary often extend to adjacent states).

In the recently completed Puerto Rico Gap Analysis Project (PR-GAP), we developed range maps for vertebrate species occurring on the islands of Puerto Rico, Vieques, Culebra, Mona, and a number of smaller islands within the commonwealth (Gould et al. 2008). In accomplishing this we addressed the issue of selecting an appropriate MMU for developing range maps. Puerto Rico has an area of 9,000 km$^2$. Using the 648 km$^2$ EMAP hexagons recommended as standard GAP protocol (Scott 2007) would have given us few map units and a limited view of the variation in species ranges within Puerto Rico. Additionally, EMAP represents only the conterminous United States and in lieu of EMAP coverage in the Caribbean, we developed the PRGAP-HEX grid with a resolution of 24 km$^2$ (Figure 1) by tessellating a larger hexagonal grid (an extension of with the EMAP grid to the Caribbean) used in U.S. Forest Service Caribbean Forest Inventory and Analysis (FIA). This hexagon grid covers Puerto Rico and the United States Virgin Islands (USVI) and provides a uniform unit of area to represent the geographic range of vertebrate species across a very heterogeneous landscape—with sharp ecotones over short distances. The final set of 483 hexagons were selected for PRGAP, including 305 occurring only over land, 161 over coastal areas, and 17 over open marine areas with small reefs and cays. The resulting range maps and predicted species distributions have been accepted and used in Puerto Rico by wildlife biologists, students, researchers, land managers, and government agencies.

We are now in the process of conducting a gap analysis of the USVI and have addressed essentially the same question, i.e. "What is the appropriate minimum mapping unit for developing range maps for the USVI Gap Analysis Project?"

## Study Area

The U.S. Virgin Islands are located in the Caribbean in the westernmost section of the Lesser Antilles. They include the three main islands of St. Thomas, St. John, and St. Croix. The main islands are surrounded by a considerable number of cays, several of which harbor endemic and endangered species. The total area of the USVI is less than 350 km$^2$ (Table 1), more than an order of magnitude smaller than the

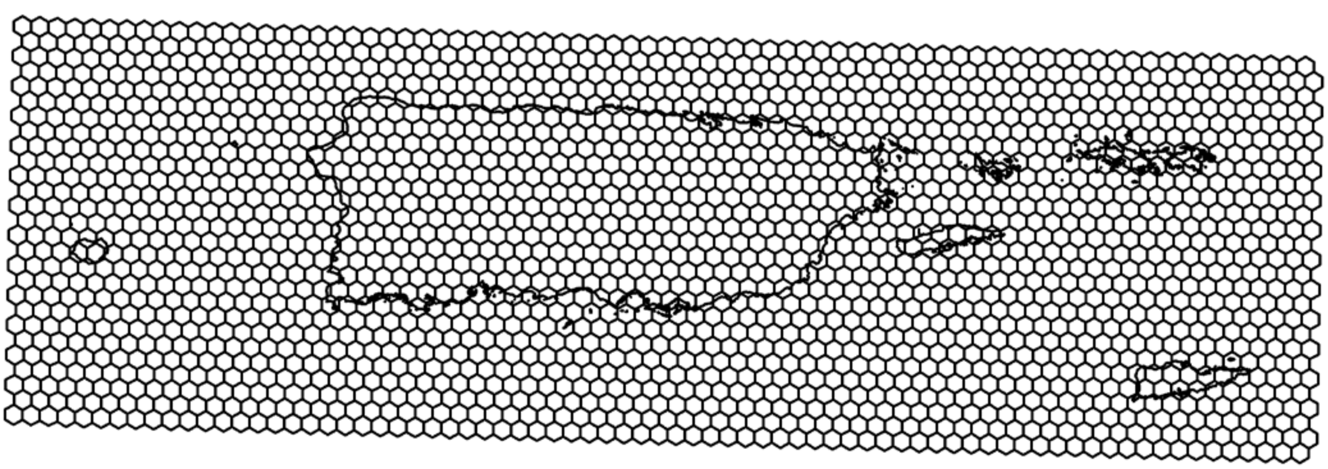


**Figure 1.** Modified EMAP hexagons covering the Puerto Rican and U.S. Virgin Island archipelagos. Each hexagon has an area of about 24 km$^2$.

