A Preliminary Assessment of Ecosystem Vulnerability to Climate Change in Panama

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I. Introduction

Human-induced climate change has shifted status from hypothesis to reality during the last decade. Global temperature averages are on the rise: of the twelve warmest years since 1850, eleven of them were between 1995 and 2006, and the Intergovernmental Panel on Climate Change has very high confidence this is a result of anthropogenic activities (IPCC, 2007). Future scenarios predict global temperature to rise between 1.8 ºC and 4.0 ºC in the next ninety years. Because climate is very much a spatially heterogeneous variable, the actual effects of global warming at the regional scale are likely to be much more pronounced. Amongst other things, climate variability, heat waves, droughts and heavy precipitation events are likely to increase in intensity and frequency, and changes in ocean currents are expected to have unpredictable consequences (IPCC, 2007).

Climate is one of the key features defining the nature of ecosystems (Hawkins *et al.*, 2003). Current global warming has already been shown to impact the Earth's biota at all scales of organization from species to ecosystems, and the rate of change is likely to accelerate in the future (Walther *et al.*, 2002), especially if the effects of climate change interact with other drivers like land-use use change and biotic exchange (Sala *et al.*, 2000). Consequences of global warming on biotic communities include shifts in species distribution and phenology (Parmesan, 2006; Thomas *et al.*, 2004), increased risk of pathogen outbreaks (Pounds *et al.*, 2006) and disturbance of predator-prey cycles (Frederiksen *et al.*, 2006). Complex effects resulting from species interactions have also been documented and will undoubtedly be a common occurrence given the high number of interacting species forming ecosystems (Ducklow *et al.*, 2007; Walther *et al.*, 2002). Therefore, as the perceived effects of climate change are very likely to increase in the future (IPCC, 2007), there is a very tangible risk that there will be important repercussions on the identity and organization of biological systems.

Panama is a neotropical country that is host to a great number of species. Like most developing countries it suffers from various social and economic issues, and these in turn are reflected in the state of the environment. For instance, 575 species are listed on the 2006 IUCN's Red List are from Panama (IUCN, 2006). It is thus very likely that climate change will interact with socio-economic pressures and increase the strain already present on Panamanian ecosystems. As a signatory to the Convention on Biological Diversity (CBD), Panama has agreed to take the necessary steps to conserve and protect national biodiversity in a sustainable manner (Emilio Sempris, *pers. comm.*). Given its high percentage of remaining forest cover – 62.4% of the original primary forest (Institute, 2007) – and the large area of the country covered by protected areas, it is a conservation opportunity with great potential. For policy-making purposes, it is essential to identify the ecosystems that are most likely to be affected by climate change in Panama as well as understand how this will impact the rate of biodiversity loss.

The purpose of our internship is to evaluate the vulnerability of Panamanian ecosystems to climate change. One of the main challenges is to define what exactly is meant by "vulnerability" and what its proper measurement is. The IPCC defines vulnerability in terms of climate change as, "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2001). This definition introduces yet another fuzzy term, "susceptibility," which in turn refers to exposure, sensitivity and adaptive capacity (Metzger *et al.*, 2005). In this study we apply this concept of vulnerability to ecosystems, in that vulnerable ecosystems are more likely to suffer biodiversity loss from climate change. We realize this is still a rather loose definition, and the general lack of understanding of the consequences of climate change for ecosystems makes it difficult to define straightforward quantifiable responses.

As a preliminary step to assess the vulnerability of biological systems to climate change, we reviewed methodologies used in both the scientific and institutional literature. We found that most studies focus on the effects of climate change on biodiversity at the species-level scale. For instance, there are numerous studies that have modeled predicted shifts in species' distribution to infer extinction risk of individual species (e.g., (Thomas *et al.*, 2004; Thuiller *et al.*, 2005b)). However, the relevance of this in terms of species' ecology is being debated (Hampe, 2004), especially since the results are strongly influenced by assumptions about species dispersal abilities (Ibanez *et al.*, 2006; Pearson, 2006). Other methods encountered include field experiments, game-theory population models, expert opinion and outcome-driven modeling and scenarios (Sutherland, 2006).

It is one thing to predict the effects of climate change on a species but quite another to try to predict the consequences on ecosystems, which are made of countless interacting biological and physical factors. While the relationship between species and ecosystem functions is far from being understood (Peterson *et al.*, 1998), there is a general consensus that biodiversity loss decreases the resilience of ecosystems to biotic and abiotic disturbances (Hooper *et al.*, 2005). In a policy-making framework, it is certainly more useful to be able to assess vulnerability at the ecosystem scale; however, due to its complexity and inherent uncertainties, this is a task that few have attempted. For example, (Scholze *et al.*, 2006) have looked at the effects of global warming on key ecosystem processes (change in forest cover/carbon storage, wildfire frequency, and freshwater availability) for the world ecosystems by using a Dynamic Global Vegetation Model (DGVM). Most studies that focused on the ecosystem scale actually use either some version of a

DGVM alone or combine it with one of the methods mentioned above (e.g., (Schroter *et al.*, 2005; Thuiller *et al.*, 2006). The short timeframe, the potential amplitude of the task and our level of expertise prevent us from using this type of methodology. We thus decided to perform a preliminary vulnerability assessment where we would analyze general characteristics of ecosystems that are likely to increase their sensitivity to climate change.

The main conservation objective underlining this study is the preservation of all of Panama ecosystem types in the future, both to minimize biodiversity loss and to maintain ecosystem services to Panamanians. Using scientific literature, we identified four key components that could increase ecosystem vulnerability to climate change: (1) sea level rise, (2) ecosystem geometry (area and shape), (3) climatic "space" and (4) species sensitivity (see the next section for a detailed description). These four variables will be created and combined using Geographical Information Systems (GIS) in order to construct an index of ecosystem vulnerability to climate change (EVCC) for the ecosystems of Panama. Because we are well aware of the uncertainties associated with a number of ecosystem responses to climate change, we will not produce a definitive measure but rather rank each ecosystem according to its vulnerability, from our calculations, to climate change under each of the four components. The EVCC will be a weighted sum of the ranks for each component. It can thus be considered more of a relative measure: it does not tell how much vulnerability an ecosystem has *per se* but how much vulnerability, *compared to other ecosystems*, it has. The index will be presented as a series of maps. Additionally, we will look at the relationship between the EVCC, the degree of human intervention in ecosystems, the current network of protected areas, the distribution of endemic species, and overall species richness, as these are relevant to Panama's involvement in the CBD. While we realize that there are a lot of uncertainties associated with this index, both with the data used and the theory behind it, we feel it will be useful as a preliminary assessment for policy-making, which will strive to meet Panama's CBD objectives and improve the extent of the protected areas network. This project also has potential to serve as a foundation for continued or more sophisticated studies on ecosystems and climate change in Panama.

II. Host Institution

The Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC) located in the City of Knowledge, Republic of Panama, is the headquarters of the Regional Visualization and Monitoring System. CATHALAC operates SERVIR which has a test bed and rapid prototyping facility managed by the NASA Marshall Space Flight Center at the National Space Science and Technology Center in Huntsville, Alabama. SERVIR addresses the nine societal benefit areas of the Global Earth Observation System of Systems (GEOSS): disasters, ecosystems, biodiversity, weather, water, climate, oceans, health, agriculture, and energy. It provides tools and technology to monitor resources and environmental conditions by utilizing satellite imagery and other data sources. Results are presented to various levels of regional governments and are also made freely available to the general public.

This resource monitoring involves daily and weekly generation of data on current conditions such as weather, climate, marine environments, natural disasters, and ecological productivity. Most of the results are used for immediate decision-support; therefore, there has not been a concentrated effort on performing in-depth analyses of trends, which is what this particular study will attempt to do.

The supervisors for this project are Emil Cherrington, the Geographic Information Systems and Natural Resource Specialist for SERVIR, and Roxana Segundo, the Development and International Cooperation Officer for CATHALAC.

III. Study Site

SERVIR shares and analyzes satellite and other types of data for all of Mesoamerica, but this study focuses on Panama and its biodiversity at the ecosystem level. See the Introduction for a more specific description of the country in the context of our project.

IV. Methods

In compliance with McGill University's research ethics statement (2007), appropriate measures were taken to maintain the integrity of this project. No certification was necessary for research subjects since all of the work was done at CATHALAC in the computer laboratory; however, credit is given to those organizations and people who provided our data. Results are not definitive since the vulnerability assessments are based on climate change scenarios and projections and because this is only a preliminary study that explores how to evaluate vulnerability.

A. Calculating the index's components: four component of ecosystem vulnerability to climate change

Each of the four components was compared to or is related to a map of ecosystems in Panama, which had been classified according to vegetation and level of human intervention. There were thirty-seven ecosystem types and 1303 ecosystem patches (e.g., there are five "Broadleaf evergreen altimontane rainforest" patches) (Appendix 1). The methodology was to compare all components individually to each of the 1303 ecosystem patches, but generalizations have been made about the thirty-seven ecosystem types. Since the domain analyses involve different data types, the overlay methods were different and are described below. The general processes of analyzing vulnerability in terms of each domain are provided, but the specific technicalities of GIS have been spared from this paper. Indices were created for each domain, according to its number ($EVCC_{1,2,3,4}$)—each $EVCC_x$ receiving a value from 0 to 20, depending on which domain of vulnerability. They were later combined to create an overall vulnerability index—EVCC.

1) Vulnerability to sea level rise – $EVCC_1$

Land loss due to sea level rise is a direct consequence of climate warming and will likely impact a number of coastal ecosystems (e.g. mangroves). A digital elevation model (DEM) provided elevation values at a ninety-meter scale. Since the IPCC (2001) "business as usual" scenario predicts a global average of a 0.6 meter rise in sea level by 2099, all areas from zero to one meter in elevation were identified. To avoid impractical results, only areas within one kilometer of coastline were included, which will be called the "coastal buffer zone." All areas of zero and one meter elevations are called "red-zones." The ecosystem patches were then assigned to the coastal buffer zone, giving each "coastal patch" an identity (Figure 1). The following calculation was used to determine $EVCC_{1'}$:

$$\text{Where } R = \frac{A_{rc}}{A_{cp}}, \quad EVCC_{1'} = R\frac{A_{cp}}{A_{ep}}, \qquad \text{(Equation 1)}$$

where R is the area of red-zones in all coastal patches of an ecosystem patch (A_{rc}) divided by the area of all the coastal patches in an ecosystem patch (A_{cp}), and A_{ep} is the area of an ecosystem patch (Figure 1). It is obvious that A_{cp} is cancelled out in this equation, but it is retained because of its importance in a further analysis.

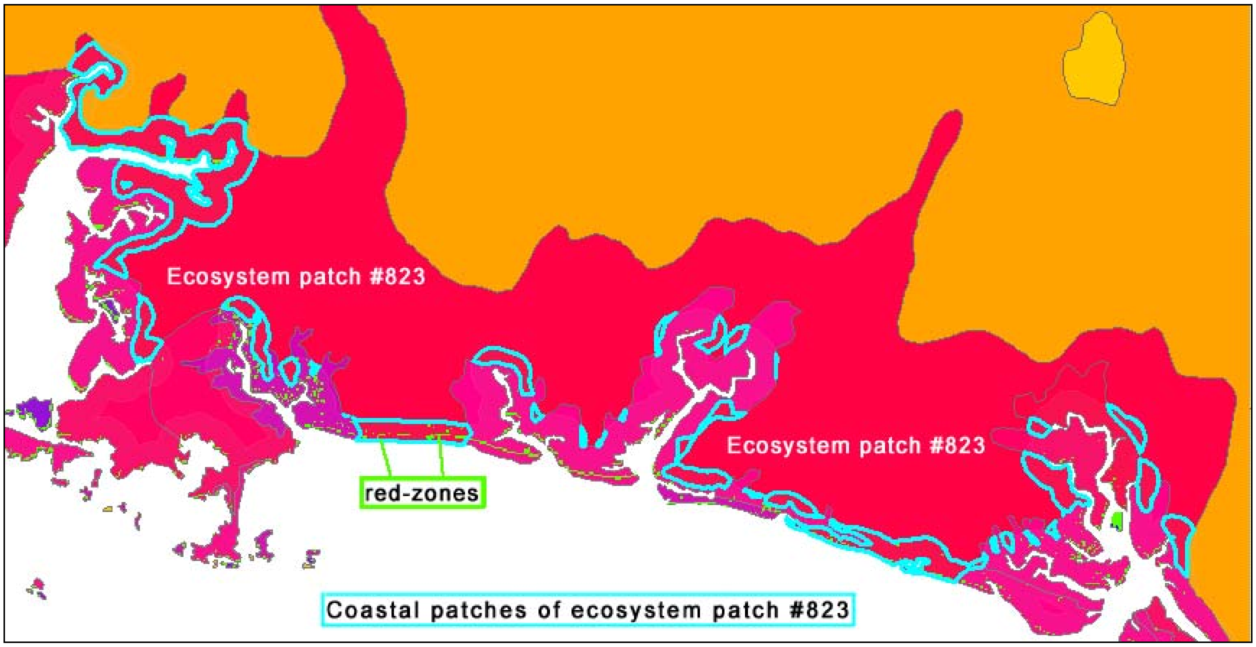


Figure 1 This example of an ecosystem patch along the Gulf of Chiriqui contains over thirty coastal patches (some too small to see at this scale). Other ecosystem patches (in different colors) break up patch #832. The tiny green dots (90m resolution) are marked as red-zones.

$EVCC_{1'}$ is not the vulnerability index for sea level rise but rather the density of red-zones in all coastal patches multiplied by the density of coastal buffer zone area in ecosystem patch area. This means that $EVCC_{1'}$ is a normalized value of how much red-zone there is in an ecosystem patch, given only the areas within one kilometer of the coast. In order to determine $EVCC_1$ the $EVCC_{1'}$ values were separated using the Geometric Interval quantitative classification scheme in ArcMap. This scheme was created especially for continuous data and since $EVCC_{1'}$ is a type of density, this is a pertinent way to assign vulnerability values to each of the 1303 ecosystem patches. Values zero to fourteen were assigned according to these intervals. The rationale behind not using one to fifteen is that there *are* ecosystem patches that should be classified with "zero vulnerability" to sea level rise because of their geographical location.

2) Ecosystem geometry (edge effect and irregularity) – $EVCC_2$

Some ecosystems are likely to be more vulnerable to climatic disturbances brought about by global warming because of their area and/or shape alone. Larger areas are less susceptible to ramifications of stochastic perturbations (Janzen, 1983). Also, the shape, more specifically the ratio of the perimeter to the area of the core, is important because of the edge effect and because ecotones—transition zones with environmental gradients—are more sensitive to external factors (Murcia, 1995; Saunders *et al.*, 1991; Shafer, 1999). A number of tools have been developed in the literature on optimal natural reserve shape, and they have been used to estimate this component of ecosystem vulnerability to climate change. Two measurements for ecosystem patch geometry were used. The first was an edge to core ratio calculation, which compares areas ($EVCC_{2a}$). The second was an attempt to evaluate of the irregularity of the ecosystem patch ($EVCC_{2b}$). A technique similar to $EVCC_1$ was used to create more "buffer zones," but this time buffers were created for each ecosystem patch—not just the coastline. Measured inwards from the border of a patch, a 500 meter "edge" was created for each patch (Figure 2). To calculate $EVCC_{2a'}$ a simple density equation was used:

$$EVCC_{2a'} = \frac{A_c}{A_e}, \qquad \text{(Equation 2)}$$

where A_e is the area of the edge in an ecosystem patch and A_c is the area of the core (even though the inverse of this equation would obviously give the edge to core ratio, but a frequent problem of A_c being equal to zero occurred because many patches were simply too small to have any core). This gave a high value for those ecosystem patches that had a relatively high amount of core compared to edge. This would mean that a higher $EVCC_{2a'}$ indicates a lower vulnerability. To create $EVCC_{2a}$ the values of $EVCC_{2a'}$ were separated into five groups using the

Natural Breaks (Jenks) classification scheme in ArcMap (low $EVCC_{2a}$ is high vulnerability). Because the Geometric Interval did not distinguish relative differences, the Natural Breaks was able to break the $EVCC_{2a'}$ values according to where there were natural boundaries or separations in the distribution.

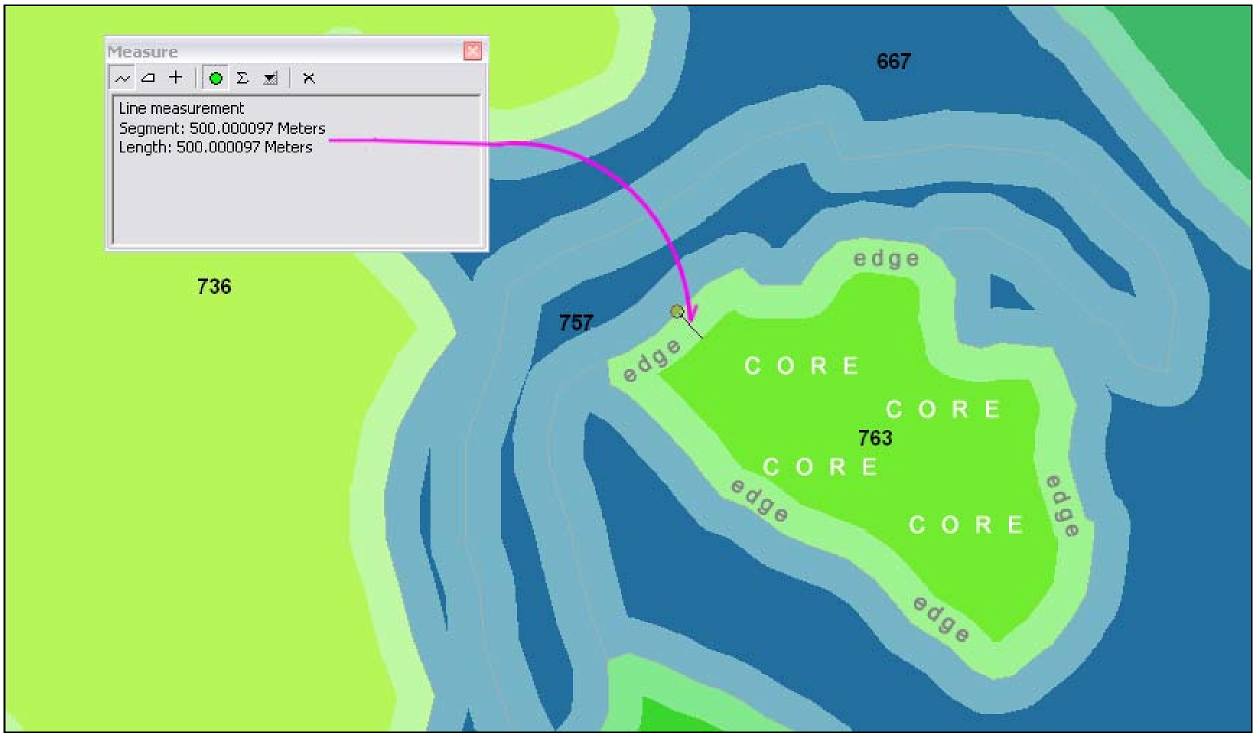


Figure 2 These ecosystem patches north of Yaviza, Darien display the 500m-wide edge areas. Comparing edge area to core area, one can see that #757 has a much higher core:edge ratio than #763 does.

Irregularity was evaluated by measuring the area and perimeter of an ecosystem patch, converting it into a perfect circle (while retaining the area), and measuring the perimeter of this circle (Figure 3). The theory behind this method is that a circle has the least perimeter per area of any shape, which means there are fewer edges that are susceptible to change. After measuring the area and perimeter of the ecosystem patch and its perfect circle, $EVCC_{2b'}$ was calculated:

$$EVCC_{2b'} = \frac{P_{ep}}{P_{circle}}, \qquad \text{(Equation 3)}$$

where P_{ep} is the perimeter of the ecosystem patch and P_{circle} is the perimeter of its perfect circle. For the same reasons as $EVCC_{2a'}$ the vulnerability index for $EVCC_{2b}$ was determined by the Natural Breaks (Jenks) scheme into five intervals.

