Future Management Strategies for El Yunque National Forest

by

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A project submitted
in partial fulfillment of the requirements
for the degree of
Master of Science
Natural Resources and Environment
at the University of Michigan
April, 2008

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ACKNOWLEDGEMENTS

Michael Billmire would like to thank Bill Gould and Olga Ramos at the International Institute of Tropical Forestry (IITF) for their generous provision of spatial data, and the entire Puerto Rico Gap Analysis Project team for their thorough research that provided the basis for much of the analysis that was conducted. Thanks to Janna, Judith, Wes, and Tom Princen for help with data collection/advising/editing.

Janna Daimler would like to thank Carolyn Pabon for initiating the study "Assessing International Tourist Values in El Yunque National Forest," and assisting in implementing the survey collection, Manuel Valdez Pizzini for previous research and advise, Thomas Princen for consistent oversight and advise, and Abbott Daimler for editing.

Wesley Wong would like to thank Mike, Janna, and Judith for their patience; El Yunque National Forest staff - Luis Rivera, for his guidance and mentorship; Pedro Rios, for his candid advice; Carolyn Pabón, for her patient support; Carolyn Krupp, for her hospitality in coordinating our research permit, Anastacio "Baby" Gomez, for enthusiastically teaching me about El Yunque plants; Benjamin Fuentes, for his kindness and hardworking attitude in the field; Dr. Julia Wondolleck, for providing wise feedback on this project and its process, and for reviewing a draft manuscript; Dr. Steven Yaffee, for providing reality checks and a necessary workspace; Dr. Bunyan Bryant, for his encouragement and perspective; Dr. Thomas Princen, for his optimism through our challenges; and Lisa Norris, of Mount Hood National Forest, for supporting my academic and professional development.

Judith Yi would like to express thanks to Dr. Mark D. Hunter, a professor with the department of the School of Natural Resources and Environment at University of Michigan for providing guidelines and advice for climatic data analysis. This study would not have been possible without his commitment and mentorship. Thanks are also extended to the National Climatic Data Center for providing access to meteorological data.

Funding for this project was provided by University of Michigan -Rackham Graduate School, University of Michigan - School of Natural Resources and Environment, USDA Forest Service El Yunque National Forest, USDA Forest Service Mount Hood National Forest. Spanish translation of the abstract and executive summary was provided by Linda Marin and Trusted Translations Inc.

ABSTRACT

U.S. National Forests revise their management plans every ten to fifteen years; in the next several years, El Yunque National Forest (EYNF), Puerto Rico, is slated to update its Land and Resource Management Plan (LRMP). This research has four focal areas intended to aid in the development of this LRMP: (1) Visitor use profile assessment; (2) climate change and variation within the forest; (3) mapping biological vulnerability to climate change within the forest; and (4) invasive species management.

Major results of the research are as follows: (1) Surveys conducted in August 2007 show that Puerto Rican residents largely come to EYNF for the purpose of relaxation and socialization while the majority of non-residents come to explore the forest, making apparent the need for a broad approach to guest accommodation in future management strategies in order to gratify the desires of guests from varying geographic origins and cultural backgrounds. (2) The climate change and variation analysis showed a significant increase (0.12°C per decade) in temperature within the forest over the past 50 years. Specifically within EYNF, the rate of temperature increase exceeds the global rate of increase. Precipitation did not show a significant trend within the time period studied. (3) Biological vulnerability to climate change was mapped using GIS analysis from overlaid weighted habitat models of 15 sensitive vertebrate species. The resulting map can be useful in prioritizing areas for management action and enables EYNF to take climate change into account in management decisions. (4) Several challenges and opportunities exist for addressing terrestrial invasive plants. To maintain the integrity of this Puerto Rican symbol of *patria* (homeland), USFS will need to take a hard look at both the particular tropical island biology and existing institutional capacity.

RESUMEN

El Servicio Forestal de los Estados Unidos revisa los planes de manejo de sus Bosques cada 10 o 15 años, por ello en los siguientes años el Plan de Manejo de Terrenos y Recursos (LRMP) de El Bosque Nacional El Yunque (EYNF), Puerto Rico sera revisado. El objetivo de este investigación fue realizar un análisis que potencialmente sirvá de ayuda en la actualización del Plan Forestal (LRMP). En este estudio cuatro áreas focales fueron definidas: Evaluación del perfil del uso del visitante.2) Evaluación del cambio y variación climática en el Bosque 3) Mapeo de la vulnerabilidad biológica al cambio climático 4) Manejo de las especies invasivas.

Los resultados de esta investigación sugieren 1) los residentes de Puerto Rico, en gran medida visitan el EYNF con fines de relajación personal y para realizar recorridos con familiares y amistades, mientras que la mayoría de los no residentes visitan el Bosque con fines de apreciación y exploración de la naturaleza. 2) El análisis del cambio y variación climática en el Bosque mostró un incremento significativo (0.12 ˚C por década) en temperatura durante los últimos 50 años. Este incremento excedió la tasa global de temperatura, mientras que la precipitación pluvial no mostró una tendencia significativa (3) La vulnerabilidad biológica al cambio climático fue identificada y representada en mapas con el uso de Sistemas de Información Geográfica (SIG) a partir de la sobreposición y ponderación de los modelos de habitat para 15 especies de vertebrados. El mapa resultante puede ser una herramienta que permita priorizar medidas de manejo y considerar los efectos del cambio climático en las decisiones de manejo. (4) Varias oportunidades y retos estan presentes en el manejo de las plantas terrestres invasivas. Para mantener la integridad de este símbolo de la patria puertorriqueña, el Servicio Forestal de EE.UU. necesitará tener en cuenta la biología de esta isla tropical y la capacidad institucional existente.

EXECUTIVE SUMMARY

This research has four focal areas intended to aid in the development of the El Yunque National Forest's (EYNF) Land and Resource Management Plan (LRMP): (1) Visitor use profile assessment; (2) climate change and variation within the forest; (3) mapping biological vulnerability to climate change; and (4) invasive plants management.

Visitor Use Profile Assessment in El Yunque National Forest

The study is aimed at analyzing how the values pertaining to EYNF of non-local visitors differ from those of local visitors. Visitor purpose and values varied among locals and non-locals in the following ways:

Purpose of Visit

- Residents of Puerto Rico come to EYNF to visit with friends and family, picnic, and for isolation more than non-locals.
- Non-locals of Puerto Rico come to EYNF for photography, to sightsee and to explore nature more than residents.
- Both groups visited the forest to hike, swim, relax and identify species.

Forest Attribute Values

- Residents of Puerto Rico, on average, placed a higher value on the tranquility, fresh air, and nature.
- Non-locals of Puerto Rico, on average, placed a higher value on the scenery, new experiences and adventure.
- Both groups placed equal value on conservation and infrastructure; opportunities for education, spending time with family, and exercise; and the intrinsic pride for Puerto Rico that EYNF holds.

Participants were asked to rate their experience in the forest by rating various points of interest within EYNF. Overall, the ratings were high for both Puerto Rico residents and non-locals (good to very good).