Puerto Rico, yet with relatively high biodiversity (Figure 2) and substantial levels of herpetofaunal endemism for such small islands (Figure 3). As on many other islands of the Caribbean, the USVI natural habitats are under a great deal of pressure from development. Historically, the islands were heavily impacted by agricultural activity (Weaver 2006), with development and urbanization increasing so that a number of species are threatened or endangered locally (Table 2). Distributions of species among the islands and cays are strongly affected by each species' dispersal abilities, human and natural disturbances (i.e. hurricanes), and variability in habitat condition among islands.

**Table 1.** Minimum map unit size, number of map units, and area in hectares for large and small hexagons and watersheds for St. Thomas, St. John, St. Croix, and the total for the U.S. Virgin Islands.

[**Abbreviations**: HUC, hydrologic unit code; ha, hectare; MMU, minimum map unit; $km^2$, square kilometer; USVI, U.S. Virgin Islands]

| | HUC 10 watersheds | | | | |
|---|---|---|---|---|---|
| | Large hexes | Small hexes | With cays | Without cays | Total area (ha) |
| MMU area ($km^2$) | 24 | 2 | variable | variable | |
| St. Thomas | 21 | 112 | 77 | 13 | 8,186 |
| St. John | 9 | 55 | 31 | 10 | 5,070 |
| St. Croix | 23 | 155 | 30 | 26 | 21,715 |
| USVI | 53 | 322 | 138 | 49 | 34,972 |

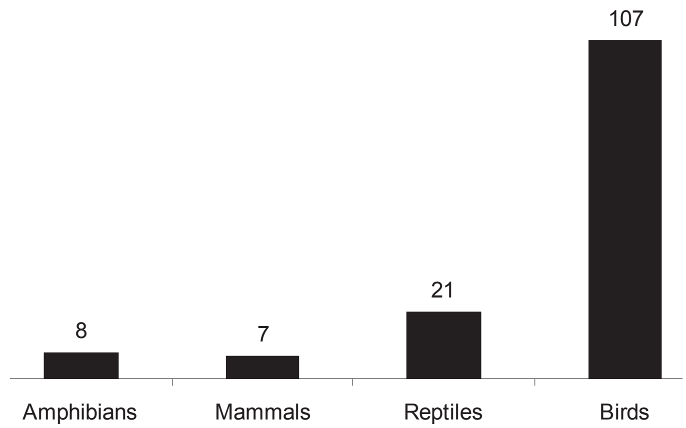



**Figure 2.** One hundred forty-three species of terrestrial vertebrates occurring in the USVI have been selected for analysis for the USVI GAP project. The majority are bird species, followed by reptiles, amphibians, and mammals.