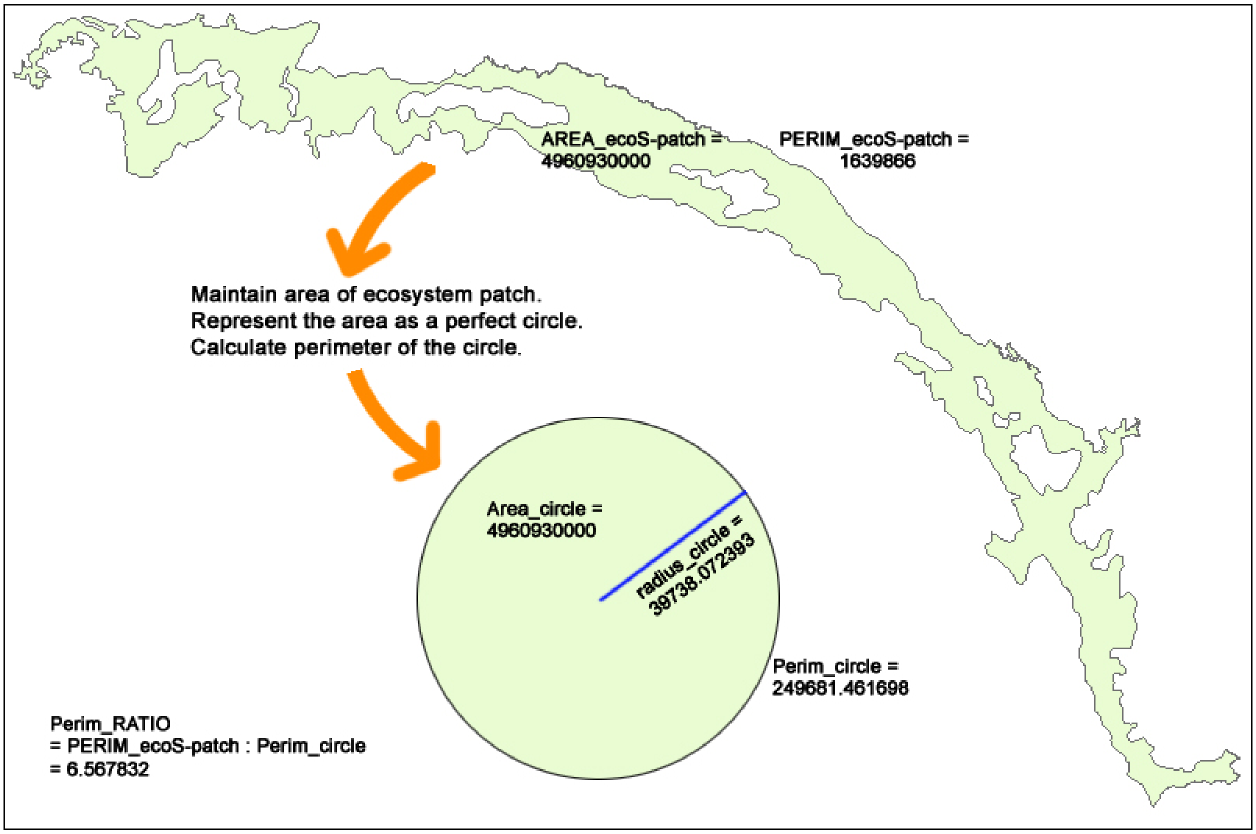


Figure 3 (not to scale) Conceptual method for obtaining $EVCC_{2b}$. This shows that the ecosystem patch's perimeter is over six times as long as a perfect circle with the same area.

$EVCC_2$ was simply obtained by adding the two methods together:

$$EVCC_2 = EVCC_{2a} + EVCC_{2b}, \qquad \text{(Equation 4)}$$

which yielded vulnerability values from one to ten.

3) Climatic "space" of ecosystems – $EVCC_3$

Ecosystems have evolved to fit specific temperatures and precipitation regimes during the year. Moreover, some ecosystems exist in regions where there are naturally large variations in climate within and between years. Each ecosystem can thus be said to be adapted to fit a climatic "space" that accounts both for average climate (e.g., average temperature and precipitation) and climatic variability. Climate change will affect the climatic conditions under which specific ecosystems occur, and vulnerability should increase as ecosystems are taken further away from the conditions in which they have been historically occurring. Moreover, ecosystems with higher annual variations in climate should be more resilient to climate change. The third component of the EVCC, the climatic "space" of ecosystems, uses historical climate data and predicted future climate to estimate which ecosystem patches, given the predicted change in climate where they occur and the variation of climate they have been historically exposed to, should be more vulnerable by climate change. We use temperature and precipitation data in our evaluation of $EVCC_3$, since they have both been shown to be important determinants of vegetation type (Hawkins *et al.*, 2003).

The historical climate data was obtained from WORLDCLIM, an electronic database that provides high-resolution interpolated climatic data (1 km^2) for the world, averaged from 1960 to 1990 (Hijmans et al. 2005). The data includes both standard variables like mean temperature and precipitation but also a set of derived bioclimatic variables, such as the precipitation of the driest quarter, that are more relevant to biological systems. The historical data obtained from WORLDCLIM were temperature and precipitation for the months of July through September as well as a number of bioclimatic variables described below.

The predicted future climate data for Panama was obtained from CATHALAC's climate change model (CCCM). The model was run at a scale of 36 km^2 from 2005 until 2099. The data used in $EVCC_3$ was monthly temperature and precipitation average for July through September of the years 2025, 2050 and 2099. The analysis was focused on those months because of data availability but also because focusing on one season of a region with a lot of inter-annual variation in climate allows us to capture more variation. In the case where data from other parts of the year become available and a third party would want to run the EVCC with them, we would suggest not averaging the data together but doing separate analyses for biologically relevant periods of the year. Of course, the magnitude of change in one period is likely to be correlated with that in another and this would have to be accounted for. Additionally, the CCCM has only presently been run with the "business-as-usual" carbon emission scenario. It would have been preferable to evaluate and compare the results of the EVCC according to a number of scenarios, but this setback is lessened by the fact that CCCM is the one with the highest resolution for that region. Low-resolution data is often targeted as one of the main problems in studies of ecological response to climate change. CATHALAC's climate change model will be run with more scenarios in the future, and other parties will have the possibility to use the framework we have set up for the "business-as-usual" to evaluate EVCC under different scenarios.

The analysis itself was conducted at a resolution of 1 km^2, using the WORLDCLIM data as a template. As a result, each 36 km^2 pixel of the CCCM were divided in 36 1 km^2 pixels which were assigned the climate values of the CCCM pixel they were derived from. While this induced a bias in the $EVCC_3$ in terms of spatial auto-correlation of the up-scaled pixel, it allowed us to include a greater number of ecosystem patches in the analysis and still provided information about the magnitude of variation in climate for each 1 km^2 pixel since the

WORLDCLIM data occurs at that resolution. A map of the excluded ecosystem patches is included in the "Results and discussion" section (Figure 7).

The Gower Metric was used to evaluate predicted change in climate in terms of temperature and precipitation for each 1 km^2 pixel (Carpenter *et al.*, 1993). The values obtained at the pixel level were then averaged at the ecosystem patch level. The Gower Metric is a measure of dissimilarity between environmental coordinates that is often used in ecology, for example in the DOMAIN model of species distributions (Carpenter *et al.*, 1993). The Gower Metric increases as difference in climate increases and as historical range in climate decreases. In other words, a pixel is deemed more vulnerable if it is predicted to have a higher change in temperature and/or precipitation within the ecosystem patch it occurs, compared to its average from 1960 – 1990.

The following steps were followed to build $EVCC_3$ (see figure 4):

a. Climatic data was compiled for each 1 km^2 pixel. Historical data included mean monthly temperature (°C) and precipitation (mm) for the months of July, August and September, mean temperature of the warmest and coldest quarters (three months), and mean precipitation of the wettest and driest quarters. Predicted data included mean monthly temperature and precipitation for July, August and September 2025, 2050 and 2099.

b. For both historical and predicted climate, mean monthly temperature and precipitation were averaged over the months of July through September.

c. For each ecosystem patch, the minimum mean temperature of the coldest quarter (T_{min}), the maximum mean temperature of the warmest quarter (T_{max}), the minimum mean precipitation for the driest quarter (P_{min}) and the maximum mean precipitation of the wettest quarter were identified (P_{max}). These values were subtracted to obtain the temperature and precipitation range for each ecosystem patch.

d. The Gower Metric for temperature and precipitation was calculated for each pixel for 2025, 2050 and 2099 by using the historical and future climate data compiled in Step 1 and the temperature and precipitation ranges of the ecosystem patch where the pixel occurs calculated in Step 2. An example for temperature is given here:

Gower Metric for cell i = $(temp_{historical} - temp_{future})/ temp_{range}$ of ecosystem patch containing i

e. A Gower Metric for temperature and precipitation for 2025, 2050 and 2099 was derived for each ecosystem patch by averaging the Gower Metric within each category (temperature and precipitation) of each of the pixels that occur in the patch.

f. For each ecosystem patch, an aggregated Gower Metric for temperature and precipitation was calculated.

$$GM_{\text{ecosystem patch}} = 4^* GM_{2025} + 2^* GM_{2050} + GM_{2099} \quad \text{(Equation 5)}$$

This pattern of weighting was chosen because, given all else is equal, an ecosystem where the rate of climate change is higher should be more vulnerable. Also, uncertainty in the accuracy of the predicted climate data increases with time.

g. The aggregated Gower Metrics for temperature and precipitation were compared amongst all ecosystem patches and ecosystem patches and were ranked from 1 to 10 using a Natural Jenks classification scheme. A score of 10 was assigned to the highest Gower Metrics.

h. $EVCC_3$ for each ecosystem patch was obtained by summing the ranks of that ecosystem patch for the aggregated Gower Metric of temperature and precipitation. Under $EVCC_3$ thus, an ecosystem patch with a score of 20 was the most vulnerable compared to other ecosystem patches in terms of both temperature and precipitation. Note that in the way $EVCC_3$ is built, temperature and precipitation were given equal weight in terms of their effect on ecosystem vulnerability. This weighting is flexible and could be adjusted in future runs of the EVCC if deemed relevant.

4) *Species sensitivity – $EVCC_4$*

A large number of studies have modeled shifts in species distribution in response to climate change and have gradually uncovered many basic characteristics that could make species more vulnerable. These include for example geographic extent and basic niche properties (Thuiller *et al.*, 2005a), thermal range (Jiguet *et al.*, 2006) and life form (for plants) (Broenniman *et al.*, 2006). Here a geographic extent of representative groups of vertebrates as defined by NatureServe's Infonatura (2007) was used for mammals, birds and amphibians to estimate species' sensitivity to climate change in each ecosystem. Thuiller and his colleagues' study (2005a) was consulted as a theoretical foundation since they found that species with smaller ranges were less likely to have suitable habitat available for them in the future. Thus, in this fourth domain of vulnerability, ecosystem types that have a higher number of species with small ranges will be deemed more vulnerable to climate change.

Estimated ranges for mammals, amphibians and birds of Panama were obtained from InfoNatura, an electronic database that provides conservation and education resources on vertebrates of Latin America and the Caribbean (InfoNatura, 2007). The resulting coverage of Panamanian vertebrate diversity was high: geographic information on ranges was available for 245 out of the 246 mammals, 845 of the 929 birds (including migratory birds), 192 out of the 196 amphibians.

Steps followed to build $EVCC_4$:

A. Separate analyses of species sensitivity were performed for each group (mammals, birds, amphibians) because of their inherent differences in range sizes (birds tend to have much bigger ranges then amphibians) (see Figure 4).

1. Total distribution area of species were calculated, including where the species occurs outside of Panama, and assigned a rank from 1 to '*x*' according to a quantile classification scheme where a score of *x* was given to the 10% smaller, and thus most sensitive, ranges. '*x*' was selected according to the number of species in the group to allow a finer definition of range categories, with '*x*' being the highest in birds and the smallest in amphibians.
2. From the species distribution we derived for each ecosystem patch which species were theoretically occurring there. The average of the ranks calculated in step 1 of all species of each group that occur within each ecosystem patch was calculated. In other words, the average of the ranks for all the birds occurring in a given ecosystem patch was calculated, the average of the ranks for all the amphibians, etc.
3. The species density of each ecosystem patch was calculated by dividing the total number of species from each group that occur in the patch by the area-rank of the

patch from 1 to 10, as determined by ranking all ecosystem patches area with a natural breaks (Jenks) scheme.

4. For each species group, the average ranks divided by the species density for each ecosystem patch were ranked on a scale of 1 to 10 using a geometric classification scheme. This second ranking was necessary so that the different number of classes assigned to each group in the initial ranking (see step 1) would not bias the resulting average species sensitivity per ecosystem patch. The ranks from all three groups were then added for each ecosystem patch.

B. $EVCC_4$ was calculated by summing for each ecosystem patch the ranks from all three groups obtained in the last step and ranking (one last time) the aggregated average ranks according to a quantile classification scheme. A rank of 5 was awarded to the ecosystem patches that had, on average, the mammals, birds and amphibians with the smallest ranges for their respective groups.

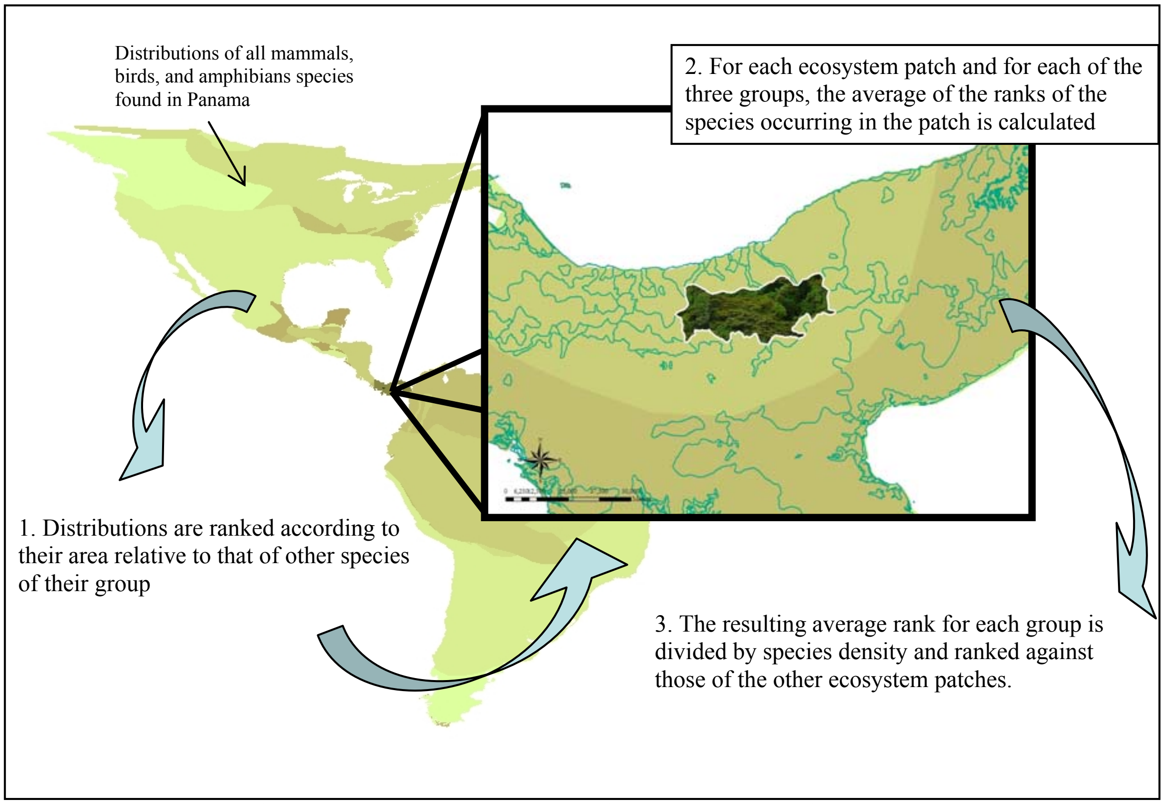


Figure 4: An outline of the main steps leading to the final calculation of $EVCC_4$

B. Constructing the index: combining four variables into one

For each ecosystem type appropriate weights were assigned to each of the four components defined above. This is important because some factors are not as pertinent to climate change or are not as reliable in either the raw data or the analyses (Table 1).

Table 1 How to rank EVCC components: Numbers in italics represent the more influential category for each domain, which is the deciding factor in the case of ties.

Domain	Pertinence to Climate Change	Reliability of Data	Overall Weight	Scale
$EVCC_1$ (sea level rise)	*3*	4	3	0 – 14
$EVCC_2$ (patch geometry)	1	*2*	2	1 – 10
$EVCC_3$ (climatic ”space”)	*4*	3	4	0 – 19
$EVCC_4$ (species sensitivity)	2	*1*	1	1 – 5

Considering that climatic “space” is at the heart of this study, it has received the highest weight. Sea level rise follows in second, and ecosystem geometry is the third most important. Species sensitivity has been given the lowest weight because of the uncertainties in the theory of species range as a driver of ecosystem patch vulnerability. There is also the problem of relying on this species presence/absence data, because there remain many parts of Panama that are quite unexplored. Given these ranks, the EVCC value for all of the ecosystem patches (except some due to resolution issues, see $EVCC_3$ results) is calculated:

$$EVCC_{total} = EVCC_1 + EVCC_2 + EVCC_3 + EVCC_4 . \qquad \text{(Equation 6)}$$

C. Displaying the index and associated products:

The EVCC index has been displayed on a simple map of Panama divided into ecosystem patches. Darker colors generally indicate higher vulnerability; refer to the legend accompanying each map. Similar maps are also available for each domain of ecosystem patch vulnerability.

D. Methods for applying index to current situations:

For discussion and application purposes, the EVCC index was overlain on other types of data. Doing this allows viewers to pinpoint areas that are especially vulnerable from the lack of protection and/or the intrinsic biotic vulnerability (due to the endemism), and this will be a useful decision-support tool pertinent to the Panama’s CBD objectives and its focus on protected areas and endemic species. The degree of human intervention, protected areas, endemism, and species richness are four applications.

1) Degree of human intervention

Degrees of intervention were assigned to each ecosystem patch (values from zero to nine), which reflect their UNESCO description. Table 2 guided the method in valuation:

Table 2 Guide to Assigning Intervention Values

Ecosystem Patch Description	Intervention Value
Populated places	9
Shrimp farming	8
Agroforestry	7
Productive system: <10% natural or spontaneous vegetation	6
Productive system: 10-50% natural or spontaneous vegetation	5
Natural system: moderately high intervention (lowlands)	4
Natural system: moderately high intervention (mountains)	3
Natural system: medium intervention	2
Natural system: low intervention	1
All others	0

Overall EVCC was compared to the degree of intervention to see which domain is the cause for the most concern.

2) *Protected areas*

The overall EVCC scores for each ecosystem patch were again compared to a map of the anthropological reserves, biological corridor, biological reserve, forest reserves, hydrological protection zones, national marine parks, national parks, national wildlife refuge, private reserves, protected forests, protective zone, recreation area, and wildlife refuges of Panama provided by CATHALAC.

3) *Species richness and endemism*

The InfoNatura (Nature Serve, 2007) database provided the names of all mammal, bird and amphibian species occurring in Panama, as well as those that are endemic. Sixteen mammals, eight birds, and twenty-nine amphibians are endemic to the country (Appendix 2). Panama was divided into a grid of 10km x 10km squares, and species richness and endemism were calculated for each.