Furthermore, comments were overwhelmingly positive; negative comments were restricted to infrastructural issues: persistent litter, disorderly bathrooms, ambiguity of trail signs and markings, and a lack of available parking.

Due to the increasing number of visitors to the forest from Puerto Rico and abroad, EYNF managers and planners must consider how to satisfy both groups. Recommendations for satisfying both groups of visitors include:

- Implement a bus service; this should reduce traffic and emissions which will promote tranquility and fresh air. Twenty-four percent of Puerto Rico residents' responses to the question of forest values were about tranquility and fresh air.

- Encourage non-local picnicking. Start a concessionaire's service to help tourists have picnics. This will mitigate overcrowding by pulling guests deeper into the forest and promote community among residents and non-locals. Furthermore, it will give non-locals a more "authentic" cultural experience.
- Identify new trail destinations. The majority of respondents from both groups stated hiking as a purpose of visit. Moreover, non-locals gave their highest average ratings to interest points that included hiking. Creating more hiking trails would increase overall visitor satisfaction while mitigating overcrowding.

Climate Change and Variation in El Yunque National Forest, Puerto Rico

Past climatic records indicate that El Yunque National Forest has become considerably drier, and will most likely continue to do so due to global warming. These changes can affect local water budgets, distribution of forest vegetation, and could cause extinction of animal and plant species. This research assesses climate change and variation across Puerto Rico by examining the seasonality and linear trends of the monthly precipitation and temperature data collected from 20 weather stations using the ARIMA model for the period of 1955 through 2008. The amplitude of precipitation variation was examined using the coefficient of variation. The results show strong warming trends over the majority of the studied areas but did not show significant change in rainfall over the same period.

Major findings:

- Most of the warming trends found at the study areas are higher than the observed global warming trend (0.216 °F [0.12 °C] /decade).
- El Verde station, which is within EYNF, exhibits a strong warming trend at a rate of 0.68 °F (0.38°C) /decade for the minimum temperature and 1.4 °F (0.78°C) /decade for the maximum temperature during the study period (1975-2008).
- The yearly temperature profile of El Verde station shows a different increasing rate of temperature when examined over three time periods: 1975-1984, 1985-1994, and 1995-2008.
- Minimum temperature increased more rapidly than maximum temperatures (0.42°F (0.23 °C) vs. 0.093 °F(0.05 °C) /decade) from 1955–2008. This is consistent with the IPCC's (Intergovernmental Panel on Climate Change) Third Assessment Report.
- Results of this study suggest that, contrary to predictions of many researchers, increasing temperature does not always coincide with less rainfall or a higher coefficient of variation for precipitation.
- Monthly mean maximum and minimum temperature, monthly mean precipitation, and coefficient of variation were plotted against longitude, latitude, and elevation). Regression analysis showed no statistically significant relationships among these variables.

The increasing temperature trends at El Verde station suggest that El Yunque National Forest is one of the most sensitive areas in Puerto Rico to global climate change. This intermediate-to-large temperature increase could evoke significant consequences. A management tool to address this observed climate change in forest management is described in the following section.

Mapping Biological Vulnerability to Climate Change: a Land Management Tool
To date, the USDA Forest Service (USFS) has not defined specific management strategies for dealing with the predicted effects of climate change. Given the findings above, it is clear that the USFS could benefit from specific strategies. A map indicating vulnerability to climate change is a useful tool that would enable EYNF managers to take climate change into account when making management decisions. Such a map was constructed via GIS analysis by creating habitat models of sensitive species living within EYNF, weighting them according to their respective degree of climate change vulnerability, and overlaying them to produce the final map (see attached map).

Management Uses
This biological vulnerability to climate change mapping tool can be used to:

- Prioritize locations for land acquisition; target areas for increased conservation protection; prioritize the planning/constructions/ removal/accessibility of roads, trails, or structures; and prioritize areas of ecological concern for management action.
- Target particular locations of interest, such as the area south of East Peak Rd. or the southern border of the forest (high vulnerability.

Intended Use and Limitations
When used for long-term management considerations, the map should:

- Serve as a supporting resource for making management decisions only in concert with all other appropriate management considerations.
- Be accompanied by field validation of the management areas in question; a simple visual assessment checklist would be suffice to serve this purpose.
- Be improved and updated electronically as new species habitat data as well as new and updated spatial data becomes available.

Use of methods outside of EYNF

- The map can serve as an example for similar management tools that can be created for other lands managed by the USDA Forest Service or other land management agencies as a method/tool for addressing climate change in land management. Provided simply the basic spatial data layers described in **Appendix 3.1**, the exact methods described are applicable to any other land area.

Invasive Plants Management Strategy
The US Forest Service's only tropical National Forest is distinguished by a long history of exotic species introductions, less pronounced seasonality, frequent hurricanes, and weather driven by the steep Luquillo Mountains and ocean patterns. Consequently, El Yunque National Forest may appear out of synch with national and regional (southern continental U.S.) Forest Service invasive species management paradigms. El Yunque's ecology and existing institutional capacity present unique challenges and opportunities for addressing invasive plants. Building upon cooperative relationships and appropriate modifications to invasive species information systems can help minimize ecological and economic damage from invasive plants.

Suggested management options:

Conduct a risk assessment to define threats and prioritize species for treatment

- Document status and likelihood of introduction, consequences of establishment, and potential for spread.
- Identify areas particularly vulnerable to invasion.
- EYNF can take the initiative, cooperating with DRNA (Department of Natural and Environmental Resources), to prepare an updated and categorized species list.

Continue dialog with researchers - compare the role of native species assemblages and so-called "proper functioning" ecosystems.

Request funding from National Invasive Species Council (NISC) to establish a pilot monitoring program

- Develop an Early Detection and Rapid Response (EDRR) model.
- Focus on small satellite populations over larger founder populations; satellite populations often rapidly grow until their range exceeds the extent of founder populations.

Utilize appropriate technology and information systems

- Short term – Encourage visiting data stewards from other USFS units (detail assignments); host SCA (Student Conservation Association) GIS interns.
- Long term – Dedicate additional staff to actively maintain local invasive species database that can be incorporated into the national database (NRIS, Natural Resources Information System).
- Utilize SCEP (Student Career Experience Program) authority to hire GIS student interns from local and other universities; interns may be converted to full time staff upon graduation.

Foster partnerships for education and awareness

- Through cooperative agreements, MOUs (Memoranda Of Understanding), and informal relationships, encourage other agencies, organizations, and individuals to be stewards for Puerto Rican natural heritage.
- Promote and support a cooperative weed management council – a localized network of neighbors and agency representatives who share success stories, treatment challenges, grant funding, etc.; possibly in conjunction with the DRNA head forester and the new Forest Health grant from International Institute for Tropical Forestry.
- Establish Amigos Del Yunque (i.e. Friends of El Yunque) – an auxiliary group that can provide donor funding and volunteer labor for habitat rehabilitation/ restoration; spotlight neighboring farmers who practice conscientious Integrated Pest Management; cultivate pride from overseas Puerto Ricans or other supporters; leverage fiscal flexibility of a non-profit organization..