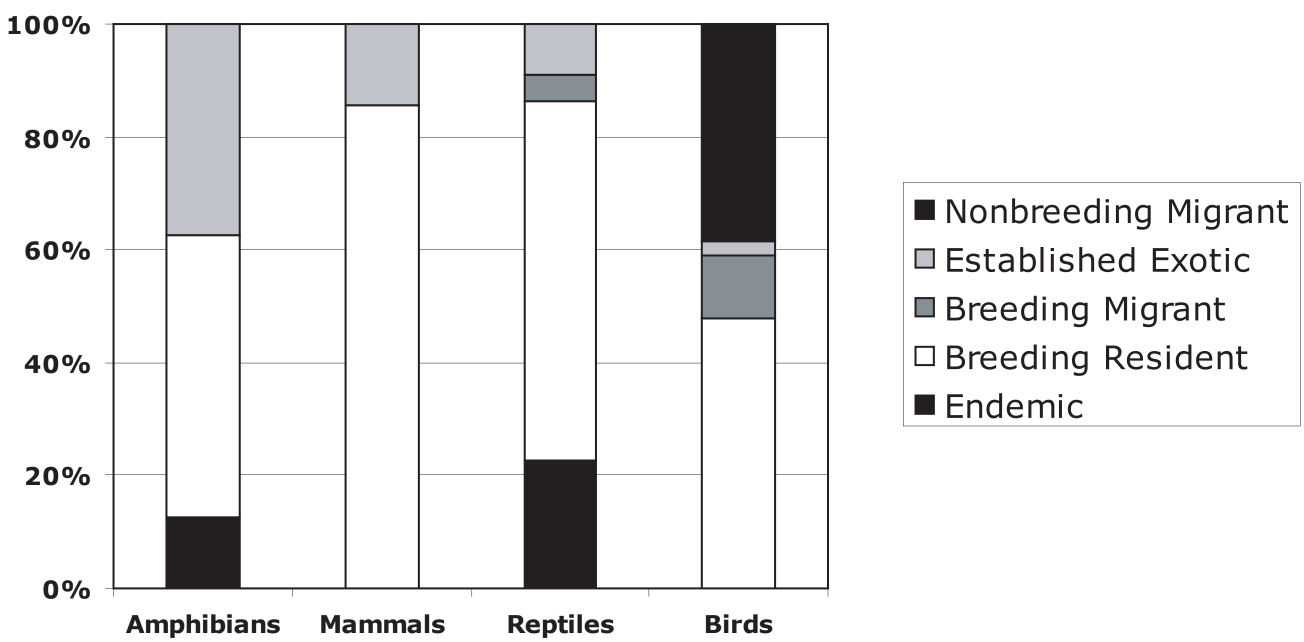



**Figure 3.** Percentage of number of species which are endemic, breeding resident, breeding migrant, established exotic, or nonbreeding migrant for amphibians, mammals, reptiles, and birds in the USVI. Ten to 20 percent of the amphibians and reptiles are endemic species. The majority of all species are breeding residents. Breeding migrants include a number of bird species and marine turtles (which use terrestrial habitat for nesting).

**Table 2.** Eight endangered (EN), threatened (LT) species as listed by the U.S. Environmental Protection Agency and 27 endangered (E), territorially endangered (TE), or threatened (T) species as listed by the Virgin Islands Endangered Indigenous Species Act.

[**Abbreviation**: USVI, U.S. Virgin Islands]

| | Scientific name | English common name | Spanish common name | Status USVI | |
|---|---|---|---|---|---|
| **Birds** | *Pelecanus occidentalis* | Brown Pelican | Pelícano Pardo | E | EN |
| | *Puffinus lherminieri* | Audubon's Shearwater | Pampero de Audubon | TE | |
| | *Otus nudipes* | Puerto Rican Screech-Owl | Múcaro Común | TE | |
| | *Chordeiles gundlachii* | Antillean Nighthawk | Querequeqúe Antillano | TE | |
| | *Phaethon lepturus* | White-tailed Tropicbird | Rabijunco Coliblanco | TE | |
| | *Anthracothorax dominicus* | Antillean Mango | Zumbador Dorado | TE | |
| | *Rallus longirostris* | Clapper Rail | Pollo de Mangle | TE | |
| | *Catoptrophorus semipalmatus* | Willet | Playero Aliblanco | TE | |
| | *Sterna antillarum* | Least Tern | Gaviota Chica | TE | EN |
| | *Geotrygon mystacea* | Bridled Quail-Dove | Paloma Perdíz de Martinica | TE | |
| | *Patagioenas leucocephala* | White-crowned Pigeon | Paloma Cabeciblanca | TE | |
| | *Ardea herodias* | Great Blue Heron | Garzón Cenizo | TE | |
| | *Oxyura jamaicensis* | Ruddy Duck | Pato Chorizo | TE | |
| | *Anas bahamensis* | White-cheeked Pintail | Pato Quijada Colorada | TE | |
| | *Nycticorax nycticorax* | Black-crowned Night-heron | Yaboa Real | TE | |
| | *Egretta thula* | Snowy Egret | Garza Blanca | TE | |
| | *Fulica caribaea* | Caribbean Coot | Gallinazo Caribeño | TE | |
| | *Sterna dougallii* | Roseate Tern | Palometa | T | LT |
| **Bats** | *Stenoderma rufum* | Desmarest's Fig-eating Bat | Murciélago Rojo Frutero | TE | |
| | *Noctilio leporinus* | Greater Bulldog Bat | Murciélago Pescador | TE | |
| | *Brachyphylla cavernarum* | Antillean Fruit-eating Bat | Murciélago Cavernícola | TE | |
| **Reptiles** | *Ameiva polops* | St. Croix Ground Lizard | Siguana de Santa Cruz | E | EN |
| | *Epicrates monensis granti* | Virgin Islands Tree Boa | Culebrón de la Isla Virgin | E | EN |
| | *Dermochelys coriacea* | Leatherback Sea Turtle | Tinglado | E | EN |
| | *Eretmochelys imbricata* | Hawksbill | Carey | E | EN |
| | *Mabuya mabouya sloanei* | Slippery-backed Mabuya | Lucía | TE | |
| | *Chelonia mydas* | Green Sea Turtle | Pejeblanco | T | LT |