V. Results and Discussion

The results are presented in a similar framework as the Methods section. Discussions on each set of results are provided directly after each results section so more congruent ideas can be deduced. Since the focus of this assessment was done on the ecosystem patch level, results have been generated for parts A and B that contain EVCCs for 1303 patches, but they are not provided in this paper for the vast amount of space they require. For a more general analysis, summarized results are also provided at the ecosystem level, in which the thirty-seven ecosystem types have been described in terms of different vulnerability components. A discussion on the different impressions people can get from these maps is given in part C, and implications of our analysis of further applications are addressed. For all results, critiques of the methods are provided in order to initiate thoughts on how improvements can be made. Also, a large table of minimums, maximums, averages, and variances, of $EVCC_{1,2,3,4}$ and overall EVCC summarized for each ecosystem type is presented in Table 4.

A. Four components of ecosystem vulnerability to climate change

1) *Vulnerability to sea level rise – $EVCC_1$*

A glance at Table 4 shows average $EVCC_1$ values on a scale of 0-14. All of the ecosystem types with a rank of zero have no land that is zero to one meter in elevation that is on the one kilometer-deep coastline. Many of these individual patches are landlocked. A six-way tie for the most vulnerable ecosystem patches (in the maximum $EVCC_1$ column) goes to patches of the following ecosystem types: mangroves, semideciduos tropical forests in lowlands (all three levels of human intervention), small islands, and populated places. Sixty-two patches have the highest $EVCC_1$ value of 14, fifty-four of them being small islands. Over half of these small islands are in Bocas del Toro, a province that also contains the other most vulnerable ecosystem types such as mangroves, various types of forests in lowlands, swampy or marshy forests, and occasionally flooded rainforests. Bocas is also the location of the only populated place patch with the highest possible $EVCC_1$ value. As seen in this province, often these ecosystem types are neighbors to one another, which Map 1 attempts to display. The Colón and Free Trade Zone area is a mix of similar ecosystem types with high patches of vulnerability. An almost identical mix of ecosystem types with patches of high vulnerability exists along the Gulf of Chiriquí.

In terms of average $EVCC_1$ the two most vulnerable ecosystem types (broadleaf evergreen rainforests dominated by palms and in swamps, and coastal vegetation growing on very new soils) only have seven and five patches, respectively, and account for an extremely small percentage of total land in Panama. This could be a cause for concern because of the rarity of this ecosystem type. See Figure 5**Error! Reference source not found.** for a histogram of these results. After mangroves and islands, which have already been discussed, come the salt and shrimp production ecosystem types. Again these patches account for a very small area of the country and are located in the *Arco Seco* of the Azuero Peninsula. They are still worth keeping in mind for their importance in the economies and food production for the country (discussed in Applications section).

The method of selecting land of only zero to one meter in elevation involved using a DEM on the 90m scale. Unfortunately it has a ±15m margin of error and slight imperfections when overlaying it with the ecosystem map, some results are not completely accurate. Still, the process identified the many of those tiny patches that would be more affected by this kind of discrepancy and often labeled them as highly vulnerable. Also, by selectively choosing land that was one kilometer or closer to the coast, some areas that of zero to one meter high were disregarded. It could have been that inland valleys go even below sea level (and are not necessarily vulnerable to sea level rise) or that expansive river deltas were wrongfully erased. The largest bulk of elevations zero to one meter high that were erased occurred in the *Arco Seco* of the Azuero Peninsua (dominating the shrimp and salt production). Whether or not this area should be classified as more vulnerable, it has already received attention for being ranked highly.

Map 1 of vulnerability to sea level rise well-illustrates the particular coastal regions that are more vulnerable than inland areas. Since the color scheme was applied to ecosystem patch and not simply which coasts are susceptible to flooding, there is the possibility of misconception in this demonstration of vulnerability. Most noticeable is the second largest ecosystem patch (Productive system with less than 10% natural or spontaneous vegetation) that covers a large portion of the Azuero Peninsula. Because many of its boundaries are coasts, there is a high chance that parts of it will be susceptible to sea level rise. This shows up in the fact that it was given an $EVCC_1$ value of 3. Had this patch been divided into smaller sub-patches, a definite difference in perception would occur.

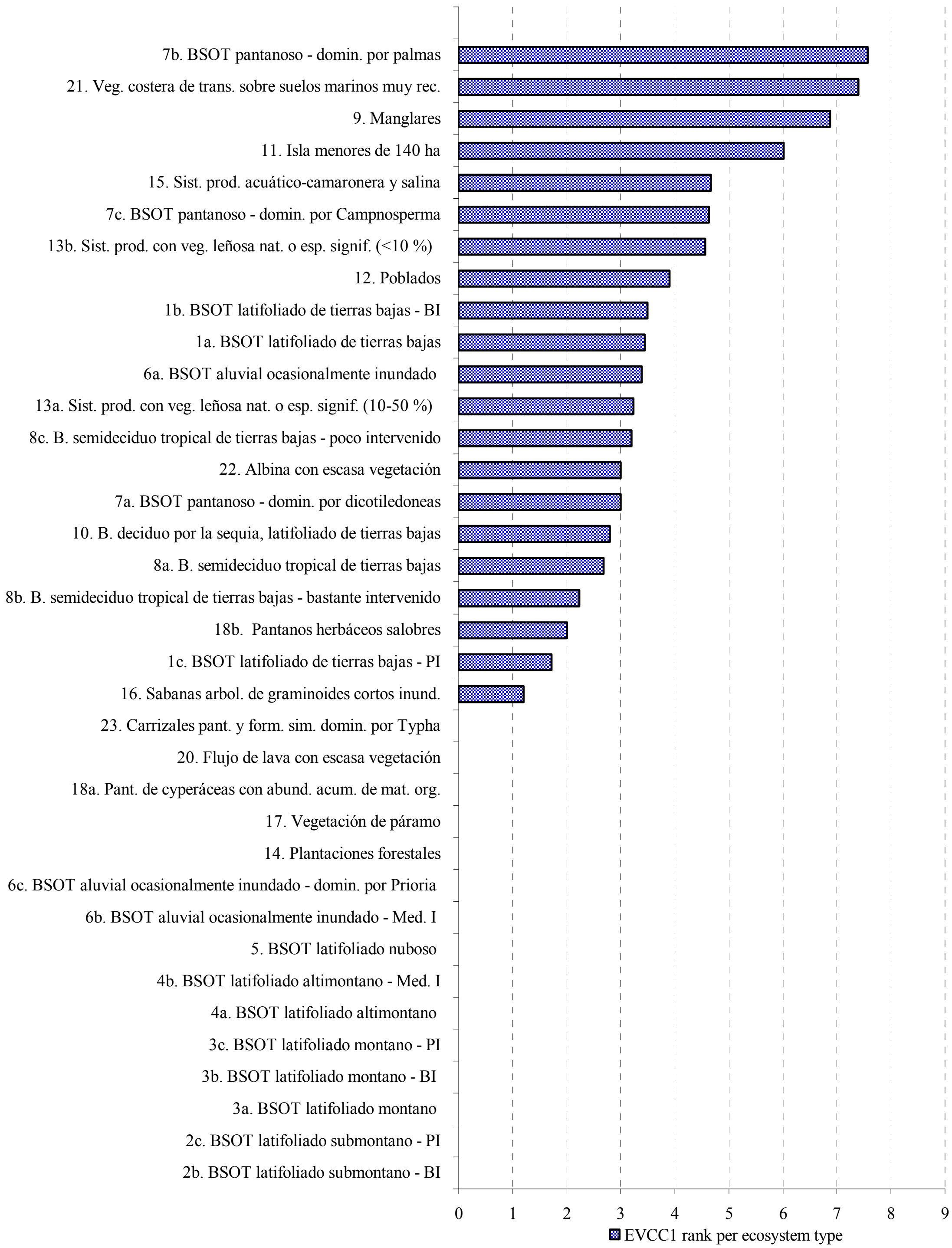
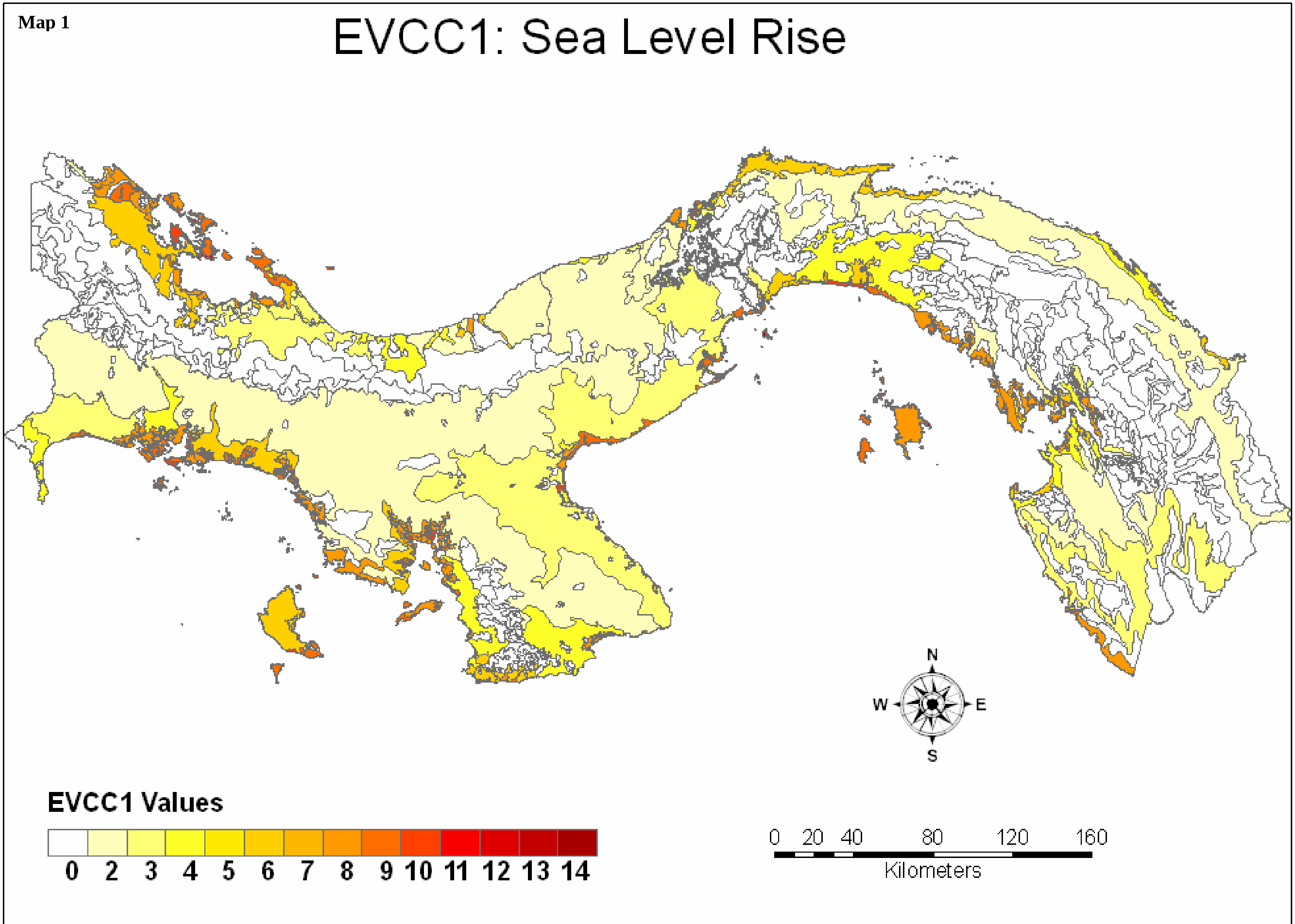


Figure 5 Distribution of average $EVCC_1$ values for each ecosystem type.

Map 1


EVCC1: Sea Level Rise
N
W
E
S
EVCC1 Values
0 2 3 4 5 6 7 8 9 10 11 12 13 14
0 20 40 80 120 160
Kilometers

2) Ecosystem geometry (edge effect and irregularity) – $EVCC_2$

It should first be pointed out that the distribution for the average $EVCC_2$ (on a scale of 1 to 10) is not as widely spread as $EVCC_1$. Despite this, ranges still exist at the extremes—$EVCC_2$ of two to ten. Probably that $EVCC_2$ is the sum of two sub-$EVCC_2$ values with often opposite values is because the average range is very concentrated from five to eight. Also, a value of one is not possible because the minimum values for $EVCC_{2a}$ and $EVCC_{2b}$ were both one. Adding two of the least vulnerable sub-values would mean that '2' is the lowest possible $EVCC_2$.

Gathering maximum values from Table 4, one can see that many of the coastal ecosystem types are again highly vulnerable. This means that they are most irregularly shaped (probably long and thin in this case) and they are relatively small (having a large edge to core ratio). A look at Map 2 shows that generally, ecosystem patches are smaller along the coastline, likely because the change in land type can increase more dramatically from coast to inland than from inland to inland. Agricultural systems also have some patches of very high vulnerability in terms of geometry, but there is a caveat here. The geometry analysis meant to capture those ecosystem patches with the most susceptibility to negative edge effects. Even though an agricultural system could have an irregular shape, the theory behind its vulnerability does not stand. That is to say, this geometrical analysis is much more pertinent for natural systems, because human-altered systems are often very buffered from surrounding environmental changes (later discussed in the Human Intervention section).

Ranking the ecosystem patches by highest $EVCC_2$ (see **Error! Reference source not found.**the Excel file or Arc data for complete results) shows that nine out of ten patches are mangrove forests. It more is important to look at ecosystem patch here because many ecosystem types have very few (and important to this geometric analysis—small) patches. This is why the histogram (Figure 6) shows coastal vegetation growing on very new soils and salt marshes with scarce vegetation to have the highest $EVCC_2$ ranks. They are definitely still important to consider because this type of ecosystem has already been shown to be vulnerable to sea level rise.

The least vulnerable, which should be in theory the most resistant to surrounding perturbations, include again many patches of lowland forest but also numerous patches in mountainous regions and agricultural patches. The fact that lowland type ecosystems have patches that have been classified as both least and most vulnerable further support the argument that this geometry analysis is not good at summarizing vulnerability based on ecosystem type. It is much more meaningful when considered for each patch.

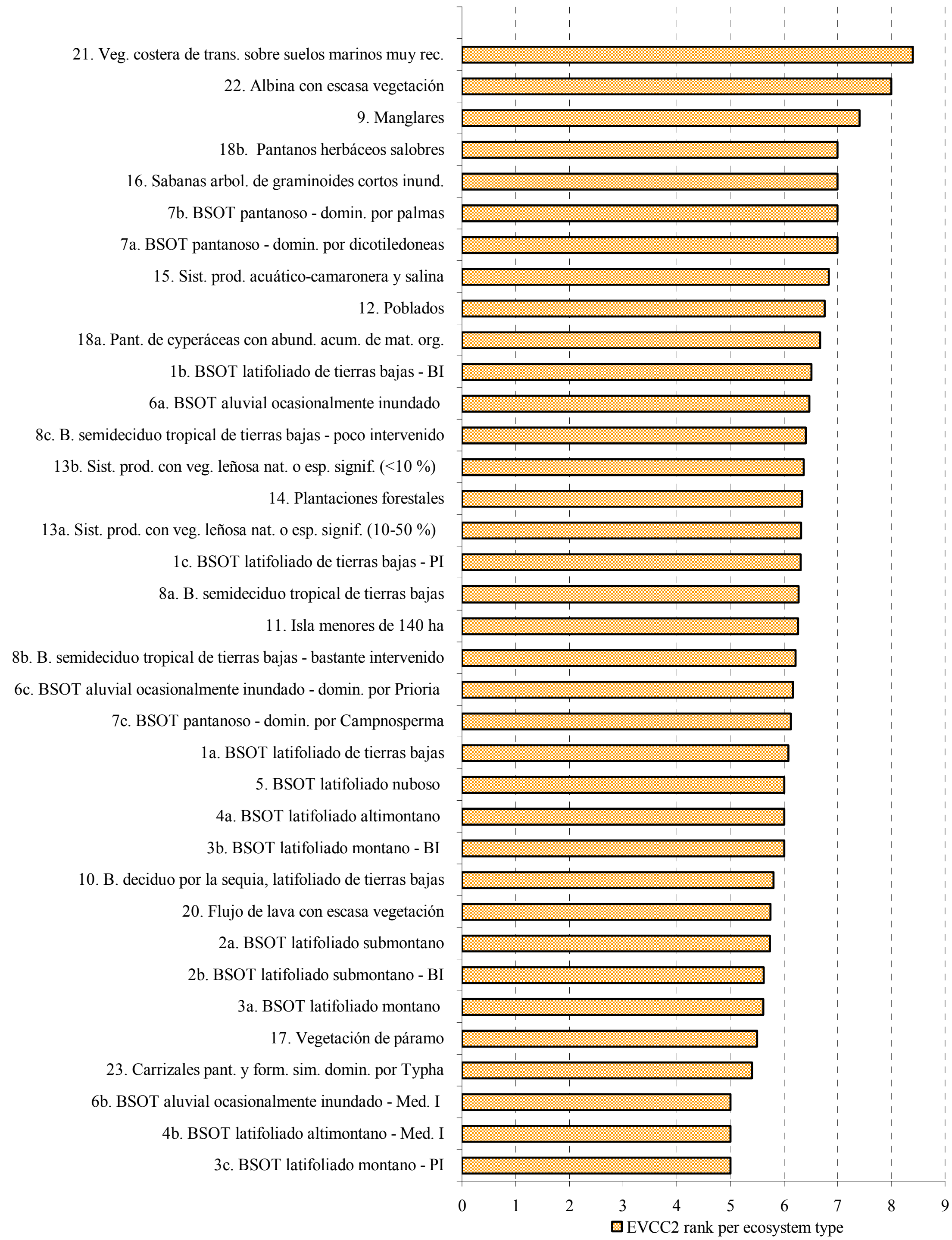
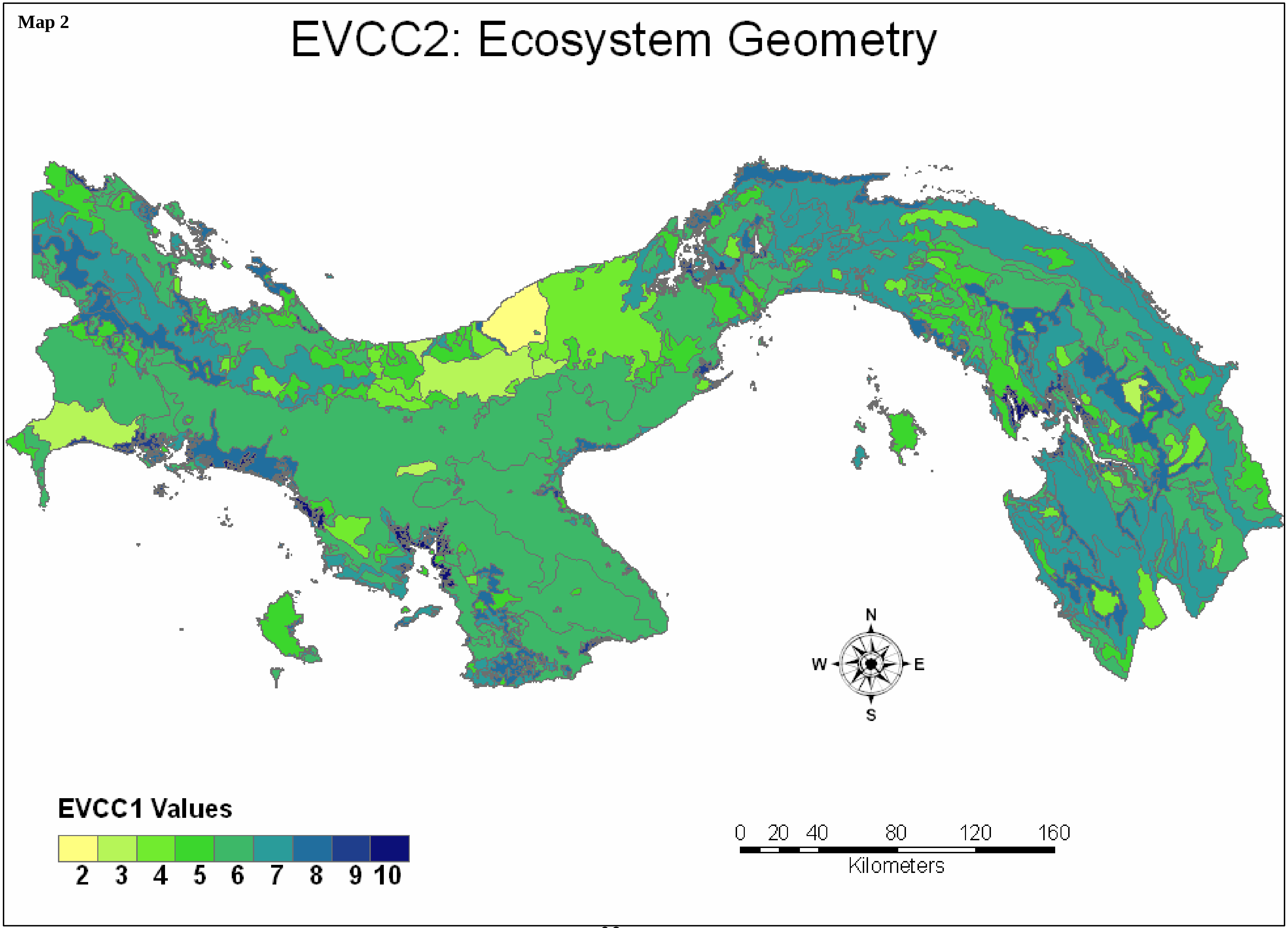


Figure 6 Distribution of average $EVCC_2$ values for each ecosystem type.