Work outside of traditional jurisdictional boundaries

- Utilize Wyden Amendment – authorizes spending federal dollars on non-federal lands to improve ecological heath of forest resources.
- Legislative proposals and realty exchanges with willing land owners to make a more effective buffer zone may prove fruitful, but proactive cooperation across jurisdictions may be more efficient at minimizing the spread of invasive species.

RESUMEN EJECUTIVO

La presente investigación incluye cuatro áreas centrales con el objeto de contribuir al desarrollo del Plan de Administración de Tierras y Recursos (LRMP, por sus siglas en inglés) del bosque nacional El Yunque (EYNF, por sus siglas en inglés): (1) evaluación de perfiles de uso de visitantes; (2) cambio y variación de factores climáticos dentro del bosque; (3) trazado de mapa para identificar la vulnerabilidad biológica a los cambios climáticos; y (4) control de plantas invasoras.

Evaluación de perfiles de uso de visitantes en el bosque nacional El Yunque

El estudio pretende analizar la forma en que los valores de los visitantes locales difieren de los valores de los visitantes extranjeros en lo que refiere al uso del EYNF. El propósito de la visita y los valores de los visitantes presentaron las siguientes diferencias entre residentes y extranjeros:

Propósito de la visita

- A diferencia de los extranjeros, hay más residentes de Puerto Rico que vienen a EYNF con familiares y amigos para realizar comidas campestres y aislarse.
- A diferencia de los residentes, hay más extranjeros que vienen a EYNF a sacar fotografías, visitar lugares de interés y explorar la naturaleza.
- Ambos grupos visitaron el bosque para hacer caminatas, nadar, distenderse e identificar especies.

Valoración de los atributos del bosque

- Los residentes de Puerto Rico, en promedio, valoran más la tranquilidad, el aire fresco y la naturaleza.
- Los extranjeros, en promedio, valoran más el paisaje, las nuevas experiencias y la aventura.
- Ambos grupos valoraron por igual la conservación y la infraestructura, las oportunidades que representa en materia de educación, pasar tiempo con la familia y hacer ejercicio, y el orgullo intrínseco que implica EYNF para Puerto Rico.

Se solicitó a los participantes que calificaran su experiencia en el bosque al analizar diversos puntos de interés dentro del EYNF. En general, las calificaciones de ambos grupos de visitantes fueron altas (bueno a muy bueno).

Además, los comentarios fueron sumamente positivos; los comentarios negativos se limitaron a cuestiones de infraestructura: presencia constante de residuos, baños descuidados, ambigüedad en las líneas de señalización y carteles de senderos, y falta de espacio disponible para estacionamiento.

Debido a la creciente cantidad de puertorriqueños y extranjeros que visitan el bosque, la gerencia y los encargados de la planificación de EYNF deben tener en cuenta cómo satisfacer a ambos grupos. Las recomendaciones para satisfacer a ambos grupos de visitantes incluyen:

- Implementar un servicio de transporte público para reducir el tráfico y la contaminación y fomentar la tranquilidad y el aire fresco. El veinticuatro por ciento de las respuestas de los puertorriqueños a la pregunta sobre los atributos del bosque giraron en torno a la tranquilidad y el aire fresco.
- Fomentar el uso del bosque como lugar para comidas campestres entre los visitantes extranjeros. Comenzar un servicio a concesión para ayudar a los turistas a realizar comidas campestres. Esto permitirá reducir la congestión de visitantes, al adentrarlos en el bosque y fomentar un espíritu comunitario entre residentes y extranjeros. Además, ofrecerá a los extranjeros una experiencia cultural más "auténtica".
- Identificar nuevos destinos de senderos. La mayoría de los encuestados de ambos grupos incluyeron las excursiones a pie como propósito de la visita. Además, los extranjeros dieron su calificación promedio más alta a diversos puntos de interés que incluían caminatas. La creación de más senderos para excursiones a pie incrementaría la satisfacción general de los visitantes a la vez que reduciría el congestionamiento de personas.

Cambio y variación de factores climáticos en el bosque nacional El Yunque de Puerto Rico

Los antecedentes climáticos indican que el bosque nacional El Yunque se ha vuelto considerablemente más seco, lo cual es muy probable que siga sucediendo debido al calentamiento global. Estos cambios podrían afectar los presupuestos de agua locales y la distribución de la vegetación forestal, además de extinguir especies animales y vegetales. Esta investigación evalúa el cambio y la variación del clima en todo Puerto Rico al examinar la variación por estaciones y las tendencias lineales de los datos de precipitaciones y temperaturas mensuales recabados de las 20 estaciones meteorológicas a través del modelo ARIMA para el período 1955-2008. La amplitud de la variación de las precipitaciones se examinó mediante el coeficiente de variación. Los resultados muestran fuertes tendencias de calentamiento en la mayoría de las áreas estudiadas, pero no demostraron cambios significativos en las precipitaciones correspondientes al mismo período.
Conclusiones principales:

- La mayoría de las tendencias de calentamiento detectadas en las áreas de estudio son más elevadas que la tendencia de calentamiento global observada (0,216° F [0,12° C] / década).

- La estación El Verde, que se encuentra dentro de EYNF, presenta una clara tendencia de calentamiento a razón de 0,68° F (0,38° C) / década para la temperatura mínima y 1,4° F (0,78° C) / década para la temperatura máxima durante el período de estudio (1975-2008).

- El perfil de temperatura anual de la estación El Verde muestra una creciente tasa de aumento de la temperatura cuando se lo analiza a lo largo de tres períodos consecutivos: 1975-1984, 1985-1994 y 1995-2008.

- La temperatura mínima aumentó más rápido que la temperatura máxima (0,42° F [0,23° C], comparada con 0,093° F [0,05° C] / década) en el período 1955–2008. Esto coincide con el tercer informe de evaluación del IPCC (Grupo Intergubernamental de Expertos en Cambio Climático).

- Los resultados de este estudio sugieren que, a diferencia de las predicciones de muchos investigadores, el aumento de temperatura no siempre coincide con una disminución de las precipitaciones o un coeficiente de variación más elevado para las precipitaciones.

- La media mensual de las temperaturas mínimas y máximas, la precipitación media mensual y el coeficiente de variación se trazaron sobre coordenadas de longitud, latitud y elevación. El análisis de regresión no demostró ninguna relación significativa desde el punto de vista estadístico entre estas variables.

Las tendencias de aumento de la temperatura en la estación El Verde sugieren que el bosque nacional El Yunque es una de las áreas de Puerto Rico más sensibles a los cambios climáticos globales. Este aumento de temperatura de nivel intermedio a grande podría tener consecuencias importantes. En la siguiente sección se describe una herramienta de administración forestal que podría resultar útil para abordar este cambio observado en el clima.