## Methods

We developed and followed four guidelines in selecting an appropriate scale for assessing species geographic ranges:

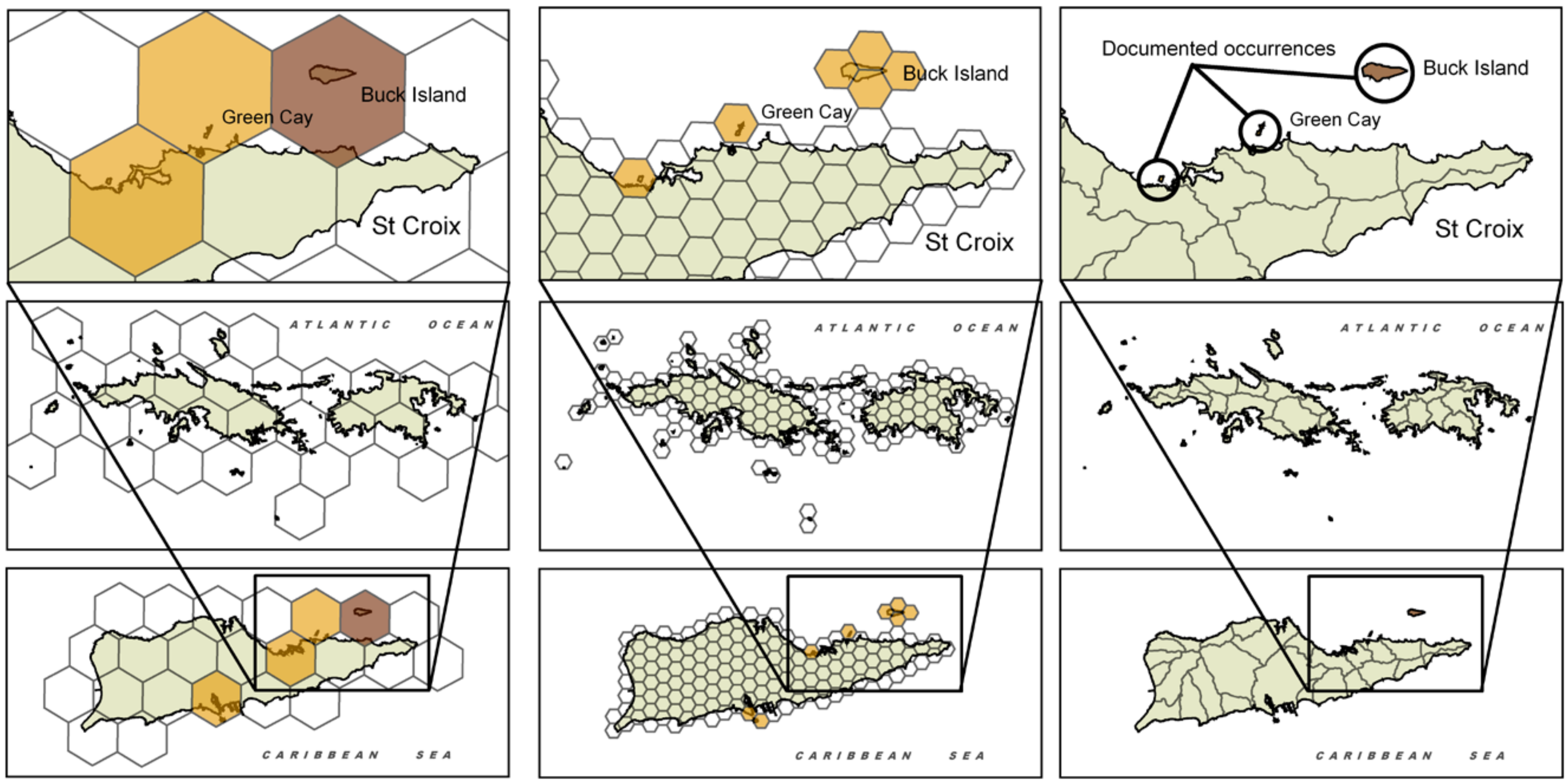
- Map units are large enough that information on species occurrences is available or can be systematically obtained for most map units.
- Map units are compatible with regional (i.e. Caribbean) analyses of species ranges.
- Map units are small enough that we can assume that species occur in the entire suitable habitat within the map unit.
- Map units allow for distinguishing different species ranges—as understood by wildlife biologists, land managers, or other experts—throughout the mapped area.