Map 2


EVCC2: Ecosystem Geometry
N
W
E
S
EVCC1 Values
2 3 4 5 6 7 8 9 10
0 20 40 80 120 160
Kilometers

3) Climatic 'space' of ecosystems – EVCC$_3$

EVCC$_3$ is an indicator of how much climate will change on average for each ecosystem patch, weighted by how much interannual variation in climate an ecosystem patch has been exposed to during the last 40 years. Only 770 out of the 1303 ecosystem patches were evaluated because of the resolution of the climate data and specificities of the type of spatial format (raster) that was used for the analysis. Figure 7 shows highlighted in light blue the ecosystem patches that were not included in the analysis. Their combined area is less than 0.16% of the Panama's total area, so their exclusion from EVCC$_3$ has minimal consequences on the overall EVCC.

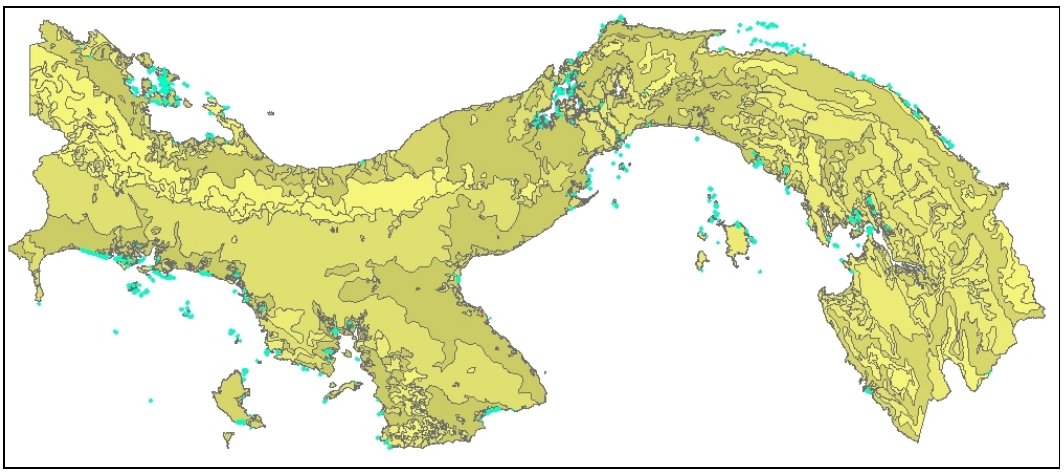


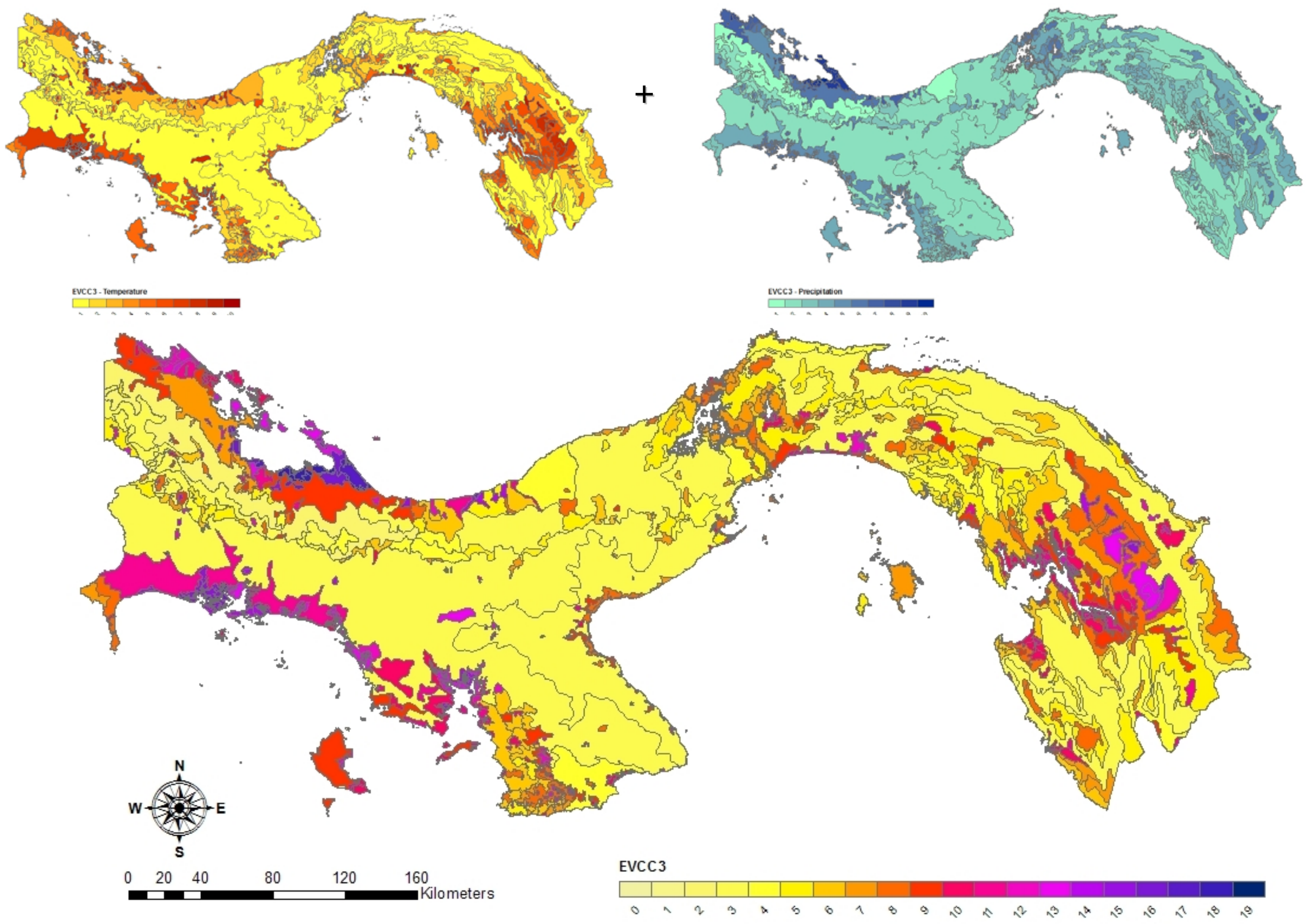
Figure 7: Ecosystem patches (in light blue) that were not evaluated under EVCC$_3$

A number of trends can be extracted by observing the EVCC$_3$ maps (Map 3). First, the most vulnerable regions of Panama, both in terms of temperature, precipitation and overall EVCC$_3$, are the Pacific and Caribbean sides of the western part of the country. The province of Bocas del Toro shows the highest vulnerability overall. In general, the interior of the country receives low vulnerability rank, including the Peninsula de Azuero but excluding some ecosystem patches in the Darien and around the Canal that are ranked with intermediate-high vulnerability. Given that a great proportion of these systems are highly exploited for agriculture, this is a positive result in economic terms. Isla Coiba has intermediate vulnerability, but its status as an island makes the micro-climate less predictable. In general, bigger ecosystem patches are less vulnerable, making an important proportion of the country's area low in vulnerability. This trend can be observed at the ecosystem type level as well, as shown in Figure 8. This figure also shows that no ecosystem type has very high vulnerability—on average—for both precipitation and temperature. Visually comparing the temperature and precipitation maps shows that vulnerability in terms of temperature and precipitation are spatially well-correlated, except for the Canal area that has more vulnerability in terms of precipitation and the Darien where vulnerability to temperature change is much more important than vulnerability to precipitation change. This trend also holds when averaging to the ecosystem type level. Figure 9 ranks ecosystem types according to overall $EVCC_3$ but details the ranking (out of 10) for precipitation and temperature. When a difference is observed, temperature often ranks higher, except for mountain ecosystems where the opposite occurs. Figure 10 details the number of ecosystem patches that have the same combination of rank for temperature and precipitation and shows that the similarity holds only at smaller ranks. In other words, ecosystem patches that are extremely vulnerable in terms of precipitation are generally not that vulnerable to temperature, but ecosystem patches that have moderate vulnerability often rank similarly in terms of temperature and precipitation.

The trends gathered from $EVCC_3$ show that the vulnerability to climate change in terms of the climatic "space" of ecosystems is asymmetrically distributed across the country and that it is wrong to assume all ecosystems will react similarly. Such analysis is useful for not only conservation purposes but also to increase the resilience of the agricultural system to global warming.

Map 3

EVCC$_3$: Climatic "space" of ecosystems



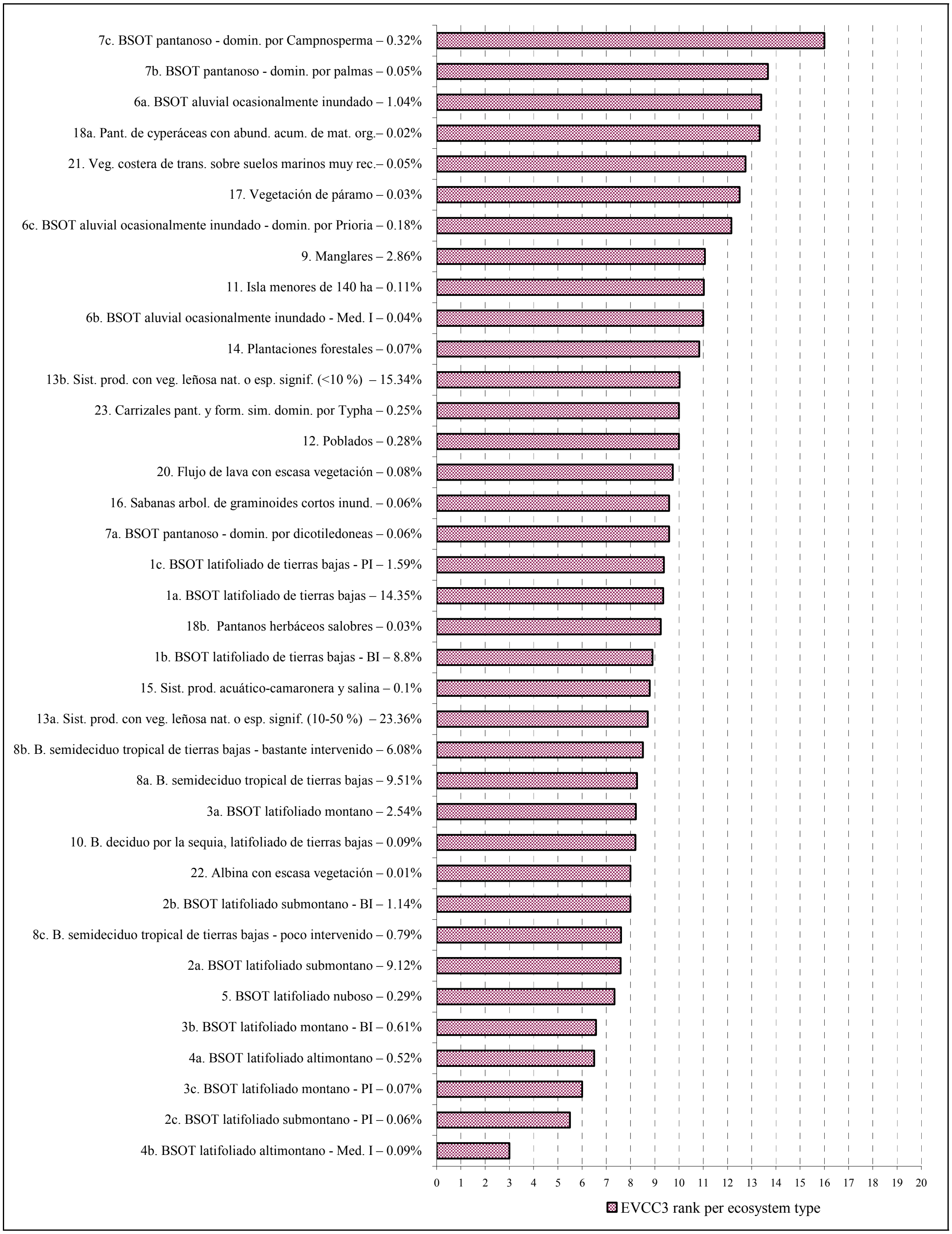


Figure 8: Average $EVCC_3$ per ecosystem type with proportion of Panama occupied by ecosystem

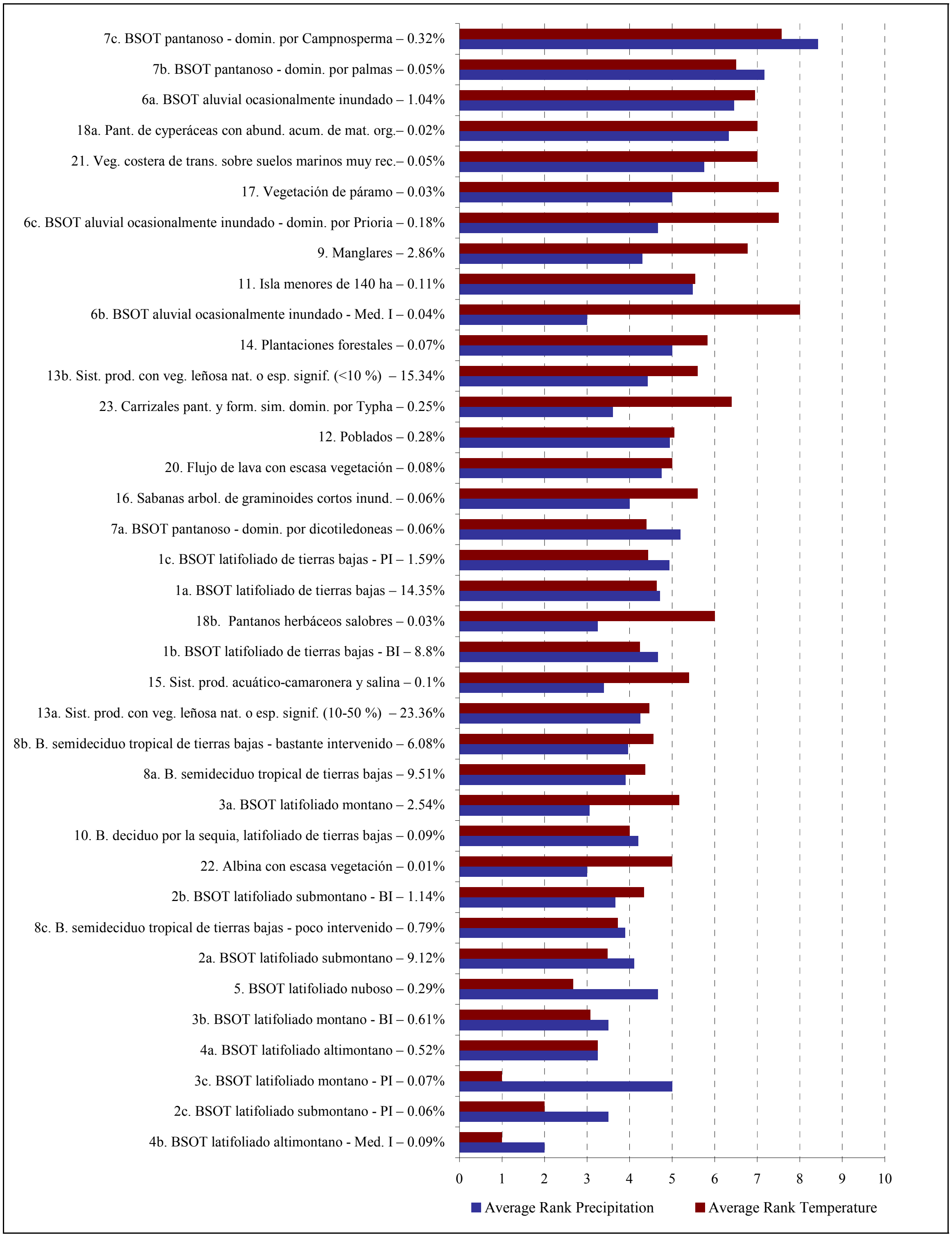


Figure 9: Average rank for temperature and precipitation per ecosystem type and proportion of Panama occupied by ecosystem

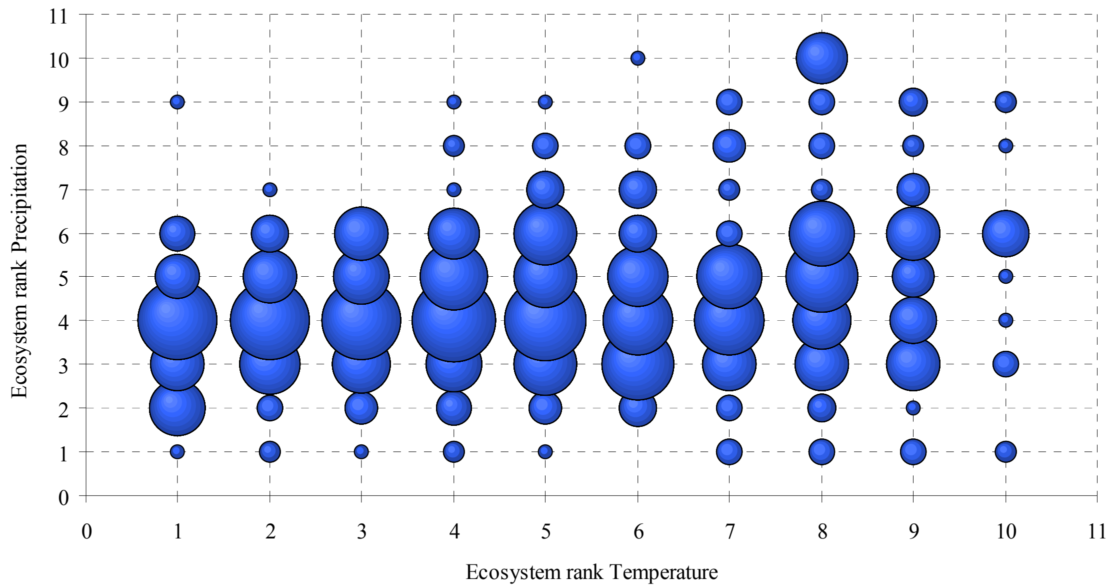


Figure 10: EVCC$_3$ rank for temperature vs. precipitation, area of bubble represents the number of ecosystem patches with that combination of rank

4) Species sensitivity – EVCC$_4$

EVCC$_4$ is a measure of how many species that are sensitive to climate change an ecosystem patch contains compared to other ecosystem patches, accounting for species density as a function of species richness and area of the patch. EVCC$_4$ was evaluated for all 1303 ecosystem patches. Map 4 displays EVCC$_4$ (refer to the Excel table or Arc file for more detailed results). This map shows average EVCC$_4$ for each ecosystem type, and Figure 12 divides EVCC$_4$ into its three components—birds, amphibians and mammals—per ecosystem type.