Trazado de mapa para identificar la vulnerabilidad biológica a los cambios climáticos: una herramienta de administración de tierras

A la fecha, el Servicio Forestal de USDA (USFS, por sus siglas en inglés) no ha definido estrategias específicas de administración para lidiar con los efectos anticipados a raíz de los cambios climáticos. A la vista de las conclusiones mencionadas anteriormente, es evidente que una serie de estrategias específicas podrían beneficiar a USFS. Un mapa que indique la vulnerabilidad a los cambios climáticos es una herramienta útil que podría permitir a los administradores de EYNF incorporar los cambios climáticos como factor a la hora de tomar decisiones de administración. Dicho mapa se construyó mediante un análisis GIS para el cual se crearon modelos de hábitat de las especies afectadas que viven dentro de EYNF, que se ponderaron según su correspondiente grado de vulnerabilidad a los cambios climáticos y se superpusieron para crear un mapa definitivo (Figura 3-2). Esta herramienta de identificación de la vulnerabilidad biológica a los cambios climáticos puede utilizarse para los siguientes fines:

- Para priorizar ubicaciones para adquisición de tierras; identificar áreas determinadas para potenciar esfuerzos de conservación; priorizar la planificación/construcción/eliminación/accesibilidad de caminos, senderos o estructuras; y priorizar áreas ecológicamente en riesgo para implementar acciones de administración.

- Como recurso de apoyo para tomar decisiones de administración junto con todos los otros factores a tener en cuenta para una administración adecuada, se recomienda reforzar esto con una validación *in situ* de las áreas de administración en cuestión para confirmar la calidad del hábitat, al menos en forma visual.

- A modo de ejemplo para herramientas de administración similares que puedan crearse para otras tierras administradas por el Servicio Forestal de USDA u otros organismos de administración de tierras como método/herramienta para incorporar el factor de los cambios climáticos en la administración de tierras. En la medida en que se incluyan los niveles de datos espaciales básicos que se describen en el **Apéndice 3.1** los métodos exactos que se mencionan pueden aplicarse a cualquier otra superficie de tierra.

Por último, si bien el mapa se diseñó como recurso para consideraciones de administración a largo plazo, se lo debería mejorar y actualizar en forma electrónica a medida que se disponga de nuevos datos de hábitat de especies, así como de datos espaciales nuevos y actualizados.

Estrategia de Manejo para las Plantas Invasivas

El Yunque es el único Bosque Nacional tropical del Servicio Forestal de EE.UU. Se distingue por una larga historia de introducción de especies exóticas. Además, El Yunque presenta una pronunciada estacionalidad climática y huracánes frecuentes, factores determinados por las escarpadas Montañas Luquillo y los patrones oceánicos de la isla. Consecuentemente, El Yunque puede estar fuera de sincronía con los paradigmas nacionales y regionales (Sur Continental de los EE.UU.) que el Servicio Forestal aplica al manejo las especies invasivas. Además, la ecología y la capacidad institucional actual de El Yunque presentan oportunidades y retos únicos para el manejo de plantas invasivas. A través del fortalecimiento de relaciones cooperativas y de modificaciones apropiadas a los sistemas de información sobre especies invasivas se puede ayudar a minimizar el daño ecológico y económico generado por dichas especies.

Opciones de manejo sugeridas:

Realizar una evaluación de riesgo para definir amenazas y priorizar species

- Documentar el estatus y probablidad de introducción, consecuencias del establecimiento y potencial de propagación.
- Identificar áreas vulnerables a la invasion.
- EYNF* en cooperación con el Departamento de Recursos Naturales y Ambientales (DRNA) puede tomar la iniciativa en la preparación de un listado de species actualizado y categorizado.

Diálogo continuo con los investigadores - Comparar el valor de los ensamblajes de las especies nativas con el "adecuado funcionamiento" de los ecosistemas.

Solicitud de financiamiento al Consejo Nacional de Especies Invasivas (NISC) para establecer un programa piloto de monitoreo

- Desarrollar un modelo de detección temprana y respuesta rápida (EDRR).
- Enfatizar el manejo de las pequenas poblaciones satélite en lugar de grandes poblaciones fundadoras. Las poblaciones satélite tienden a crecer rápidamente hasta que su área excede el área de las poblaciones fundadoras

Utilizar sistemas de información y tecnologías apropiadas

- En el corto plazo – Fomentar la visita de personal calificado en el manejo información. Estos visitantes provenientes de otras unidades de USFS realizarían tareas detalladas. Además, de promover estancias para internos de la Asociación de Estudiantes para la Conservación (SCA) que tengan experiencia en Sistemas de Informacion Geográfica (SIG)..
- En el largo plazo – Asignar personal adicional para el mantenimiento y actualización de la base de datos de especies locales invasivas. Dicha base de datos puede ser incorporada en la base nacional Systema de Información de Recursos Naturales (NRIS)
- Hacer uso del Programa de Experiencia Profesional para Estudiantes (SCEP) para la contratación de estudiantes con experiencia en Sistemas de Información Geográfica (SIG). Estos estudiantes potencialmente podrían convertirse en personal de tiempo completo una vez que se graduaran

.