These guidelines vary with species and ultimately a best fit must be decided upon that is acceptable for most of species within our study.

We integrated our experience from Puerto Rico GAP with ideas and information derived from stakeholders meetings in the USVI to develop a flexible system of creating range maps of different resolutions using documented and probable species occurrence records and we describe that system here. The stakeholders gave us the following suggestions regarding range maps for the USVI:

- Decrease size of hexagon mapping unit to increase accuracy of vertebrate species occurrence mapping. Some species occupy very small regions that may not be adequately mapped with the original hexagon size (24 $km^2$).
- Include watersheds as distinct entities in analysis due to significant differences in amount of precipitation each collects throughout the year (i.e. we may use watersheds as a surrogate for climatic subregions as they vary predictably in moisture availability and vegetation).

We have decided to use a set of multiple scale integrated mapping units (Figure 4) for mapping species ranges in the USVI.




a. b. c.

**Figure 4.** Three sets of minimum map units developed to display species ranges for the USVI. These include the (a) large hexes (24 km$^2$ area) contiguous with the PRGAP hexagons and range maps, (b) small hexagons (2 km$^2$ area) nested within the large hexagons, and (c) HUC 10 sub watersheds. This example shows the St. Croix ground lizard (*Ameiva polops*), which occurs on three small cays off the island of St. Croix. The range of the lizard is represented by about 75 km$^2$ (36 km$^2$ occurring over land) using the large hexagons, 8 km$^2$ (2.1 km$^2$ occurring over land) using the small hexagons, and less than 1 km$^2$ when restricted to the three cays on which it occurs. In this instance, for a species limited in distribution by the water barrier, we can use the watershed range map to depict its range and restrict its predicted distribution to suitable habitat within that range.

## Range Maps

We developed three integrated sets of minimum map units to display species ranges for USVI and model species predicted distributions. These include a grid of 24 $km^2$ hexagons contiguous with PRGAP hexagons and range maps, a grid made up of 2 $km^2$ hexagons nested within larger hexagons, and subwatersheds and cays (WRI/NOAA 2005). The subwatersheds are Hydrologic Unit Code (HUC) 14 (NHD 2005). The three sets of map units are integrated in the sense that the occurrence data for any species (confirmed point locations, areas, or probable occurrences based on literature or expert opinion) is intersected with each set of map units to produce three distinct range maps for each species in our analyses. The different range maps have advantages of their own and we hope will subsequently prove useful as we develop species predicted distributions in USVI and products for land managers, research and conservation:

- The 24 $km^2$ hexagon grid will allow us to assess species distributions for Puerto Rico and USVI as a single integrated dataset. Several species occur across the suite of islands, and for all species we can put their range in a regional perspective. The U.S. Virgin Islands are part of the Puerto Rican bank and share a similar geological history, although St Croix has been disconnected from other islands for a much longer period dating back to at least the Pliocene, around two to five million years ago (Heatwole et al. 1981). In addition, USVI shares many vertebrate species with Puerto Rico. The 24 $km^2$ hexagon grid, however, was considered too big to map species ranges in USVI by stakeholders. In using this grid the islands are not covered by a significant number of hexagons; for example St John is covered by seven 24 $km^2$ hexagons. This could lead to excessively overestimating the distribution of some of the species across the islands, especially those of reptiles and amphibians, whose populations are sometimes characterized of occurring in small areas and whose dispersal capabilities are sometimes constrained by habitat segmentation due to roads or other man made barriers.
- In contrast, 2 $km^2$ hexagons may be more suitable to map species ranges on small islands with significantly mixed ecosystems and topographic diversity. A square kilometer of land surface in USVI may encompass many different types of ecosystems, including mangroves, dry forests, herbaceous wetlands, grasslands, as well as different types of topographic patterns, such as plains, mountains, valleys, and beaches. Smaller hexagons provide a systematically placed, same-sized minimum mapping unit, but on a finer scale which makes resulting range maps more useful to local land managers by allowing greater depiction of range variability within the USVI. A total of 322 hexagons cover the USVI which is manageable in terms of gathering information and developing an occurrence database (Table 1). This method, however, does not avoid the problem of erroneously mapping species distribution across islands (Figure 4), especially because the islands and the cays in USVI are very close together on occasion. In addition, vertebrate occurrence records in the USVI are not abundant, no single agency maintains and manages this type of data, and the information available sometimes does not provide precise location such as coordinates. Thus, a consequence of reducing the size of the hexagon will be that range maps will reflect a greater degree of false absence of species across the landscape.