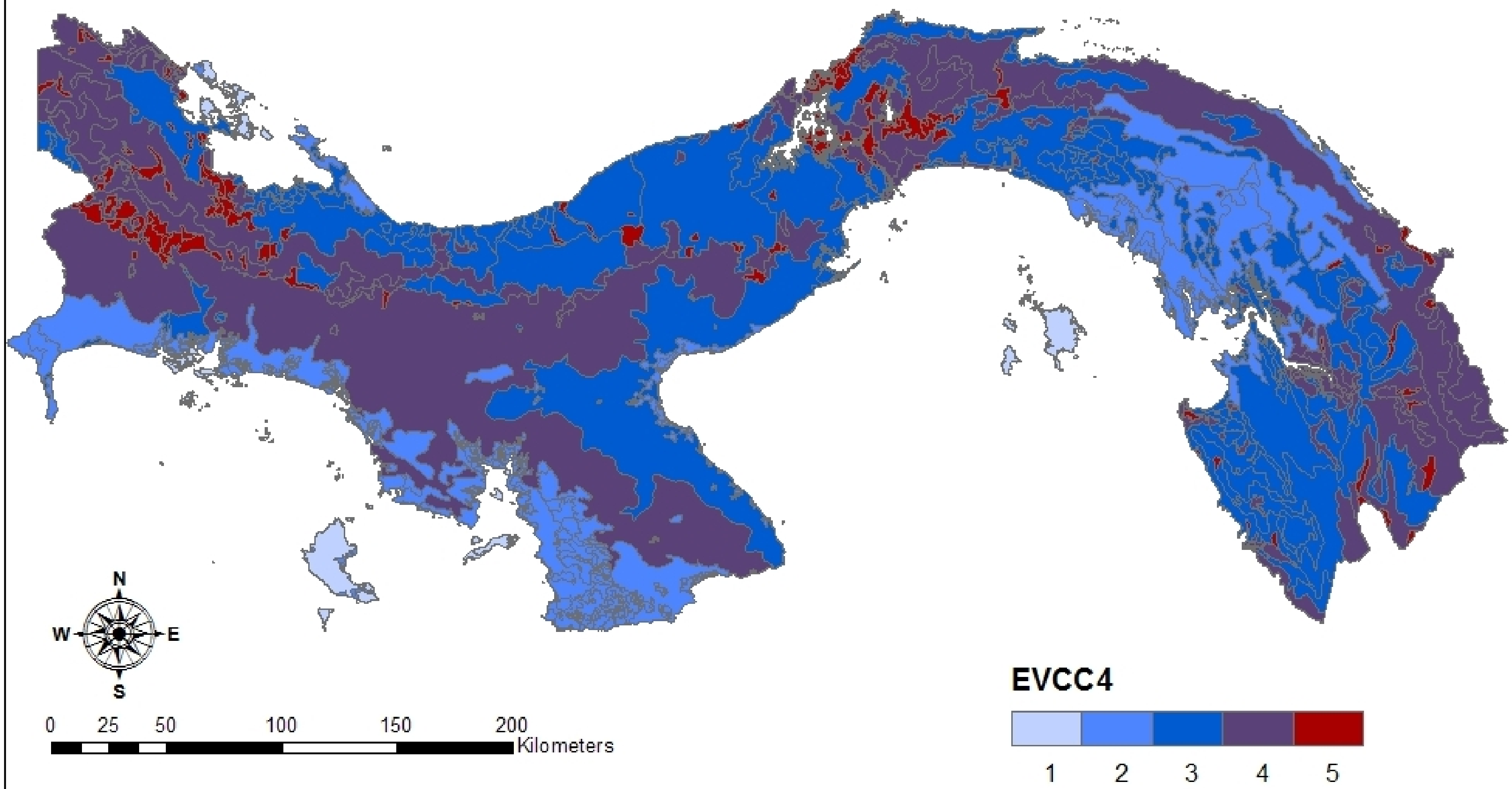
A noticeable result is that mountains ecosystems appear more vulnerable. The northwest part of the country is also more vulnerable, although this might be partly biased from the fact that the biggest ecosystem patch was very species-rich and that accounting for species density did not completely eliminate the area effect. Islands generally got lower scores, and this is probably due to their low species density compared to the mainland. It would be worthwhile to look more closely at endemic species in islands as these are likely to be sensitive to climate change. It is interesting to visually compare the map of endemism in Panama (see Map 6) with the map of $EVCC_4$. $EVCC_4$ appears to be correlated with endemism, which would be expected given that endemic species should have the smallest ranges of species within their groups. Finally, Figure 12 tells us that species sensitivity ranks of mammals, amphibians and birds are not necessarily correlated with themselves or with $EVCC_4$, although mammals and birds are generally more similar per ecosystem type.

The methodology used to measure $EVCC_4$ appears appropriate. As shown in Table 2, accounting for species density per ecosystem patch allowed us to remove the area effect that occurs when one only considers the average number of sensitive species. This effect results from the fact that a larger area can contain relatively more species with smaller ranges. It would probably be necessary to explore how the choice of the classification scheme (quantile and geometric) affects the resulting $EVCC_4$. It might prove worthwhile to justify a more scientifically grounded choice of classification that might be more appropriate to the type of data used and/or biologically relevant. It is important to keep in mind that $EVCC_4$ can only be as good as the initial species distributions used to construct it so that care must be taken to have distributions as accurate as possible to start with.

Due to data availability reasons, $EVCC_4$ only considered birds, mammals and amphibians. While this yields interesting results, uncertainty still remains as to how extinctions affect ecosystem stability and what the relationship is between ecosystem diversity, stability and function (Hooper *et al.*, 2005). In other words, it is uncertain that a higher number of species that are sensitive to climate change will make necessarily make an ecosystem more vulnerable to it. It is also important to keep in mind that climate change is one of the many threats facing species, and thus, $EVCC_4$ cannot be considered in isolation for specific species.

Map 4

EVCC$_4$ – Species sensitivity



For instance, the puma is the mammal with the widest distribution and as a result was not classified as sensitive. However, it is extremely vulnerable to other drivers and already has disappeared from a number of ecosystems. Ideally, $EVCC_4$ would be built on actual distribution maps, not on potential, as what it aims at ultimately is to estimate the risk of extinction and including species that have already disappeared from the ecosystem add another bias to the measure. Additionally, a possible way to make $EVCC_4$ less uncertain in terms of ecosystem vulnerability and more relevant in terms of the UNESCO's ecosystem classification would be to look at tree and other vegetation distributions. Focusing on the primary trophic level might also be more ecologically relevant when one is trying to link sensitivity and risk of extinction to ecosystem stability.

The theory behind $EVCC_4$, while intuitive, is still new (Thuiller *et al.*, 2005a) and is itself very uncertain. It will be important to keep up-to-date with the scientific literature to adjust $EVCC_4$ in terms of what is learned about species sensitivity to climate change. Despite its inherent uncertainty, it still provides useful results about the distribution of species' ranges while being a first attempt to link studies of climate change at the species level with an understanding of climate change vulnerability at the ecosystem level. The facts that 1) $EVCC_4$'s theory is rooted in many outstanding issues about our understanding of ecosystems, including the diversity-stability relationship, 2) that $EVCC_4$ is easy to quantify and 3) that it can be applied practically makes it a metric worthwhile to investigate both for ecology and conservation.

Table 3 Average $EVCC_4$ rank per ecosystem type

	Average ecosystem patch area (m^2)	
$EVCC_4$ Rank	Average species range	Average species range and density
1	274771.59	2850058.63
2	11219409.43	55318330.35
3	21173321.81	104512348.92
4	39363662.95	174075080.23
5	244691013.67	16272026.14

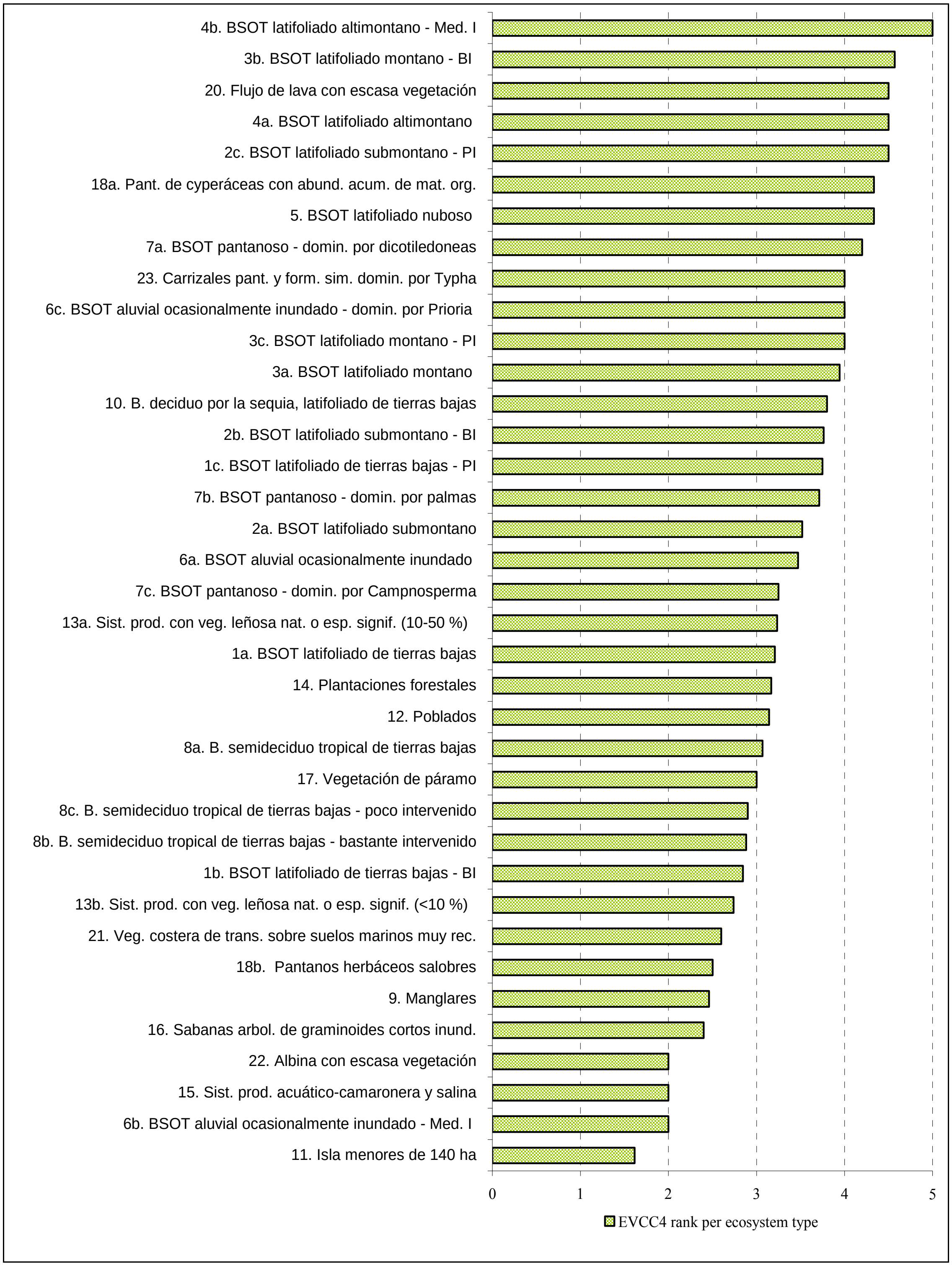


Figure 11: Distribution of $EVCC_4$ values for each ecosystem type

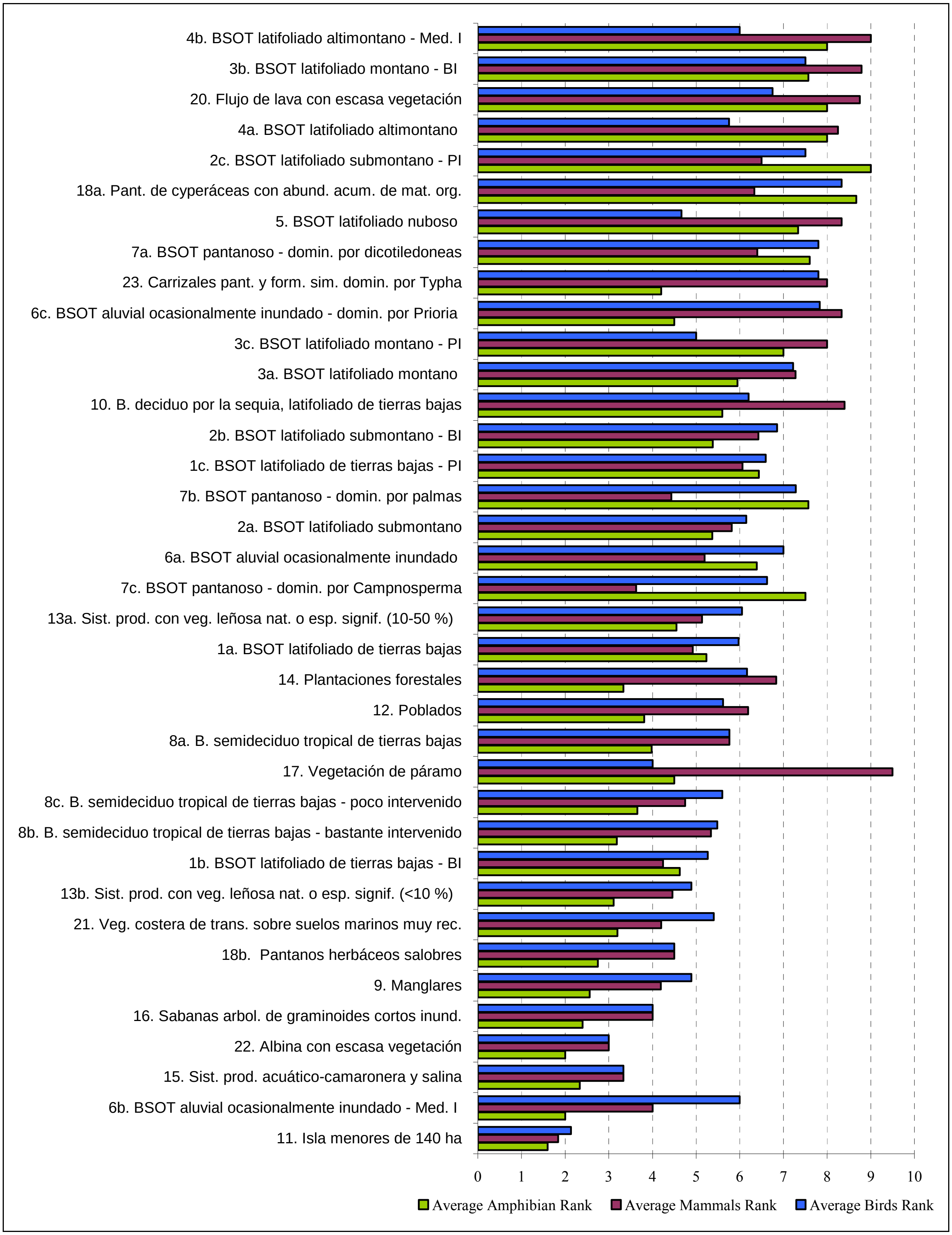


Figure 12: Distribution of bird, mammal and amphibian sensitivity ranks for each ecosystem type, ranked by total $EVCC_4$

B. Overall EVCC index

Even though justification is provided in deciding how to weigh each of the $EVCC_x$ values, the EVCC equation was still formulated somewhat arbitrarily. As Table 4 shows, each individual EVCC was ranked on a different scale. Species sensitivity was on a scale from 1-5, geometry from 1-10, sea level rise from 0-14, and climatic "space" was ranked from 0-19.

This scoring scheme highlights the ecosystem types with both the highest single EVCC values and highest average EVCC values. Red is the highest, orange the second, and yellow the third. In the case of a tie, all values have been assigned the same color (e.g., Max_EVCC2 has one red rank and a ten-way tie for orange, which means there will be no yellow). A column with "-no-F" means that it does not consider any EVCC_F values even though they have been given colors. The table is ranked by the overall score, which was determined by adding the number of each color-highlight for ecosystem type, where red=3, orange=2, and yellow=1 (e.g., Mangroves: 3*(2 red) + 2*(0 orange) + 1*(2 yellow) = 8), but it does not include EVCC_F because there would be redundancies in the score. Mangroves lead this ranking scheme because they had the highest maximum EVCC twice. The highest average overall EVCC is 30 for tropical evergreen swampy rainforests dominated by palms, but the variance of that value is extremely high. There are only seven patches of this ecosystem type, so the likelihood of an evening out of random variation is much lower than many other ecosystem types. But this argument does not work for islands—the most numerous-patched ecosystem type—which also has a high overall average EVCC variance. This can be explained by the large range that the islands carry—the minimum and maximum EVCCs can be very high or very low, depending on the individual ecosystem patch. An important general observation is that the ecosystems with the highest scores are mangroves, new coastal vegetation, swamps or marshlands, lowlands, and small islands.