Impulsar asociaciones que promuevan la educación y concientización

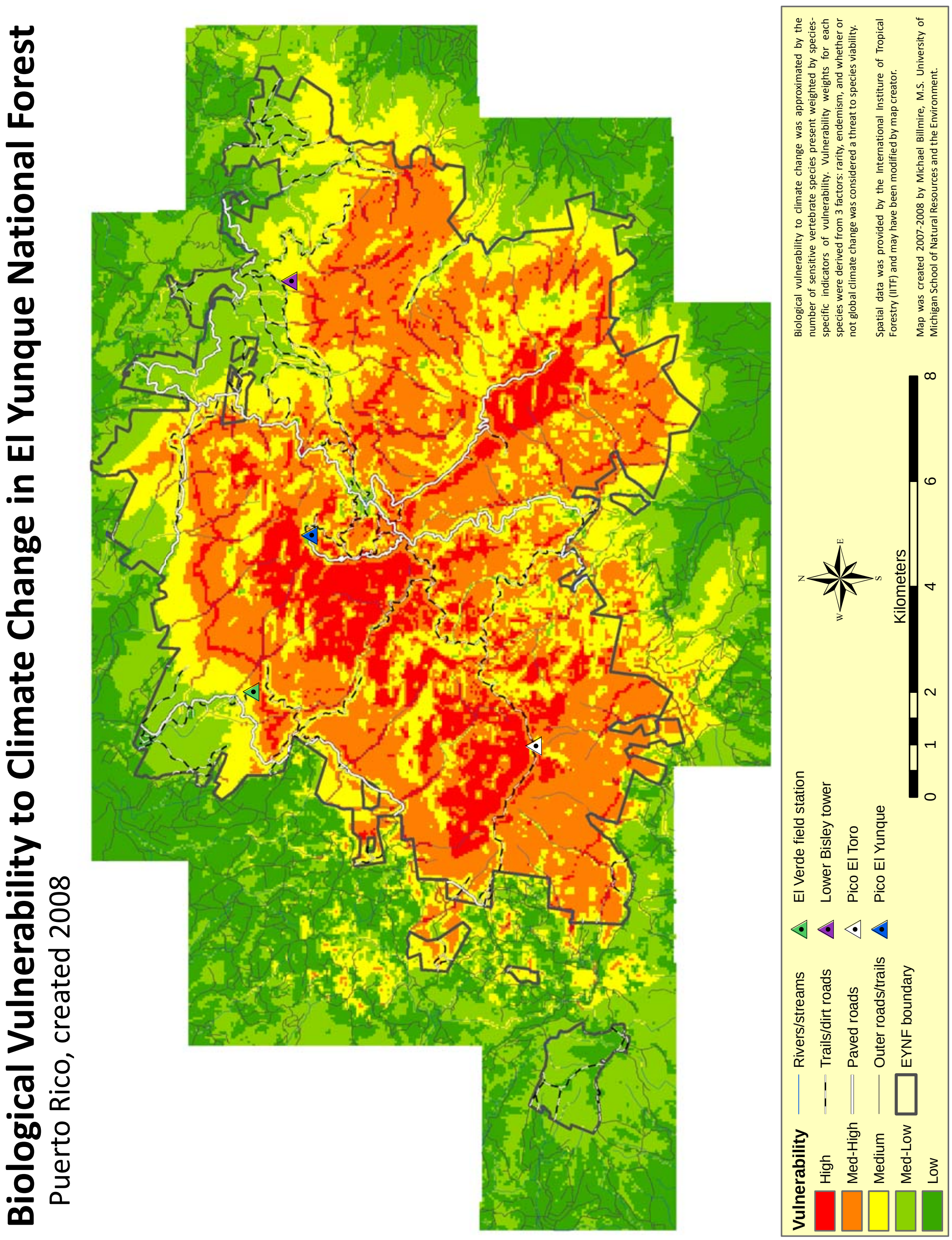
- A través de acuerdos cooperativos, Memorandos de Entendimiento (MOUs), o bien mediante relaciones informales se puede fomentar que las agencias, organizaciones, e individuos sean guardianes de la herencia natural Puertorriqueña.
- Promover y apoyar la creación de un consejo cooperativo para el manejo de malezas. Este consejo es una red local de vecinos y representantes de agencias que comparten historias de éxito, retos encontrados, estrategias en la obtención de financimiento, etc. Posiblemente, dicho consejo pueda ser apoyado por el DRNA y el Instituto Internacional de los Dasonomía Tropical (IITF), a través de fondos proporcionados por Salud de Bosque.
- Establecer Amigos Del Yunque (i.e. Friends of El Yunque) – un grupo auxiliar que puede proveer de donadores de financimiento y trabajo voluntario para la rehabilitación y/o restauración. Además, el grupo Amigos del Yunque también tendria entre sus funciones: 1) resaltar la actividad de aquellos agricultores vecinos al Bosque que concientemente realizan Manejo Integrado de Plagas; 2) cultivar el orgullo de los Puertorriqueños y no Puertorriqueños que vive fuera y dentro de Puerto Rico; y 3) Aprovechar la flexibilidad fiscal que puede tener como organización sin fines de lucro.

Trabajar fuera de los límites jurisdiccionales tradicionales

- Utilizar la Enmienda Wyden, que autoriza el gasto de dólares federales en tierras no federales con el objetivo de mejorar la salud ecológica de los recursos forestales.

- Las propuestas legislativas e intercambios de propiedad con aquellos dueños dispuestos a realizar una zona de amortiguamiento eficaz pueden ser fructiferas. Sin embargo, una cooperación proactiva a lo largo de las jurisdicciones podría ser más eficiente en impedir la propagación de species invasivas.

*Acronimos institucionales están en sus formas originales sin traducción.



Final map of biological vulnerability to climate change for inclusion with executive summary

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INTRODUCTION

Ecological Context

Puerto Rico's El Yunque National Forest (EYNF) is unique among US federal lands; it is the only tropical forest in the National Forest System. It contains the wild habitat for reduced populations of the endangered Puerto Rican Parrot (*Amazona vittata*), 13 species of coqui frogs (*Eleutherodactylus* spp.), the Luquillo Experimental Forest Reserve, a Long Term Ecosystem Research (LTER) site, federally designated Wild and Scenic Rivers, and the newly designated El Toro Wilderness (USFS 2007). Furthermore, the EYNF touts more biodiversity than all other National Forests combined (USFS 2006).

Socio-economic Context

The intrinsic aesthetics of El Yunque draw over 1.2 million annual visitors (USDA Forest Service 2006). Nature-focused tourism remains a significant contribution to the Puerto Rican economy. Recreation visits to El Yunque account for close to $500 million directly or indirectly to Puerto Rico's GDP (USDA Forest Service 2006).

Since the 1950s the overall island economy continues to shift away from an agricultural based society to one based on manufacturing, services, and government employment. Tax incentives have been used to draw U.S. manufacturing companies to the island {Irizzary et al __, Potter 1993}. Puerto Rico imports most of its consumer goods from the U.S. and most exported goods are produced from imported raw materials or parts. Despite this dependent economic model, Puerto Rico enjoys a higher standard of living than other Caribbean states thanks to various U.S. development and welfare programs. These complexities are related the three major political philosophies: statehood, commonwealth, and independence (USDA Forest Service 1997). Puerto Rican culture represents an amalgam of indigenous, African, European, and North and South American heritages.

Cultural Context

Officially designated as the Caribbean National Forest from 1935 to 2007, the rainforest in the Sierra de Luquillo has always been known as "El Yunque" to Puerto Ricans and off-island visitors. This name is derived from indigenous Taino words referring to the white clouds around the mountains {Bosworth 2003, _____}. In 2007 a Presidential Executive Order officially changed the name to reflect the pride that many Puerto Ricans have for El Yunque. Many *Boricuas* (Puerto Ricans) today respect the spiritual values of El Yunque; the protective role that the forest and mountains had in buffering the impact of Hurricane Hugo in 1989 over much of the island affirmed its sacredness (USDA Forest Service 1997).

Policy Context

National Forests revise their management plans every ten to fifteen years; in the next several years, the EYNF is slated to update its Land and Resource Management Plan (LRMP) (Cruz 2007). This work is intended to aid Forest planners in the development of their LRMP by providing research on visitor use profiles, invasive species management, and information and methods for dealing with global climate change (GCC).

Climate Change Context

As a small island territory, Puerto Rico is highly vulnerable to climate change due to limited physical size, high susceptibility to tropical cyclones, and extremely intense population density (at 1137 people per sq. mile, it is exceeded in the U.S. only by New Jersey and among the Caribbean islands only by Barbados) (IPCC 2001, CIA World Factbook). Since 1900, the Caribbean Islands have experienced an increase in average annual temperature that exceeds 0.5° C in addition to both an increase in temperature variability and a decrease in annual rainfall by 250 mm (IPCC 2001). General Circulation Models predict a continuation of these trends, projecting an increase in annual mean temperature by 2.03° C (± 0.43) and a 5.2% (± 11.9) decrease in rainfall (with a large decrease in the dry season offsetting a smaller increase in the wet season) by 2050 for the Atlantic Ocean and Caribbean Sea. Other effects of enhanced carbon dioxide conditions include a suggested 10-20% increase in the intensity of tropical cyclones (IPCC 2001), and a rise in global mean sea level of 15-95 cm (IPCC 1995) by 2100.