- Lastly, watersheds offer distinctive habitat characteristics and sometimes harbor different biological communities. For example, some watersheds receive more precipitation than others within the same ecological lifezone. Subwatershed map units have the benefit of delimiting natural boundaries, and allow for greater confidence a species likely occupies the entire suitable habitat within the map unit. USVI is comprised of three main islands with 49 watersheds and numerous cays, 89 of which are included in USVI GAP. There are limitations to using this grid. Because watersheds usually cover a broad elevational gradient, and some species have particular elevational preferences, this method might add additional error to the predicted distribution of these species. Given that the highest elevation in the USVI is 474 m this might not be a problem, but a good effort must be made to identify the elevational requirements of vertebrate species in order to take this into account when modeling predicted habitat distributions.

As an example of the integrated range maps, the St. Croix ground lizard (*Ameiva polops*), occurs on three small cays off the island of St. Croix (Figure 4). Its range is represented by 75 km$^2$ using 24 km$^2$ hexagons (a), 8 km$^2$ using 2 km$^2$ hexagons (b), and less than 1 km$^2$ when restricted to the three cays on which it occurs (c). The St. Croix ground lizard is limited by a water barrier between islands and the watershed range map constrains its predicted distribution to suitable habitat within that range. If we use either the 24 km$^2$ (a) or the 2 km$^2$ hexagon grid (b), to map its distribution, it appears as though it occurs on St. Croix, which is not the case because it was extirpated from that island, probably through the predatory effect of the introduced Small Indian Mongoose (Platenberg et. al 2005).

In contrast, for a species such as the Great Egret (*Ardea alba*), unrestricted by a water barrier, we might use the 24 km$^2$ hexagon (Figure 5) to better represent the species range and constrain its predicted distribution within the USVI. These species have the potential of using all suitable habitat within a vast region in the USVI. This option is also more convenient in case there is a lack of occurrence records.

Conversely, the 2 km$^2$ hexagon range map is more suitable for species that occur in the main islands and whose population are scattered and disconnected. This is the case of some of the amphibians, such as the yellow mottled coqui (*Eleutherodactylus lentus*) (Figure 6). This smaller mapping unit has the advantage of providing a greater resolution in the case that there is an ample set of species occurrence data available.