Table 4 Summary of individual (EVCC_1,2,3,4) and overall (EVCC_F) with statistics and rankings

Ecosystem Type	# patches	Min_EVCC1	Max_EVCC1	Ave_EVCC1	Var_EVCC1	Min_EVCC2	Max_EVCC2	Ave_EVCC2	Var_EVCC2	Min_EVCC3	Max_EVCC3	Ave_EVCC3	Var_EVCC3	Min_EVCC4	Max_EVCC4	Ave_EVCC4	Var_EVCC4	Min_EVCC_F	Max_EVCC_F	Ave_EVCC_F	Var_EVCC_F	**Highlights**	**Highlight-no-F**	RED-no-F	ORANGE-no-F	YELLOW-no-F	**Score-no-F**
I.A.5. Bosque de manglar	137	0	14	6.9	11.9	5	10	7.4	1.4	0	16	10.3	13.7	1	5	2.5	1.0	8	40	27.1	33.8	**5**	**4**	2	0	2	**8**
VI.B.3. Vegetación costera de transición sobre suelos marinos muy recientes	5	0	10	7.4	17.3	7	9	8.4	0.8	0	17	10.2	39.7	2	3	2.6	0.3	22	32	28.6	15.3	**4**	**3**	1	2	0	**7**
I.A.1.f.(2) Bosque siempreverde ombrofilo tropical aluvial ocasionalmente inundado	36	0	12	3.4	17.9	4	9	6.5	1.4	0	19	13.0	22.3	1	5	3.5	0.8	12	40	26.4	60.1	**4**	**3**	1	1	1	**6**
I.A.1.g.(2) Bosque siempreverde ombrofilo tropical pantanoso dominado por palmas	7	0	10	7.6	11.6	5	8	7.0	1.3	0	18	11.7	38.6	2	5	3.7	1.6	18	38	30.0	61.0	**3**	**2**	1	1	0	**5**
I.A.1.g.(3) Bosque siempreverde ombrofilo tropical pantanoso dominado por Campnosperma	8	0	8	4.6	10.6	5	8	6.1	1.0	0	18	14.0	40.9	2	5	3.3	0.8	9	35	28.0	69.7	**3**	**2**	1	1	0	**5**
I.A.3.a. Bosque semideciduo tropical de tierras bajas - bastante intervenido	76	0	14	2.2	16.8	4	9	6.2	1.6	0	15	8.3	8.2	1	5	2.9	1.4	10	30	19.6	25.5	**2**	**2**	1	1	0	**5**
I.A.3.a. Bosque semideciduo tropical de tierras bajas – poco intervenido	20	0	14	3.2	22.8	4	9	6.4	1.7	0	11	6.9	8.7	1	5	2.9	2.1	12	29	19.4	13.4	**2**	**2**	1	1	0	**5**
I.A.3.a. Bosque semideciduo tropical de tierras bajas	59	0	14	2.7	16.4	3	9	6.3	1.5	0	15	7.3	14.3	1	5	3.1	1.5	10	30	19.3	16.1	**2**	**2**	1	1	0	**5**
Isla menores de 140 hectareas	530	0	14	6.0	33.4	6	9	6.3	0.3	0	18	0.8	8.7	1	5	1.6	1.3	7	38	14.7	41.6	**3**	**3**	0	2	0	**4**
V.D.1.a. Pantanos de cyperáceas con abundante acumulación de material orgánico	3	0	0	0.0	0.0	6	7	6.7	0.3	11	18	13.3	16.3	3	5	4.3	1.3	23	27	24.3	5.3	**2**	**2**	0	2	0	**4**
SP.A. Sistema productivo con vegetación leñosa natural o espontánea significativa (10-50 %)	60	0	10	3.2	15.7	4	9	6.3	1.3	0	18	8.1	15.9	1	5	3.2	1.7	8	37	20.9	43.1	**2**	**2**	0	2	0	**4**
P. Poblados	21	0	14	3.9	27.8	5	8	6.8	0.7	0	15	8.6	20.8	1	5	3.1	2.0	16	40	22.4	39.5	**2**	**1**	1	0	0	**3**
I.A.1.d.(1) Bosque siempreverde ombrofilo tropical latifoliado altimontano (1500-2000 m Car, 1800-2300m Pac) - medianamente interv.	1	0	0	0.0	0.0	5	5	5.0	0.0	3	3	3.0	0.0	5	5	5.0	0.0	13	13	13.0	0.0	**1**	**1**	1	0	0	**3**
SP.B. Sistema productivo con vegetación leñosa natural o espontánea significativa (<10 %)	46	0	12	4.6	16.0	3	9	6.4	1.7	0	15	9.2	16.3	1	5	2.7	1.6	9	34	22.8	29.6	**1**	**1**	0	1	0	**2**
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas - bastante intervenido	45	0	12	3.5	18.1	4	9	6.5	1.3	3	15	8.9	9.8	1	5	2.8	1.8	12	36	21.8	41.2	**1**	**1**	0	1	0	**2**
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas	77	0	12	3.4	16.0	2	9	6.1	1.7	0	17	8.7	15.0	1	5	3.2	2.1	11	32	21.5	26.4	**1**	**1**	0	1	0	**2**
VI.D. Albina con escasa vegetación	1	3	3	3.0	0.0	8	8	8.0	0.0	8	8	8.0	0.0	2	2	2.0	0.0	21	21	21.0	0.0	**1**	**1**	0	1	0	**2**
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500m Caribe, 1200-1800 m Pacífico) - bastante intervenido	14	0	0	0.0	0.0	5	7	6.0	0.8	3	13	6.6	8.7	3	5	4.6	0.4	12	25	17.1	11.1	**1**	**1**	0	1	0	**2**

VI.A.d. Flujo de lava con escasa vegetación	4	0	0	0.0	0.0	5	7	5.8	0.9	6	14	9.8	18.9	4	5	4.5	0.3	16	23	20.0	12.7	**1**	**1**	0	0	1	**1**
I.A.1.d.(1) Bosque siempreverde ombrofilo tropical latifoliado altimontano (1500-2000 m Caribe, 1800-2300 m Pacífico)	4	0	0	0.0	0.0	5	8	6.0	2.0	3	12	6.5	19.0	4	5	4.5	0.3	13	22	17.0	15.3	**1**	**1**	0	0	1	**1**
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico) - poco intervenido	2	0	0	0.0	0.0	4	6	5.0	2.0	5	6	5.5	0.5	4	5	4.5	0.5	13	17	15.0	8.0	**1**	**1**	0	0	1	**1**
I.A.1.g.(1) Bosque siempreverde ombrofilo tropical pantanoso dominado por dicotiledóneas	5	0	9	3.0	18.0	6	8	7.0	0.5	9	11	9.6	0.8	3	5	4.2	0.7	20	32	23.8	25.2	**0**	**0**	0	0	0	**0**
I.A.1.f.(2)(a) Bosque siempreverde ombrofilo tropical aluvial, ocasionalmente inundado dominado por Prioria	6	0	0	0.0	0.0	5	8	6.2	1.4	9	14	12.2	4.6	3	5	4.0	0.4	18	26	22.3	7.5	**0**	**0**	0	0	0	**0**
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas - poco intervenido	32	0	12	1.7	11.1	4	8	6.3	1.4	5	16	9.4	11.0	1	5	3.8	2.1	15	32	21.2	26.1	**0**	**0**	0	0	0	**0**
V.C.2.b. Vegetación de páramo	2	0	0	0.0	0.0	5	6	5.5	0.5	12	13	12.5	0.5	3	3	3.0	0.0	21	21	21.0	0.0	**0**	**0**	0	0	0	**0**
SP.C. Sistema productivo acuático-camaronera y salina	6	0	12	4.7	21.9	5	8	6.8	1.4	0	11	7.3	14.3	2	2	2.0	0.0	19	25	20.8	5.8	**0**	**0**	0	0	0	**0**
V.E.1.a.2. Pantanos herbáceos salobres	4	0	8	2.0	16.0	6	8	7.0	0.7	7	12	9.3	4.3	2	4	2.5	1.0	17	31	20.8	46.9	**0**	**0**	0	0	0	**0**
I.B.1.a.(1) Bosque deciduo por la sequía, latifoliado de tierras bajas	5	0	8	2.8	15.2	4	7	5.8	1.7	6	10	8.2	2.2	3	5	3.8	0.7	17	29	20.6	24.3	**0**	**0**	0	0	0	**0**
SP.B.1. Plantaciones forestales	6	0	0	0.0	0.0	6	7	6.3	0.3	7	15	10.8	9.0	2	4	3.2	1.0	17	23	20.3	4.7	**0**	**0**	0	0	0	**0**
V.A.2.d. Sabanas arboladas de graminoides cortos inundables	5	0	6	1.2	7.2	6	8	7.0	0.5	7	12	9.6	3.3	2	4	2.4	0.8	19	23	20.2	3.2	**0**	**0**	0	0	0	**0**
VII.B. Carrizales pantanosos y formaciones similares principalmente de Typha	5	0	0	0.0	0.0	4	7	5.4	1.8	9	11	10.0	1.0	4	4	4.0	0.0	17	21	19.4	3.3	**0**	**0**	0	0	0	**0**
I.A.1.f.(2) Bosque siempreverde ombrofilo tropical aluvial ocasionalmente inundado - medianamente intervenido	1	0	0	0.0	0.0	5	5	5.0	0.0	11	11	11.0	0.0	2	2	2.0	0.0	18	18	18.0	0.0	**0**	**0**	0	0	0	**0**
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500 m Caribe, 1200-1800 m Pacífico)	18	0	0	0.0	0.0	4	8	5.6	1.3	3	14	8.2	14.9	2	5	3.9	1.3	10	24	17.8	16.8	**0**	**0**	0	0	0	**0**
I.A.1.e.(1) Bosque siempreverde ombrofilo tropical latifolado nuboso (2000-3000 m Caribe, 2300-3000 m Pacífico)	3	0	0	0.0	0.0	6	6	6.0	0.0	5	9	7.3	4.3	3	5	4.3	1.3	14	20	17.7	10.3	**0**	**0**	0	0	0	**0**
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico) - bastante interv.	21	0	0	0.0	0.0	3	8	5.6	1.5	4	13	8.0	10.6	2	5	3.8	1.8	12	22	17.4	11.4	**0**	**0**	0	0	0	**0**
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico)	27	0	0	0.0	0.0	3	8	5.7	1.4	2	14	7.6	11.2	2	5	3.5	1.1	9	24	16.9	13.5	**0**	**0**	0	0	0	**0**
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500 m Caribe, 1200-1800 m Pacífico) - poco intervenido	1	0	0	0.0	0.0	5	5	5.0	0.0	6	6	6.0	0.0	4	4	4.0	0.0	15	15	15.0	0.0	**0**	**0**	0	0	0	**0**

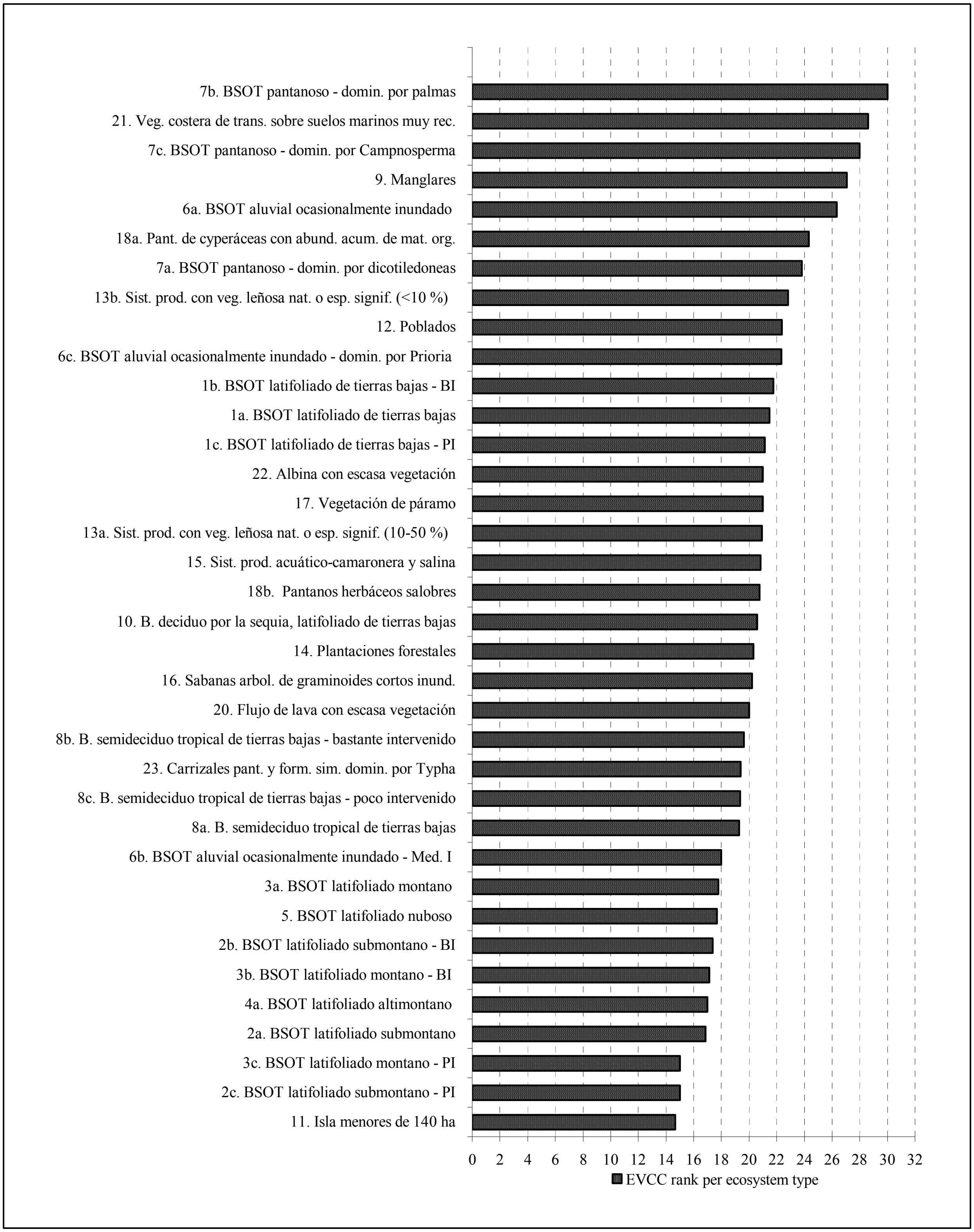
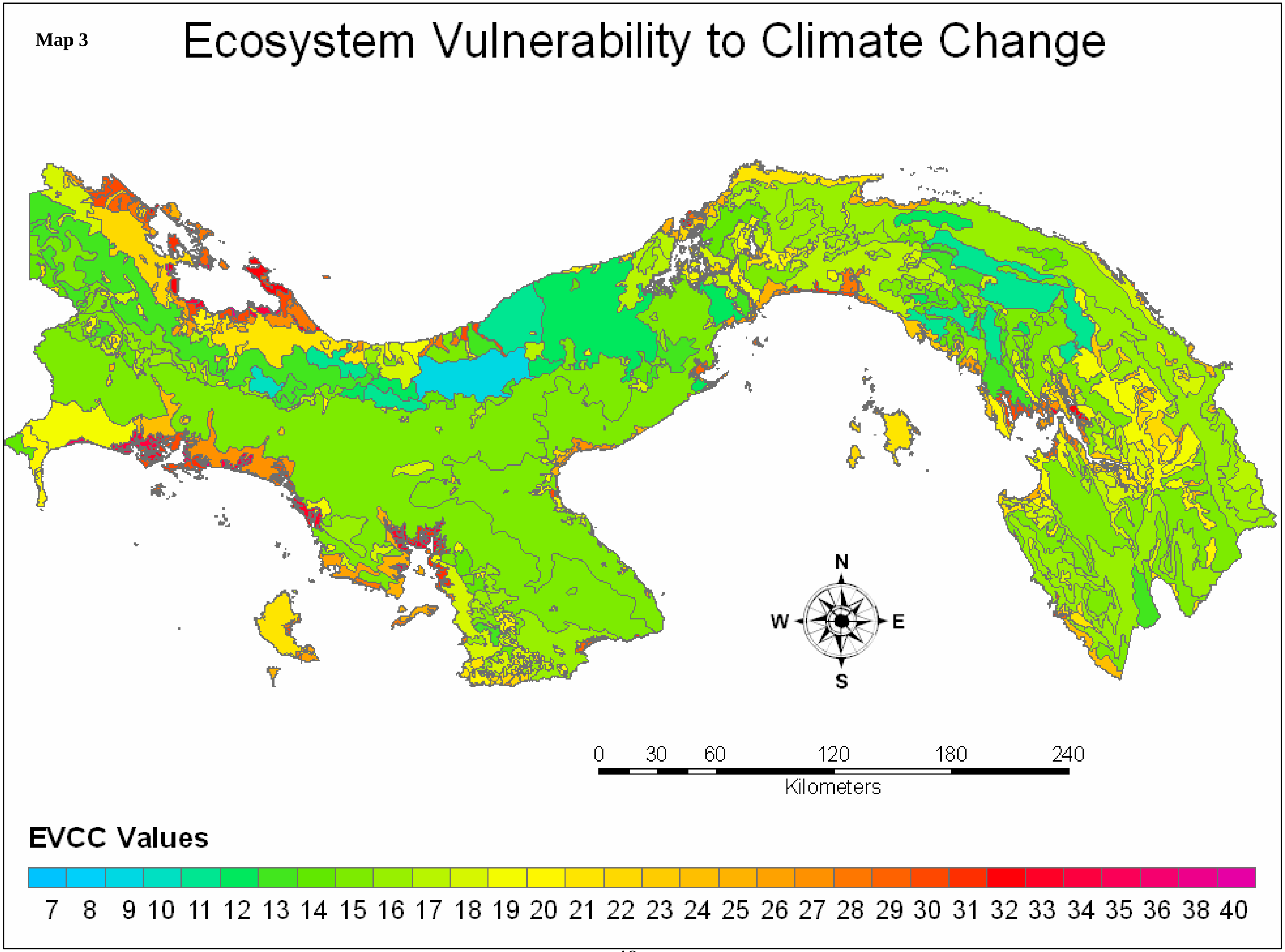


Figure 13 Distribution of average overall EVCC values for each ecosystem type


Map 3
Ecosystem Vulnerability to Climate Change
N
W
E
S
0 30 60 120 180 240
Kilometers
EVCC Values
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 38 40

C. Applications of the index

Only the overall EVCC values are compared to the three applications. Relationships between the EVCC index and the applications are provided and discussed in each section.

1) Degree of human intervention

Before comparing the EVCC to this measurement, the percent area of each intervention level was calculated (Table 5).

Table 5 Percentage of human intervention

	Level of Intervention	Total area of intervention type (ha)	% area of Panama
0	None documented	3096464.7364	41.58%
1	Natural system with low intervention	187260.6452	2.51%
2	Natural system with medium intervention	9389.7263	0.13%
3	Natural system with high intervention in mountains	130335.2176	1.75%
4	Natural system with high intervention in lowlands	1107875.1517	14.88%
5	Productive system with 10-50% natural veg	1739669.8057	23.36%
6	Productive system with <10% natural veg	1142648.6367	15.34%
7	Agroforestry	5267.1732	0.07%
8	Shrimp / Salt production	7391.1249	0.10%
9	Populated place	21170.0424	0.28%
	All area of Panama	*7447472.2601*	*100.00%*

These results are based solely on UNESCO's descriptions of ecosystem types and their delineations on its ecosystem map. The three mid-levels (4, 5, and 6) of intervention account for over half of the land in Panama. The areas with the highest levels of intervention (agroforestry, shrimp and salt production, and populated places) cover less than one-half percent of the land, but are should not be deemed insignificant because of the strong human interest placed in these systems (e.g., ecosystem services).

Table 6 EVCC values compared to Degrees of Intervention

	Level of intervention	Avg_EVCC$_1$	Ave_EVCC$_2$	Ave_EVCC$_3$	Ave_EVCC$_4$	Ave_EVCC
0	none	5.0987	6.4086	4.6817	2.2658	18.4548
1	Natural system with low intervention	2.1636	6.2727	8.2545	3.4727	20.1636
2	Natural system with medium intervention	0.0000	5.0000	7.0000	3.5000	15.5000
3	Natural system with high intervention in mountains	0.0000	5.7714	7.4286	4.0857	17.2857
4	Natural system with high intervention in lowlands	2.7025	6.3223	8.5207	2.8678	20.4132
5	Productive system with 10-50% natural veg	3.2333	6.3167	8.1333	3.2333	20.9167
6	Productive system with <10% natural veg	4.5652	6.3696	9.1522	2.7391	22.8261
7	Agroforestry	0.0000	6.3333	10.8333	3.1667	20.3333
8	Shrimp / Salt production	4.6667	6.8333	7.3333	2.0000	20.8333
9	Populated place	3.9048	6.7619	8.5714	3.1429	22.3810

Red = highest average; orange = second highest; yellow = third highest.
Blue = most commonly ranked with high vulnerability

Table 6 demonstrates the individual and overall average EVCC values for each level of intervention. Notable levels are zero, six, eight, and nine (highlighted in blue) because of the frequency of high vulnerabilities (red, orange, and yellow). The zero intervention level includes all islands less than 140 hectares, of which there are over 530 ecosystem patches (Appendix 1). That average EVCC$_1$ is the highest here makes sense because so many islands are susceptible to flooding due to sea level rise. They also receive a high EVCC$_{2a}$ values because often islands have no "edge" in the edge to core ratio. Intervention level six, productive systems with less than 10% natural or spontaneous vegetation-type ecosystems received the highest overall average EVCC. Except for EVCC$_4$ (which makes sense because this is a highly cultivated ecosystem type that has likely removed native species and decreased biodiversity), all EVCC$_{1,2,3}$

are relatively high. The fact that this study has ranked this intervention level as the second most vulnerable according to climatic "space" is worth attention. Farming relies upon climatic cycles that have been learned and adapted to for centuries, and the geographical locations of the patches of this agricultural ecosystem type are such that climate change projections illustrate some of the highest changes in temperature and precipitation. Intervention level eight—shrimp and/or salt production—can mostly be explained by the combination of their close proximity to coastlines and the almost absent slope of the land. The farming of shrimp and salt requires vast extents of flat land that are occasionally inundated by sea water at the highest high tides of the year. It is obvious that sea level rise will greatly impact these areas. Perhaps the most worrisome to policymakers is that the populated places have received the second highest overall average vulnerability. They lie in the upper half of sea level rise vulnerability and in the lower half of species sensitivity. The pertinence of its high $EVCC_2$ ranking is questionable because it is not one of the *natural* systems, which are more susceptible to ramifications of stochastic processes when they have irregular shapes or many edges to welcome the perturbations. This human-dominated system is very buffered by these types of effects. It is also notable that the projected changes in temperature and precipitation have more of an impact here than other places.