Focal Components

Chapter 1: *Assessing International Tourist Values in El Yunque National Forest*

The chapter was dedicated to the questions: From where do international tourists come to visit the forest? And, how do their values pertaining to forest resources differ, if at all, from the values of local visitors? Understanding the differing geographic origins and values of visitors will aid the forest staff in developing a plan that will ensure a balance between use and conservation.

Chapter 2: *Climate Change and Variation in El Yunque National Forest*

To our knowledge, no weather pattern analysis has been done using the meteorological observation data from the regions. This study aims to assess climate change and variations in the EYNF as well as the entire region by examining seasonality and linear trend of the monthly precipitation and temperature data collected from 20 weather stations, and to suggest recommendations on planning future developments in the area.

Chapter 3: *Mapping Biological Vulnerability to Climate Change*

To date the US Forest Service has not explicitly included strategies for adapting to climate change in any of their LRMPs. This chapter focuses on the provision of a management tool that will allow EYNF managers to take climate change into account when making management decisions. This tool was developed via GIS analysis and shows the spectrum of biological vulnerability to climate change across the forest.

Chapter 4: *Invasive Species Management Strategy*

Managing invasive species in El Yunque National Forest requires careful consideration of ecological distinctions between the continental U.S. and the U.S. territory of Puerto Rico. National and regional Forest Service invasive species guidance may appear out of synch with El Yunque, given a long history of exotic species introductions, less pronounced seasonality, and climate driven by steep Luquillo Mountains and ocean patterns. Additionally, institutional capacity and relationships between the federal government and the Commonwealth of Puerto Rico may further complicate implementation of a continental invasive species management paradigm. Nevertheless, El Yunque National Forest (and other potential partner agencies/organizations) should and can meet the challenges and opportunities for addressing terrestrial invasive plants presented in this chapter.

CHAPTER ONE:

ASSESSING INTERNATIONAL TOURIST VALUES IN EL YUNQUE NATIONAL FOREST

CHAPTER SUMMARY

Over two hundred visitors to El Yunque National Forest in August of 2007 were surveyed to compare the responses of residents of Puerto Rico with visitors from outside the island. The significant differences between the two groups related to the purpose of visit and the values the visitors placed on forest attributes. Generally, the purpose of visitation for residents of Puerto Rico related to leisure activities such as picnicking and visiting with friends and family, while non-residents came to EYNF to sightsee, explore nature and take photos of the forest. Residents were found to have a tendency to place more value on the tranquility of the forest than non-residents, who, on average, placed more value on the forest's scenic atmosphere and opportunity for adventure. Forest planners are recommended to implement a bus service, encourage non-local picnicking in the forest, and encourage the use of overlooked trails and/or develop new trail destinations.

INTRODUCTION

This research is aimed at answering questions posed by Carolyn Pabon, the forest planner of El Yunque National Forest (EYNF) in Puerto Rico. The questions posed are: From where do international tourists come to visit the forest? And, how do their values pertaining to forest resources differ, if at all, from the values of local visitors?

The information provided by this research will be available for use in the Land and Resource Management Plan to be developed by the interdisciplinary team and recreation staff of EYNF over the next several years. Understanding the values of visitors of differing geographic origins will aid the forest staff in developing a plan that will ensure a balance between use and conservation.

BACKGROUND

El Yunque National Forest is under the jurisdiction of the United States Department of Agriculture Forest Service (USFS); it is the USFS's only tropical forest. It is a popular destination for people who live in Puerto Rico as well as visitors to the island. The forest consists of 28,000 acres in the Sierra de Luquillo mountain range, with peaks reaching 3,500 feet (Pizzini et al. 1993). El Yunque is near the northeast corner of the island and offers many opportunities for education and recreation. El Portal Rain Forest Center, the forest's main visitor center, has a bridge at the level of the forest canopy, information staff, educational exhibits and a theater which plays educational videos about the forest.

Recreational activities at the forest include hiking, swimming, sightseeing, and picnicking. There are multiple trails to various destinations including waterfalls, mountain peaks, and panoramic views. There are designated swimming areas as well: Juan Diego Creek, Bano de Oro, Bano Grande, Bano de las Damas and Puente Roto. For sightseeing there are roadside locations, such as the Yokahu Tower and the Las Cabezas de San Juan, as well as lookouts accessible by hiking, such as the tower at Mt. Britton or the view from El Toro trail. Picnicking areas include Sierra Palm Recreation Site, Palo Colorado Recreation Area, Caimitillo Recreation Area, and Quebrada Grande.

Many visitors come to the forest each year from all over the world. Results from the USDA Forest Service National Visitor Use Monitoring Project for El Yunque National Forest in 2006 found that the forest receives about 1.2 million visitors per year, considerably higher than results from the same study in 2001, which estimated 469,000 visitors for the year 2000. According to the 2006 study, about 50.5% of visitors to the forest are ethnically Spanish, Hispanic, or Latino; this is less than results from the 2001 survey, which found the same ethnic groups to account for 58.5% of visitors. In 2006, 57% of the visitors came from the mainland United States and 37% were residents in Puerto Rico. The change in visitor volume and demographics could have profound influences on forest use, and this is a necessary consideration for forest planners (National Visitor Use Monitoring Results 2001, National Visitor Monitoring Results 2006).

Survey Methodology

Survey collection was utilized to acquire demographic data for this study. From August 10th to the 30th, 204 surveys were collected in four forest locations: Yokahu Tower, a highly frequented, easily accessible, and scenic tower near the entrance to the park; La Mina Falls, a swimming hole approximately one hour's hike from the trailhead; Palo Colorado Picnic Area and Information Center, an accessible picnic area with light concessions and public restrooms; and Mt. Britton Lookout Tower, a popular hiking destination approximately one hour's hike from the trailhead. These locations were selected to ensure that information was collected from visitors with varying interests. Due to a seasonal lull in the number of people visiting the forest, surveys were distributed indiscriminately at each location. Survey response rate is estimated at 90 percent.

The survey was designed to be accessible to individuals of a broad range of educational backgrounds (Complete survey available: Appendix 1.1). The questions were simple and designed to elicit responses that display the values of the visitors. The surveys were administered by Janna Daimler, a master's student from the School of Natural Resources and Environment at the University of Michigan.

Survey participants were given the option of filling out a survey in either English or Spanish. The Spanish version of the survey was translated from English by Yadira Enriquez, a professional English/Spanish translator. A copy of the translated survey is provided in Appendix 1. 1.

Statistical Methodology

Comparative statistical methods were utilized to quantify the differences between the responses of visitors who live in Puerto Rico and the responses of visitors from other locations. Hypothesis testing, specifically a two proportion z-test, was used to test the hypothesis that the responses of both groups were equal to the questions: "What is the purpose of your visit to the forest?" and "What do you value most about a forest visit?" The alpha level used to gauge the significance of the differences between responses was $\alpha=.05$. Analysis of variance was used in order to compare the data from the questions asking participants to rate various points of interest.