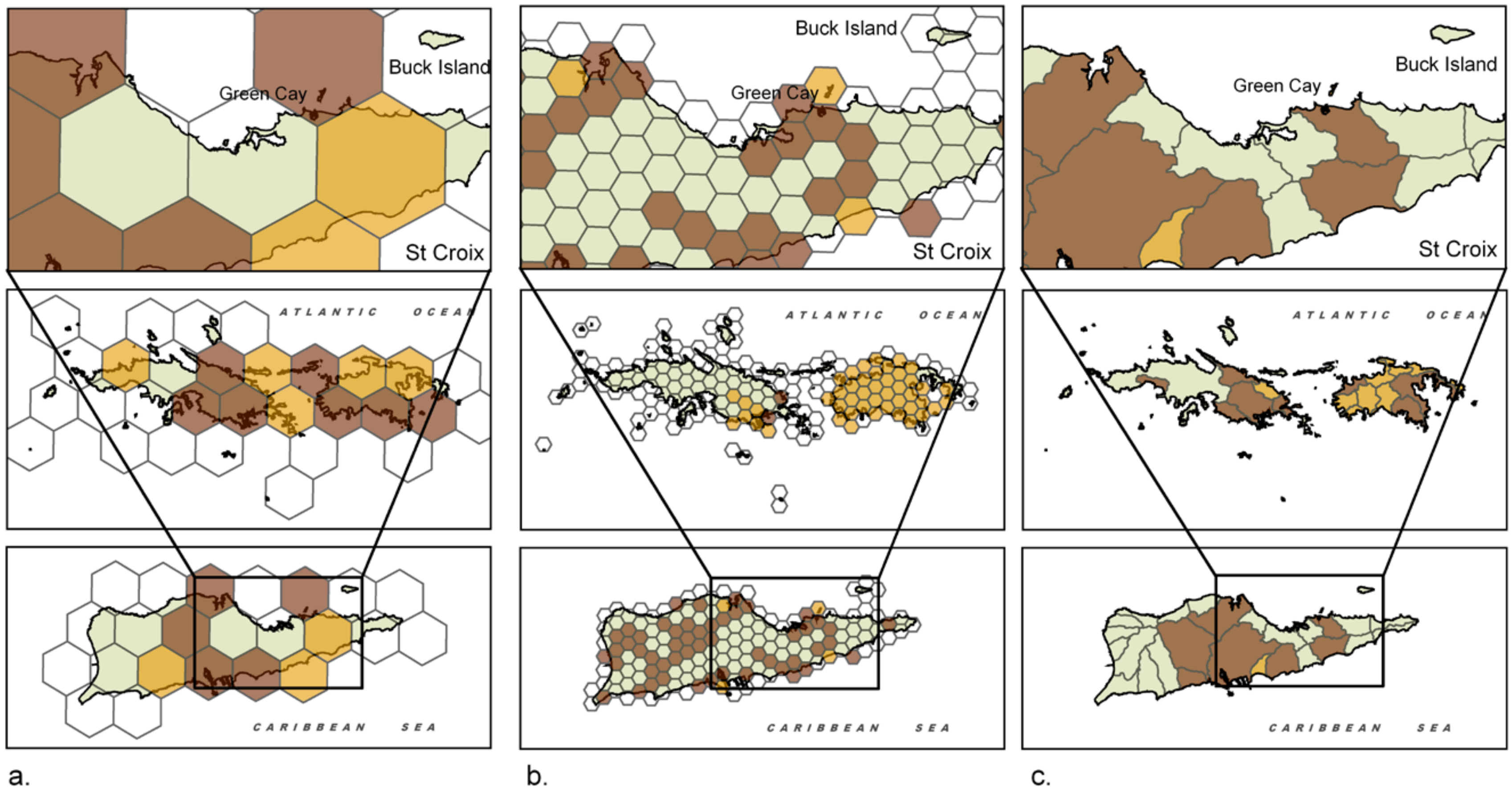



**Figure 5.** These three sets, similar to those used in Figure 4, show the distribution of the Great Egret (*Ardea alba*). The Great Egret's range is (a) 480 km$^2$ (209 km$^2$ occurring over land) when using the 24 km$^2$ hexagon, (b) 124 km$^2$ (75 km$^2$ occurring over land) when using the small 2 km$^2$ hexagon, and (c) 193 km$^2$ when using the subwatersheds as mapping units. Mapping the distribution of species that have great dispersal abilities will benefit from the use of a bigger hexagon or the subwatershed units.