2) Protected areas

The percentage of area protected in each ecosystem type is compared to its mean EVCC value in (Figure 8). This shows that some of the most vulnerable ecosystem types are also the ones with the least protection on average. Also, the average overall EVCC per area (at a resolution of 1 km^2) and the four individual EVCC components were calculated for all areas that are protected, all areas that are not protected, and the whole of Panama (see Table 7). This allows for an evaluation of how the current protected area network accounts for ecosystem vulnerability to climate change according to the EVCC. The average EVCC should be higher within protected areas if the network generally protects more vulnerable regions. If the average EVCC is lower inside protected areas, the protected areas network is inadequate in protecting vulnerable areas. We found the latter to be the case for the overall EVCC, $EVCC_1$ and $EVCC_3$, but the effect is much more pronounced in $EVCC_1$. Nonetheless, the fact that in almost no case is the average EVCC in protected areas higher means that the current network of reserve is inadequate to protect the vulnerable areas of Panama in terms of future climate change. Additionally, something to keep in mind with this analysis is that protected marine areas are excluded because the ecosystem patch map does not include aquatic ecosystems.

Table 7: Average EVCCs per area in Panama as a whole and inside and outside of protected areas

	inside PAs	outside PAs	Panama
EVCC	17.63062	17.787722	17.842452
$EVCC_1$	1.34952	1.978375	2.197648
$EVCC_2$	6.384813	6.094201	5.992869
$EVCC_3$	5.129844	5.132692	5.133686
$EVCC_4$	4.766585	4.582453	4.518249

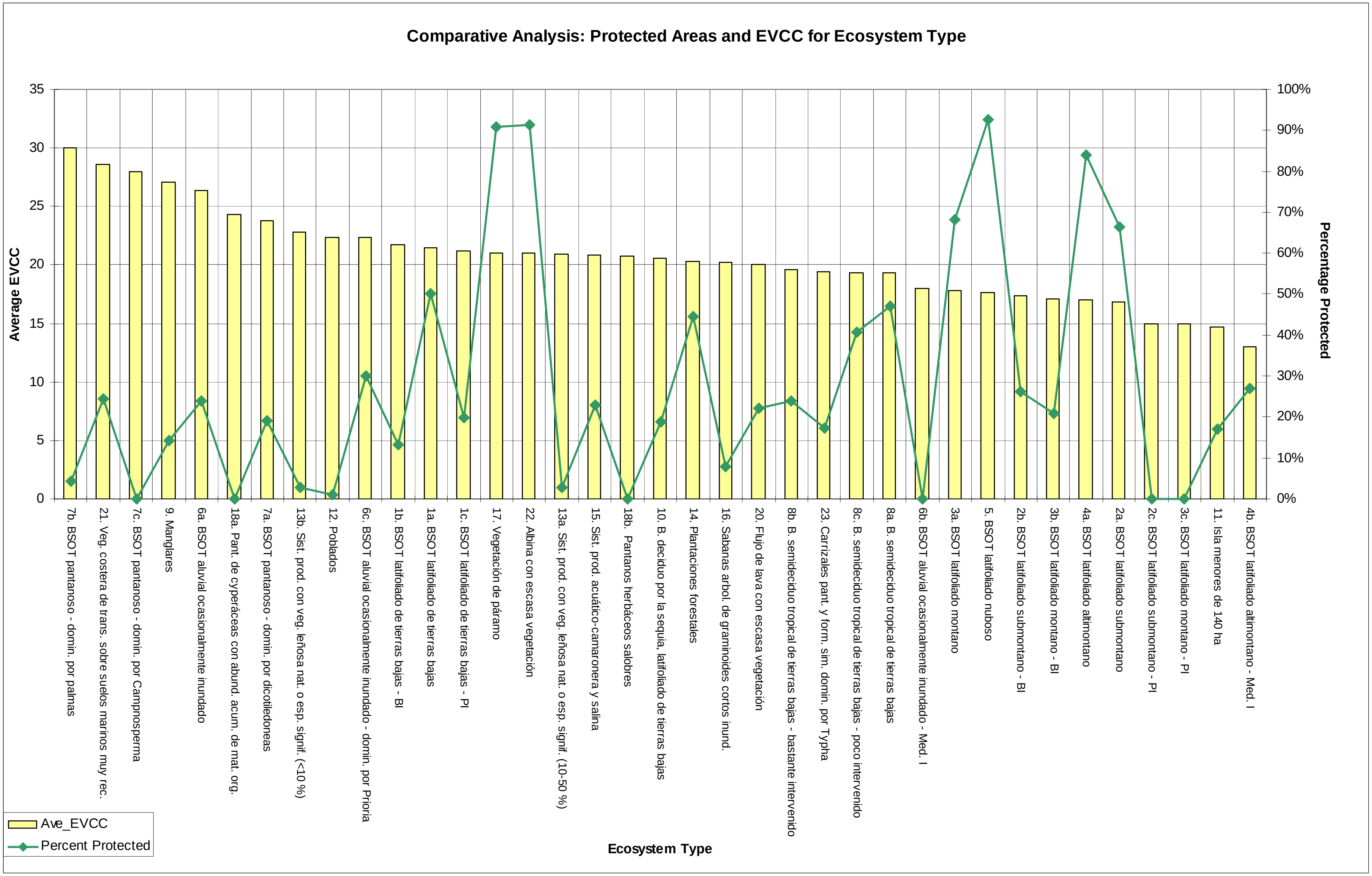


Figure 8 Protected Areas Analysis

3) Species richness and endemism

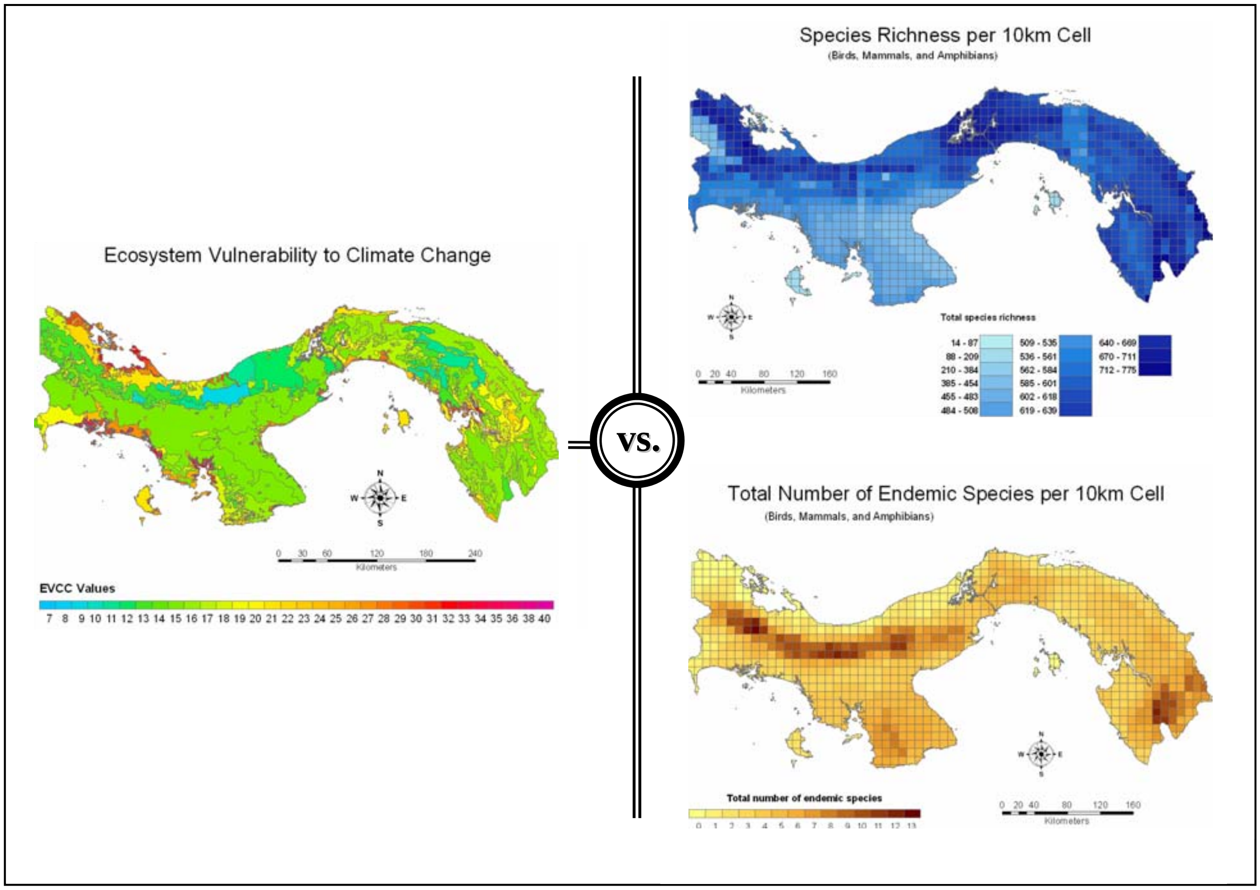


Figure 9: Comparing the overall EVCC with patterns of species richness and endemism in Panama

Species richness and endemism were calculated for each cell of a 10 x 10 km grid of Panama (right part of Figure 9). It should be noted that endemism for mammals, birds, and amphibians is inversely related to the species richness in Panama. That is, there are more birds than mammals and more mammals than amphibians in the country, but in terms of endemism, there are the most amphibians and the least birds. For each cell, the overall EVCC was compared with a map of species richness and endemism to see if any patterns could be extracted or whether areas of high biodiversity also happened to be more vulnerable to climate change according to the EVCC (Figure 9). Generally correlations were found for neither species richness nor endemism excepting for $EVCC_3$ where regions of high endemism had a low score (this is reflected in the overall EVCC as well) (Figure 10). In order to highlight regions that had both high species richness and overall EVCC, species richness per ecosystem patch was multiplied by overall EVCC score to yield Map 6. The region that stands out the most in this map is Bocas del Toro. Western Panama, the areas of the Canal and the south of the Darien are highlighted as well.

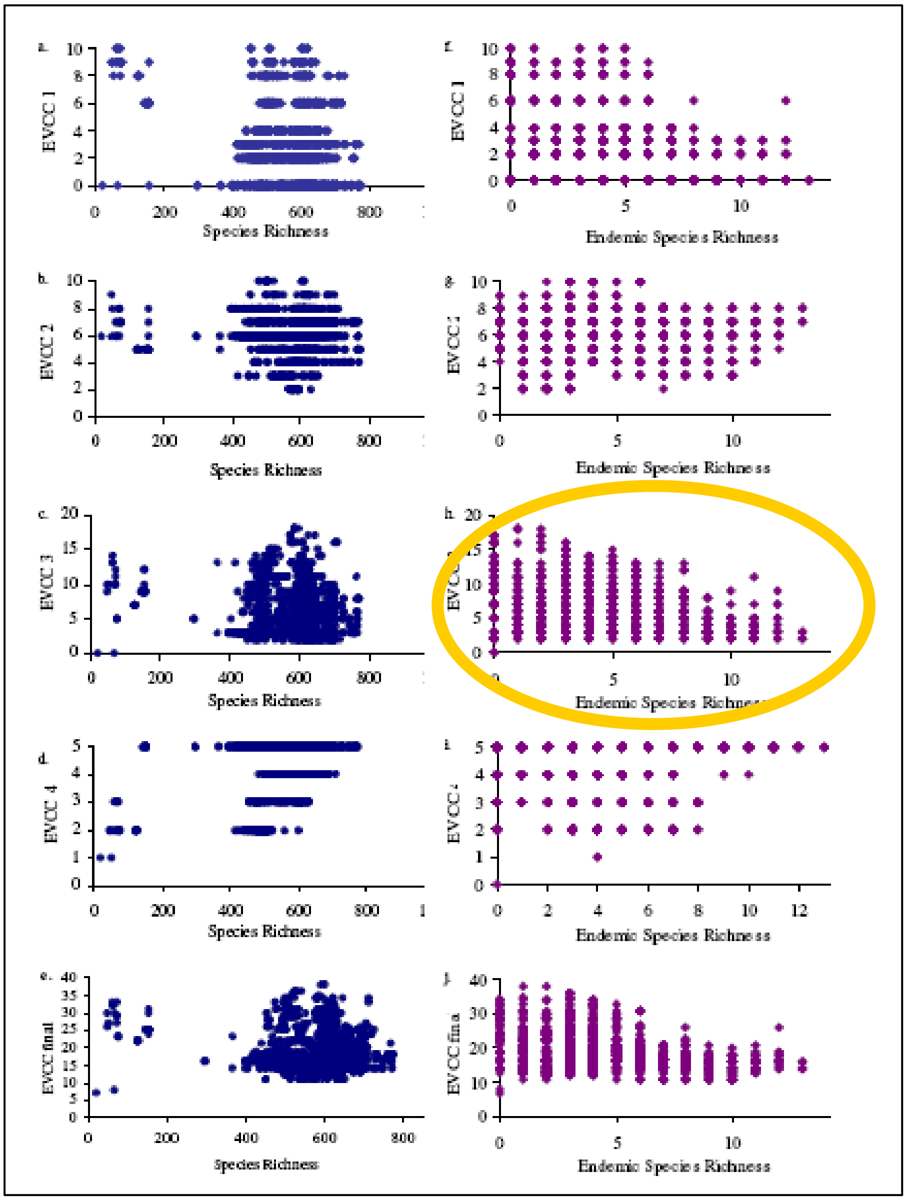
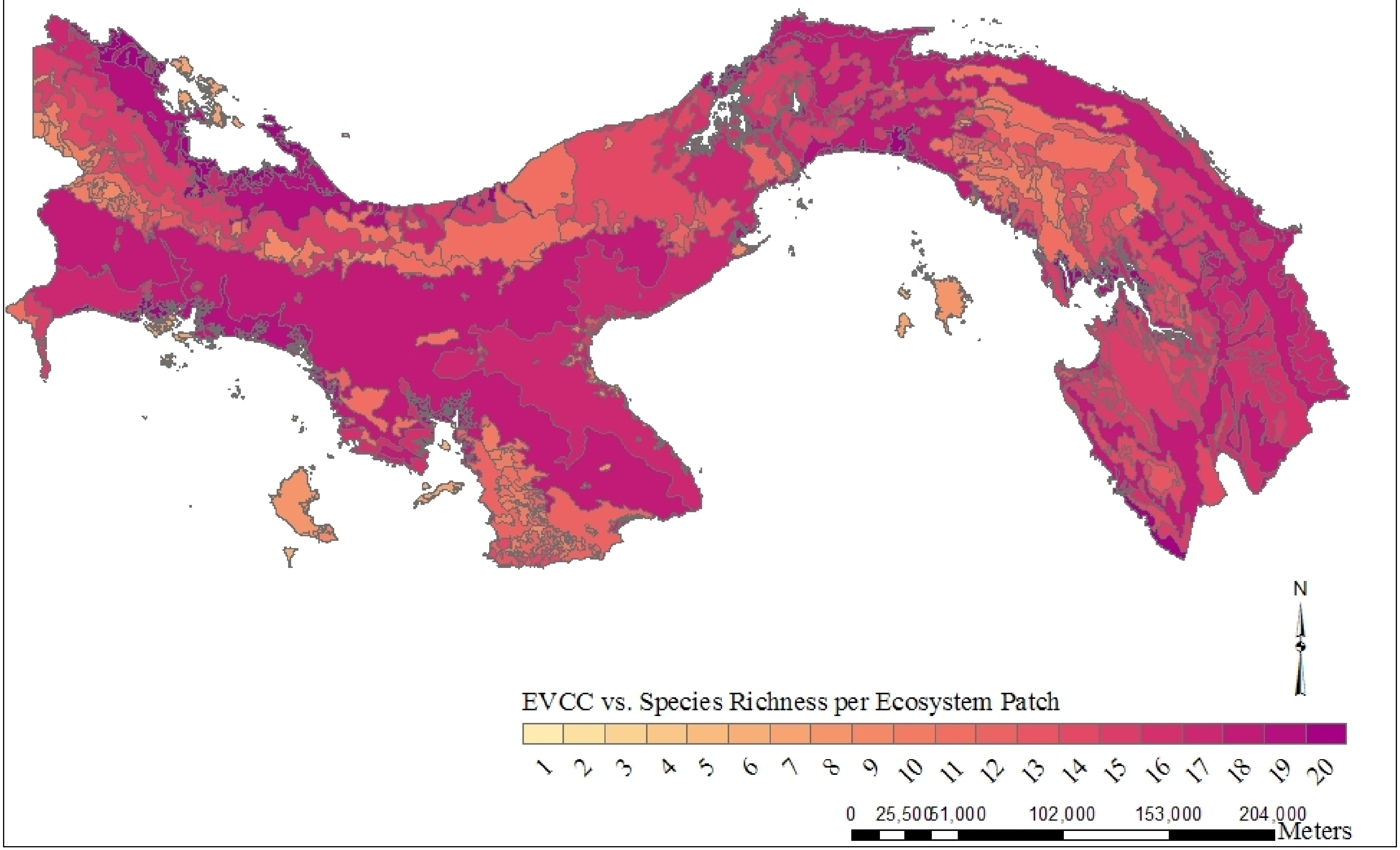


Figure 10: Correlation of species richness (a-e) and endemism (f-j) with EVCCs for each cell of a 10x10 km grid of Panama

Map 6

Combining overall EVCC with species richness



VI. Conclusions

The objective of this project was to conduct a preliminary assessment of ecosystem vulnerability to climate change in Panama. The final results include both a set of maps from which spatial information (including specific information on ecosystem patches and trends) can be extracted and an analysis of the EVCC in turns of applications relevant to conservation. These were communicated in a comprehensive format to the host institution as both a hard copy (including a copy of important GIS data and maps) and a presentation. This project can not only be valuable for the conservation of biodiversity of Panama both also to other regions by providing a framework that can be followed to build EVCC assessments in other geographical locations.

Again, the EVCC is a preliminary assessment and is far from perfect. There are a number of issues that could be addressed to improve it and a number of uncertainties that need to be accounted for when applying the EVCC in policy-making. We outline some of them here.

First, certain types of data were unavailable at the time of the assessment but should preferably be included in future assessments if possible. These include CCM scenarios other than “business-as-usual,” and higher climate resolution for the CCM and tree distributions. Moreover, islands are underrated in this assessment because of overlaying issues in $EVCC_1$ (such that an island’s overall elevation is misrepresented) and because many of them were not included in $EVCC_3$ since they are so small. Also, future climate for islands is harder to predict because of micro-climate issues brought by the surrounding water masses. Finally, the effects of the ranking scheme on the overall EVCC should be investigated. While efforts were put into using the most relevant scheme for each data type, it might well be that these had unintended effects on the overall distribution of the EVCC.

Second, the EVCC can only be as good as its input data. There are a number of uncertainties in the accuracy of the data and thus, the results are not definitive. Possible problems include the digital elevation model of sea level rise vulnerability, predictions of future climatic conditions and species distributions. There are also uncertainties associated with the theories behind the EVCC. Considerable efforts were put into including the latest scientific consensus on the effects of climate change on species and ecosystems, but these ideas are always evolving. Likewise, it might well be that the four components selected to build the EVCC are not enough, or too much, and this should be investigated in light of the most recent scientific literature. In general, studies like this performed in GIS should be used as *indicators* of where further research or conservation efforts should be directed. These results cannot replace on-sight situation analyses, but at least such projects can pinpoint locations of high concern. It is essential to use a comprehensive framework to address uncertainty in data and theory, especially in areas like climate change where these uncertainties are high.

To conclude, EVCC has the potential to be a very interesting tool for conservation and ecology. It is very much a work-in-progress and has been structured in a flexible way so that it can be easily improved. One of the biggest challenges in using the EVCC in conservation will be to weigh its relative importance in comparison to other human drivers of biodiversity loss, such as like habitat degradation, over-exploitation of resources and invasive species. Notwithstanding all the uncertainties associated with the EVCC, this is the first attempt at quantifying vulnerability to climate change at the ecosystem level and sets up a template that can be used directly or adjusted according to specific needs. Because it estimates an important threat to ecosystems, climate change, which is usually over-looked in biodiversity assessments, can become a very useful tool for conservation.