Results

The first question posed by the Forest planner, "from where do international tourists come to visit the forest?" is answered simply. Of the 204 surveys collected, 122 were collected from visitors from outside of Puerto Rico; this does not represent the percentage of non-local visitors, since it was desired to have an equal amount of both groups surveyed. Ninety-three percent of the non-locals surveyed came from the United States and the other seven percent came from Canada (2.5%), Central America (1.6%), Europe (1.6%), Mexico (0.8%) and South America (0.8%).

The second question, "how do their values pertaining to forest resources differ, if at all, from the values of local visitors?" will be discussed throughout the rest of the chapter. Through the surveys, information was collected from participants respecting four distinct parameters: (1) purpose of participants' visit to the forest, (2) participants' values pertaining to the forest, (3) participants' ratings of forest facilities and (4) participants' comments on their experiences of the forest. For the remainder of this paper, these four parameters will be identified through the subheadings *Purpose*, *Values*, *Ratings* and *Comments*.

Purpose:

In order to obtain information regarding the purpose of a participant's visit, the question was posed, "What is the purpose of your visit to the forest? (circle all that apply)," and a comprehensive list of options was provided: bird watching, hiking, swimming, sightseeing, passing through, relaxation, isolation, photography, exploring nature, picnicking, identifying rare species and/or visiting with family and friends. The responses to this question are indicated in Table 1-1, below. Statistically significant values are indicated by an asterisk (*).

The hypothesis test demonstrated a statistically significant difference between responses of residents of the island and responses of foreign visitors to the island in five of the twelve options provided under this parameter. Also, a sixth option within this parameter, "isolation," was found to have a p value of 0.0516, which is very close to statistical significance and is most likely "practically important." The responses are represented in Figure 1-1 and only the categories which varied with statistical significance are represented in Figure 1-2.

Purpose of Visit					
	p value	Residents (82)		Non-Locals (112)	
Bird watching		5	(3%)	8	(2%)
Hiking		24	(13%)	39	(12%)
Swimming		7	(4%)	13	(4%)
Sightseeing	*p=0.0000	23	(13%)	83	(25%)
Passing through		9	(5%)	9	(3%)
Relaxation		27	(15%)	41	(12%)
Isolation	p=0.0516	4	(2%)	1	(0%)
Photography	*p=0.0052	13	(7%)	40	(12%)
Exploring nature	*p=0.0132	22	(12%)	52	(15%)
Picnicking	*p=0.0287	6	(3%)	2	(1%)
Identifying rare species		2	(1%)	2	(1%)
Visiting (family or friends)	*p=0.0495	42	(23%)	48	(14%)

Table 1- 1 The number of respondents who chose each option for a purpose of their visit, the percentage of responses each category received out of all responses and the p-value for the hypothesis test that the categories represent are represented in the table. An asterisk (*) indicates statistical significance.

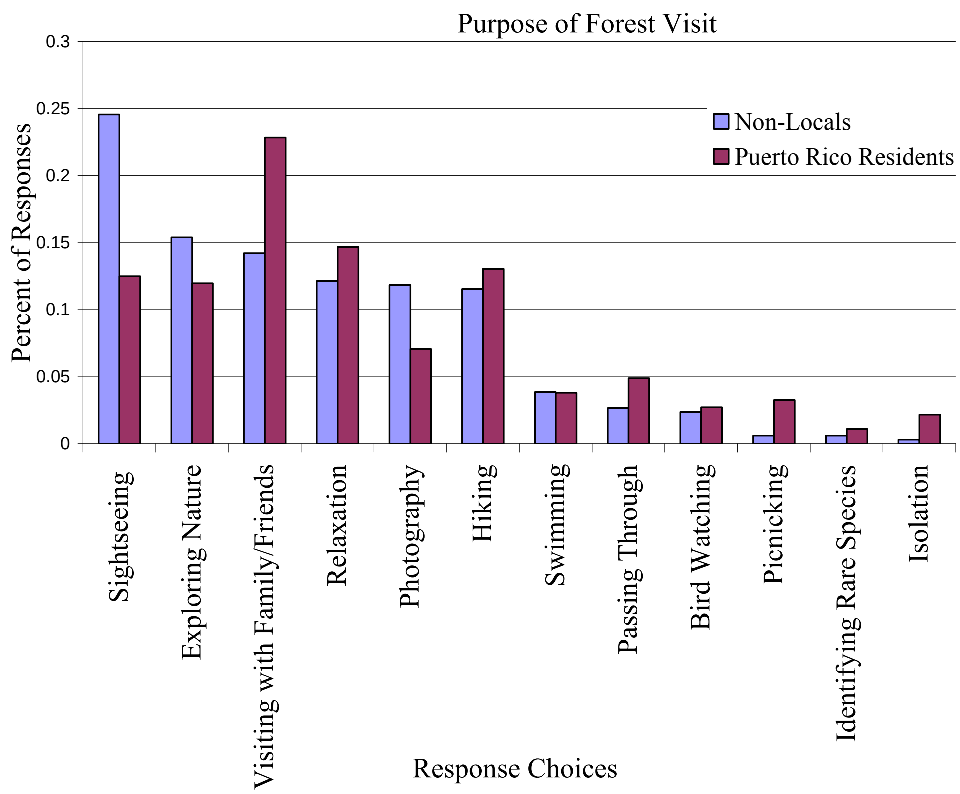


Figure 1- 1 Participants responded to the question “What was the purpose of your visit to the forest?” by circling as many choices as desired. The percentage of responses per category from total responses is represented.

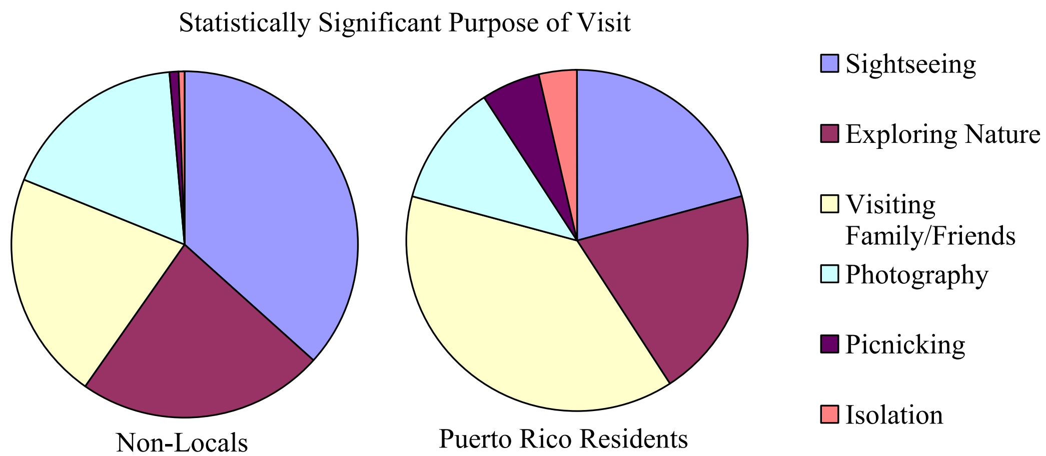


Figure 1- 2 The difference in responses of residents and non-residents of Puerto Rico to the question of the purpose of their visit that were statistically significant are represented above.