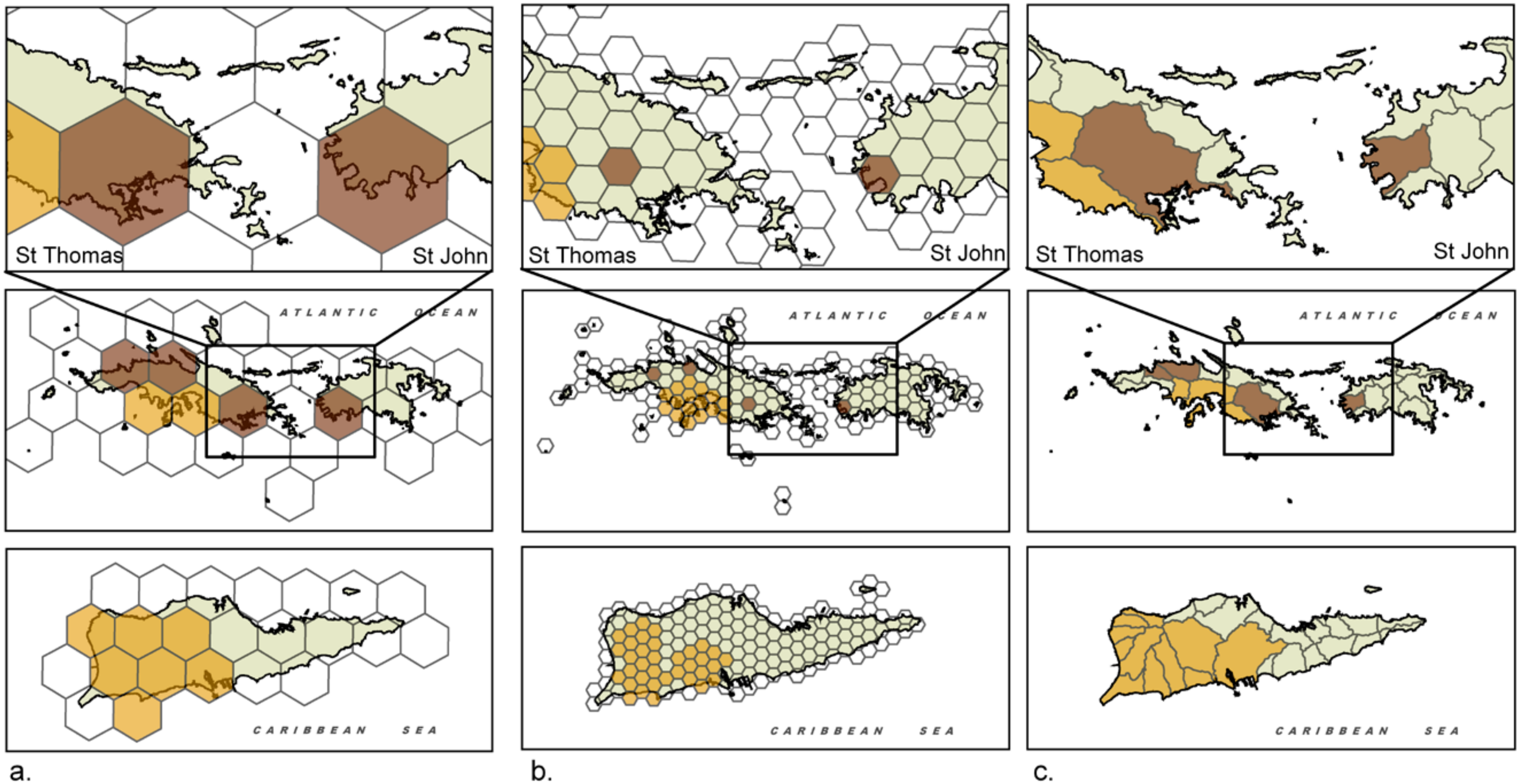



**Figure 6.** These three sets, similar to those used in Figure 4, show the distribution of the yellow mottled coqui (*Eleutherodactylus lentus*) using the three different grids (24 km² hexagon, 2 km² hexagon, and subwatersheds). The yellow mottled coqui's range is (a) 312 km² (183 km² occurring over land) when using the 24 km² hexagon, (b) 110 km² (87 km² occurring over land) when using the 2 km² hexagon, (c) 175 km² when using the subwatersheds as mapping units. Some amphibians, such as the *E. lentus*, tend to have a patchy distribution because their populations usually are not connected. In these cases mapping the species distribution will benefit from a smaller mapping unit.

## Conclusion

The ultimate value of developing a multiple scale system of range mapping will be determined as we begin to use the range maps for modeling species distributions, and as the resulting predicted distributions are used in conservation analyses and land management decisions. Although setting up additional geospatial datasets has represented additional effort, we feel the flexibility of the range mapping system will broaden the applicability and increase the long term value of the USVI Gap Analysis Project datasets.

Reducing the size of the hexagons and taking into account watersheds was considered a significant advantage by stakeholders.

## Acknowledgements

This research has been supported by the U.S. Geological Survey Biological Resources Division National Gap Analysis Program cooperative agreement No. 01HQPG0031 and the U.S. Department of Agriculture Forest Service International Institute of Tropical Forestry (IITF) GIS and Remote Sensing Laboratory. Thanks to the National Park Service, the Division of Fish and Wildlife of the USVI Department of Planning and Natural Resources (DPNR), the Coastal Zone Management of DPNR, The Nature Conservancy (TNC), the University of the Virgin Islands (UVI), the Conservation Data Center (CDC-UVI). Thanks to Grizelle González and anonymous reviewers for comments on this manuscript. All research at IITF is done in collaboration with the University of Puerto Rico.

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