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Appendix 1. Ecosystem Types and Frequencies

UNESCO ecosystem type	# of patches	Total area (ha)
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas	77	1068489.0140
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas - bastante intervenido	45	654997.4415
I.A.1.a.(1) Bosque siempreverde ombrofilo tropical latifoliado de tierras bajas - poco intervenido	32	118382.9463
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico)	27	679494.4446
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico) - bastante intervenido	21	84856.4851
I.A.1.b.(1) Bosque siempreverde ombrofilo tropical latifoliado submontano (500-1000 m Caribe, 700-1200 m Pacífico) - poco intervenido	2	4747.5028
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500 m Caribe, 1200-1800 m Pacífico)	18	189520.8868
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500 m Caribe, 1200-1800 m Pacífico) - bastante intervenido	14	45478.7325
I.A.1.c.(1) Bosque siempreverde ombrofilo tropical latifoliado montano (1000-1500 m Caribe, 1200-1800 m Pacífico) - poco intervenido	1	5093.5239
I.A.1.d.(1) Bosque siempreverde ombrofilo tropical latifoliado altimontano (1500-2000 m Caribe, 1800-2300 m Pacífico)	4	38690.5909
I.A.1.d.(1) Bosque siempreverde ombrofilo tropical latifoliado altimontano (1500-2000 m Caribe, 1800-2300 m Pacífico) - medianamente intervenido	1	6594.3574
I.A.1.e.(1) Bosque siempreverde ombrofilo tropical latifoliado nuboso (2000-3000 m Caribe, 2300-3000 m Pacífico)	3	21339.9920
I.A.1.f.(2) Bosque siempreverde ombrofilo tropical aluvial ocasionalmente inundado	36	77392.5517
I.A.1.f.(2) Bosque siempreverde ombrofilo tropical aluvial ocasionalmente inundado - medianamente intervenido	1	2795.3689
I.A.1.f.(2)(a) Bosque siempreverde ombrofilo tropical aluvial, ocasionalmente inundado dominado por Prioria	6	13410.2662
I.A.1.g.(1) Bosque siempreverde ombrofilo tropical pantanoso dominado por dicotiledóneas	5	4124.8543
I.A.1.g.(2) Bosque siempreverde ombrofilo tropical pantanoso dominado por palmas	7	3760.6590
I.A.1.g.(3) Bosque siempreverde ombrofilo tropical pantanoso dominado por Campnosperma	8	23960.6124
I.A.3.a. Bosque semideciduo tropical de tierras bajas	59	708492.0301
I.A.3.a. Bosque semideciduo tropical de tierras bajas - bastante intervenido	76	452877.7101
I.A.3.a. Bosque semideciduo tropical de tierras bajas - poco intervenido	20	59036.6721
I.A.5. Bosque de manglar	137	212650.1390
I.B.1.a.(1) Bosque deciduo por la sequía, latifoliado de tierras bajas	5	7059.7005
Isla menores de 140 hectáreas	530	8291.8601
P. Poblados	21	21170.0424
SP.A. Sistema productivo con vegetación leñosa natural o espontánea significativa (10-50 %)	60	1739669.8057
SP.B. Sistema productivo con vegetación leñosa natural o espontánea significativa (<10 %)	46	1142648.6367
SP.B.1. Plantaciones forestales	6	5267.1732
SP.C. Sistema productivo acuático-camaronera y salina	6	7391.1249

V.A.2.d. Sabanas arboladas de graminoides cortos inundables	5	4329.8005
V.C.2.b. Vegetación de páramo	2	2484.9664
V.D.1.a. Pantanos de cyperáceas con abundante acumulación de material orgánico	3	1305.0761
V.E.1.a.2. Pantanos herbáceos salobres	4	2002.2752
VI.A.d. Flujo de lava con escasa vegetación	4	5987.8219
VI.B.3. Vegetación costera de transición sobre suelos marinos muy recientes	5	3855.5363
VI.D. Albina con escasa vegetación	1	874.2372
VII.B. Carrizales pantanosos y formaciones similares principalmente de Typha	5	18385.8150
TOTAL	**1303**	**~7446911**

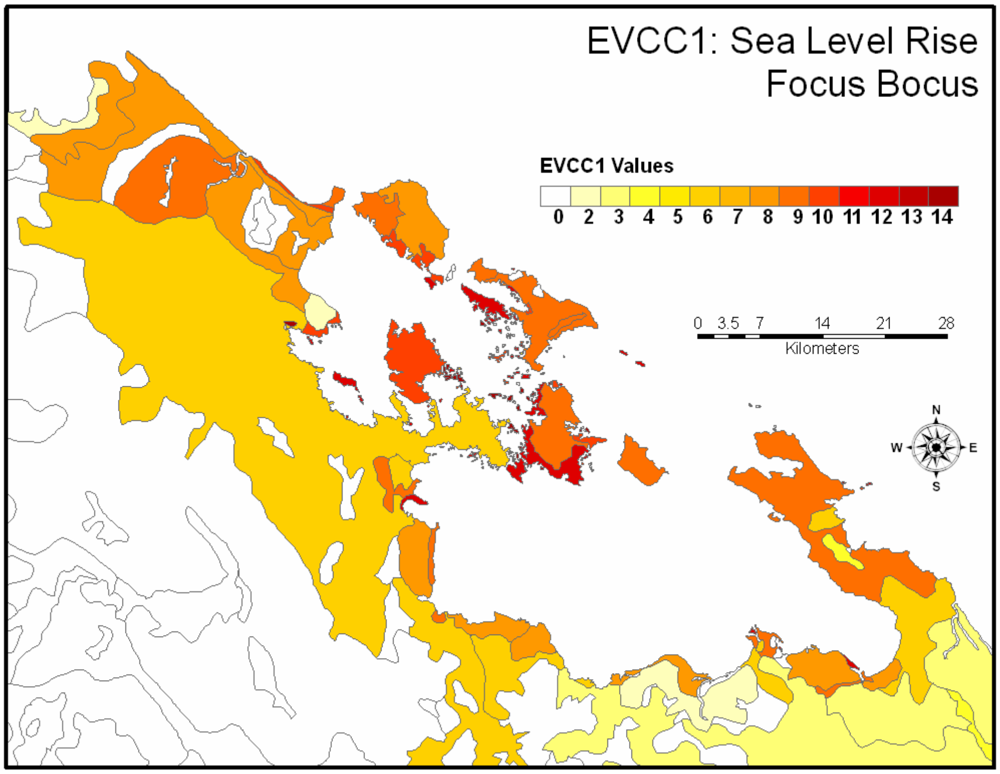
Appendix 2. Endemic Species in Panama

Scientific Name	Common Name	Range (hectares)
Mammalia		
Alouatta coibensis	Coiba Island Howling Monkey	782260
Bassaricyon pauli	Chiriqui Olingo	139384
Bradypus pygmaeus	Escudo Island Three-toed Sloth	341
Coendou rothschildi	Rothschild's Porcupine	5829280
Cryptotis endersi	Ender's Small-eared Shrew	142297
Cryptotis mera	Darien Small-eared Shrew	645692
Dasyprocta coibae	Coiban Agouti	?
Dermanura incomitata	Isla Escudo Fruit-eating Bat	341
Isthmomys flavidus	Yellow Isthmus Rat	647036
Liomys adspersus	Panamanian Spiny Pocket Mouse	2636778
Marmosops invictus	Slaty Slender Mouse Opossum	2064606
Neacomys pictus	Painted Bristly Mouse	322680
Orthogeomys dariensis	Darien Pocket Gopher	1832796
Rhipidomys scandens	Mount Pirri Climbing Mouse	215628
Tylomys fulviventer	A Climbing Rat	10469
Tylomys panamensis	Panama Climbing Rat	359135
Aves		
Anthracothorax veraguensis	Veraguan Mango	3044498
Chlorospingus inornatus	Pirre Bush-Tanager	98657
Leptotila battyi	Azuero Dove	530265
Margarornis bellulus	Beautiful Treerunner	48672
Piculus callopterus	Stripe-cheeked Woodpecker	538297
Phylloscartes flavovirens	Panama Tyrannulet	1727088
Pselliophorus luteoviridis	Yellow-green Finch	121165
Selasphorus ardens	Glow-throated Hummingbird	228079
Amphibia		
Atelopus certus		10510
Atelopus limosus		44119
Atelopus zeteki	Golden Frog	158879
Bolitoglossa anthracina		111536
Bolitoglossa cuna		38846
Bolitoglossa taylori		87142
Bufo peripatetes		12818
Caecilia volcani		700454
Dendrobates arboreus		22822
Dendrobates claudiae		6940
Dendrobates speciosus		37580
Dendrobates vicentei		153146
Eleutherodactylus azueroensis		150366
Eleutherodactylus emcelae		175598
Eleutherodactylus jota		5850

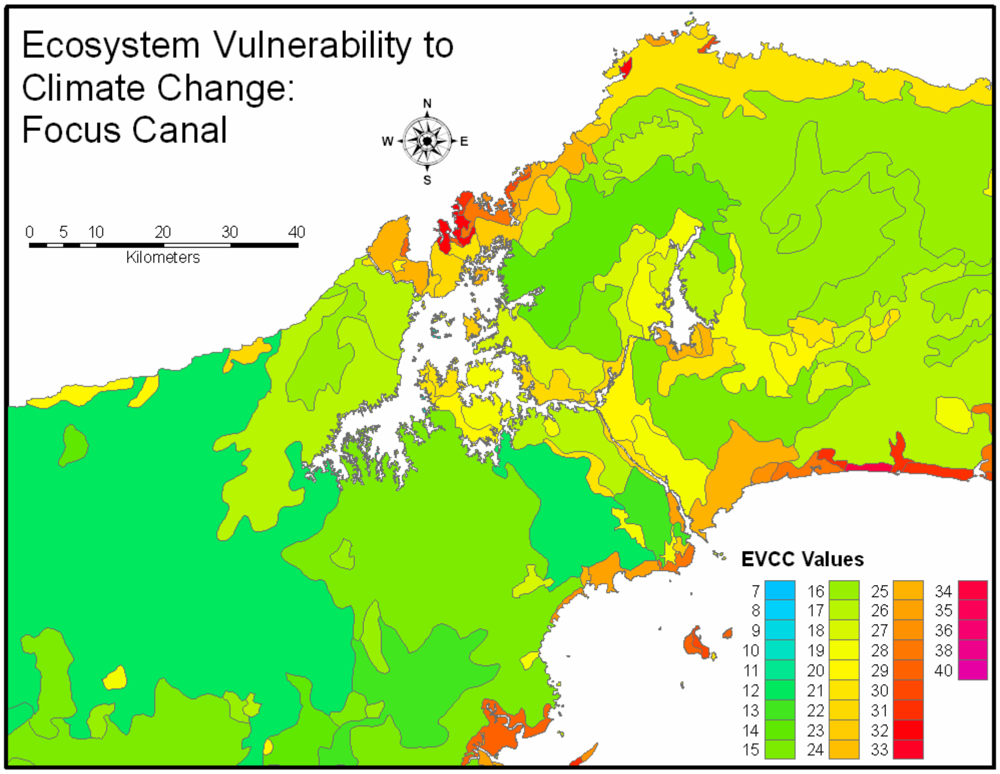
Eleutherodactylus laticorpus		28252
Eleutherodactylus monnichorum		13670
Eleutherodactylus museosus		336100
Eleutherodactylus punctariolus		379358
Epipedobates maculates		?
Hyla graceae		187471
Hyla infucata		4965
Hyla thysanota		6550
Oedipina maritime		182
Oscaecilia elongate		5062
Pipa myersi		63184
Rana pipiens	Northern Leopard Frog	445030
Rana sp. 2	Common Leopard Frog	?
Scinax altae		1251113
AREA of PANAMA		**~7446911**

Note: One endemic mammal and two endemic amphibians do not have a range attributed to them because there are discrepancies between the online database and the Arc files. These three species have not been recorded in the GIS and therefore cannot be included in the $EVCC_4$. This is possibly because the online database is more up to date than the Arc files.

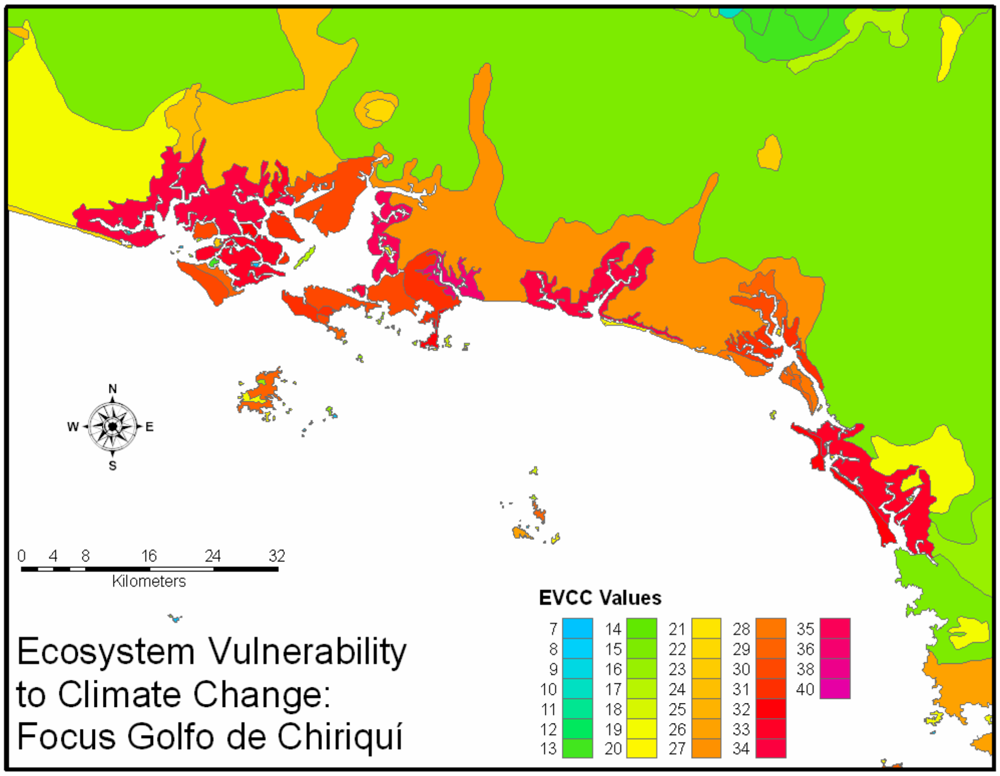
Appendix 3. Special Focus Maps



Map 4 Sea Level Rise Focus: Bocas del Toro. This display of one of the regions in Panama with some of the highest $EVCC_1$ values shows small islands, tropical evergreen swampy rainforests dominated by palms, and mangroves.



Map 5 Overall EVCC Focus: Canal Zone. The Colón area frequently has high-vulnerability ecosystem patches of the types: mangroves and populated places.



Map 6 Overall EVCC Focus: Golfo de Chiriquí. The high-vulnerability patches here are commonly lowland tropical rainforests, fairly intensive agricultural areas, as well as more small islands and mangroves.

Appendix 4. Chronogram of Activities & Time Spent

Dates, times, descriptions	Total person-hours spent on internship
4 January (17:00-19:00) • Internship Cocktail – introductions and visit to CATHALAC	0
11 & 12 January (8:30-16:30) • Orientation to CATHALAC and SERVIR with Milton Solano	32
13 January (20:00-20:30) • Informal meeting with Dr. Roberto Ibáñez to explain preliminary ideas of the project	1
15 January (19:30-20:30) • Meeting with supervisor Emil Cherrington to start refining the study question: "What areas are vulnerable to climate change?"	2
18 & 19 January (8:30-16:30) • Preliminary requests for data required for the project • Meeting with Noel Trejos (specialist in Integrated Management of Water Resources and Community Development) to discuss possible field work (18 Jan, 13:00) • Video-meeting with SERVIR Project Manager from NASA Dan Irwin (18 Jan, 15:00) • Meeting with Joel Peréz Fernandez (specialist in Weather and Climate Technology) to learn about climatological data and models (19 Jan, 15:00)	32
25 & 26 January (8:30-16:30) • Preliminary literature review on climate change's effects on biodiversity • Overview of spatial analysis, algorithm, and interpolation capabilities of ArcGIS for temperature data (esp. Krigging) • Further research on how to measure vulnerability (esp. measuring at ecoregion vs. ecosystem scale for Panama)	32
1 & 2 February (8:30-16:30) • Further literature review o Included 2001 IPCC Report (Vol. 2: Impacts, Adaptation, and Vulnerability) • Meeting with Dan Irwin to explain project ideas and to learn what high resolution climate change models are available (1 Feb, 10:00) • Teleconference with Jean-Nicolas Poussart in Havana (GIS expert in assessment and management land-based pollution) to discuss how to make indices	32

5 – 9 February (8:30-16:30) *Internship Week #1* • Further literature review • Refined variables to measure ecosystem vulnerability • Compared UNESCO's Arc data to its written descriptions on Panama's ecosystems • Informal "Progress Report" presentation to Emil Cherrington: the study question and in what domains research will be done, goals, objectives, hypotheses, methods, concerns, and final products (9 Feb, 11:00)	80
12 – 14 February (8:30-16:30) *Internship Week #2* • Further literature review • Preparation of Work Plan – Progress Report (due 14 Feb 18:30)	80
1 & 2 March (8:30-16:30) • Finalizing research and project development • SERVIR workshop	32
8 & 9 March (8:30-16:30) • Measuring EVCC variables – determining vulnerability to sea level rise	32
15 March (8:30-16:30) • Measuring EVCC variables – determining vulnerability to sea level rise • Preparing informal presentation & mock-presentation to Emil Cherrington	16
16 March • Informal presentation of projects to other PFSS internship groups	0
17 March (13:00-17:00) • Measuring EVCC variables – summarizing sea level rise vulnerability & preparing climatic 'space' analysis	4
19 – 22 March (8:30-16:30) *Internship Week #3* • Measuring EVCC variables – summarizing sea level rise vulnerability, analyzing ecosystem geometries, & analyzing climatic 'space' • Experts workshop – sat in on an meeting for monitoring climate change and SERVIR information sessions; described project to Dr. Carey Yeager of USAID	64
25 March (13:00-17:00) • Measuring EVCC variables – analyzing ecosystem geometries	4
29 & 30 March (8:30-16:30) • Measuring EVCC variables – analyzing ecosystem geometries & climatic 'space'	32
2 & 3 April (13:00-17:00) • Measuring EVCC variables – analyzing ecosystem geometries & climatic 'space'	16
4 April (13:00-19:00) • Measuring EVCC variables – analyzing ecosystem geometries & climatic 'space' • Information meeting on symposium and final projects, brief meeting with Dr. Roberto Ibáñez to discuss presentation	12

5 & 6 April (9:00-18:00) • Measuring EVCC variables – analyzing climatic 'space' & preparing species sensitivity analysis • Measurement of degree of human intervention for ecosystems • Overlaying EVCC variables with protected areas and degree of human intervention	36
7 April (10:00-18:00) • Measuring EVCC variables – analyzing climatic 'space' & species sensitivity • Overlaying EVCC variables with protected areas and degree of human intervention	16
16 – 20 April (8:30-16:30) *Internship Week #4* • Creating final products (maps, final report)	80
21 & 22 April (10:00-18:00) • Creating final products	32
23 - 25 April (8:30-17:30) • Completion of final products • Presentation of results to CATHALAC	54
•	0
26 April • Submission of final products Internship symposium (8:00)	
Days spent (not necessarily full): 50	**Total person-hours: 721**

Note: Most, but not all, days involved both researchers working simultaneously. This is reflected in the person-hours.

Appendix 5. Notes of Gratitude – Contact Information

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