Forest Values:

In order to obtain information regarding a participant's values as they pertain to the forest, the question was posed, "What do you value most about a visit to the forest?" Space was provided on the survey for residents to give free responses (this method was utilized in order to encourage candidness in the responses of participants). Though responses varied greatly, all were suitably organized into eleven aggregate classifications: *infrastructure*, *adventure*, *education*, *tranquility*, *conservation*, *family togetherness*, *Puerto Rican pride*, *exercise*, *scenic atmosphere*, *fresh air*, and *nature*.

Of these 11 classifications, the variation between resident visitors and non-local tourists was statistically significant in five: adventure, tranquility, scenic atmosphere, fresh air and nature. The data is available in Table 1-2, below. An asterisk (*) indicates statistical significance. The responses are represented in Figure 1-3, and only the categories which varied with statistical significance are represented in Figure 1-4.

Forest Attributes Most Valued					
	p-value	Residents (131)		Non-Locals (173)	
Infrastructure		4	(3%)	5	(3%)
New sights/Adventure	*p=0.0023	0	(0%)	14	(8%)
Education		1	(1%)	3	(2%)
Tranquility	*p=0.0384	19	(15%)	14	(8%)
Conservation		14	(11%)	21	(12%)
Fresh air	*p=0.0001	12	(9%)	0	(0%)
Family togetherness		1	(1%)	2	(1%)
Puerto Rican pride		1	(1%)	1	(1%)
Exercise		1	(1%)	2	(1%)
Scenic atmosphere	*p=0.0019	17	(13%)	47	(27%)
Nature	*p=0.0475	61	(47%)	64	(37%)

Table 1- 2 The number of responses to the question of forest attributes most valued in the forest in each of the 11 categories, the percentage of responses each category received out of all responses, and the p-value for the hypothesis test that the categories represent are shown in the table. An asterisk (*) indicates statistical significance.

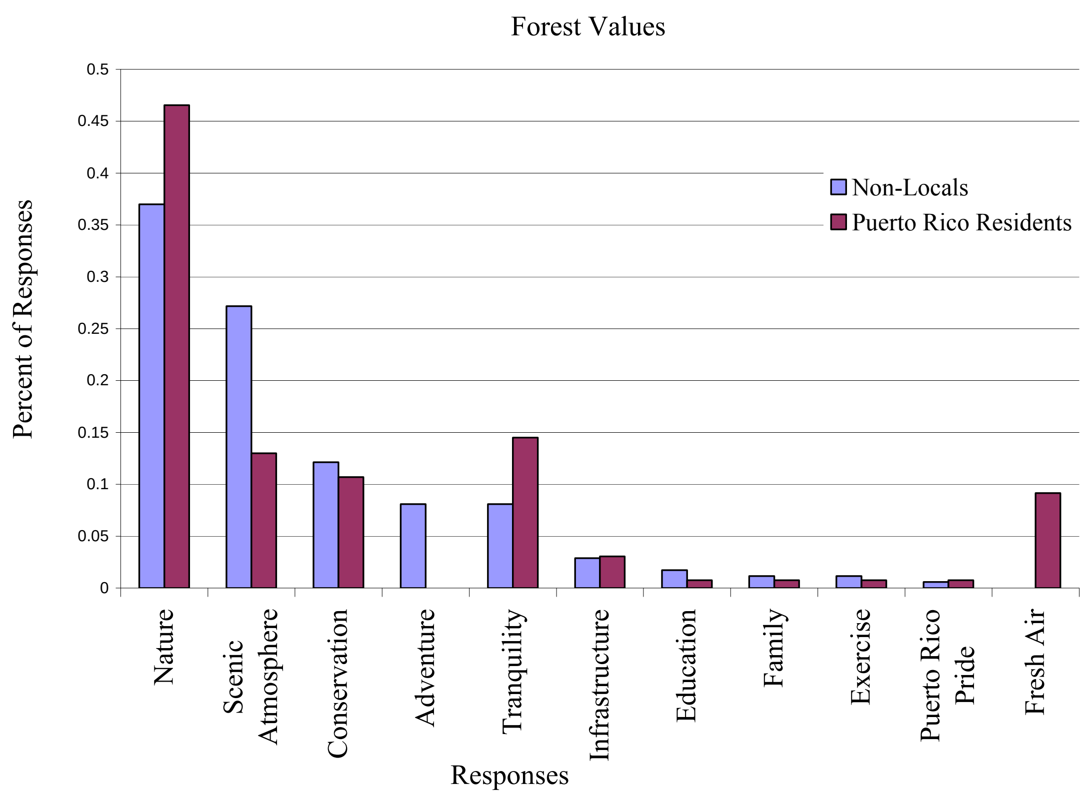


Figure 1- 3 Participants were asked what they value most in a forest visit. The responses in each category are demonstrated as a percentage of total responses for each group.

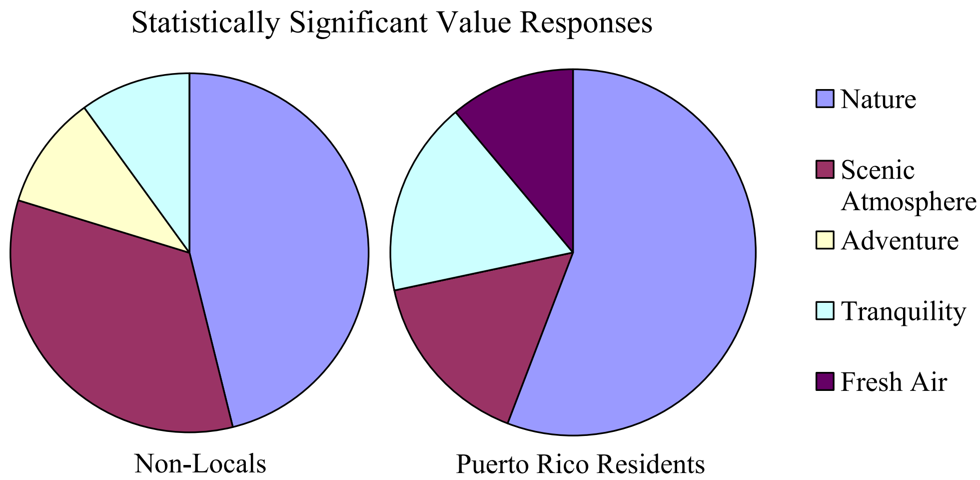


Figure 1- 4 The difference in responses of residents and non-residents of Puerto Rico that were statistically significant are represented above.

Ratings:

The ratings given to points of interest were very similar for residents of Puerto Rico and non-local visitors. Analysis of variance indicated no statistically significant difference between the two groups. The ratings were high; the average rating for each interest group ranged from 4.3 to 4.7 on a scale of one to five (five being the most positive rating possible). The relatively high ratings correspond closely to data from the National Visitor Use Monitoring survey conducted in 2006, which also used a rating system of one to five. NVUM average ratings ranged from 4.4 to 4.9. Ratings from the present study are represented in Figure 1-5, below.

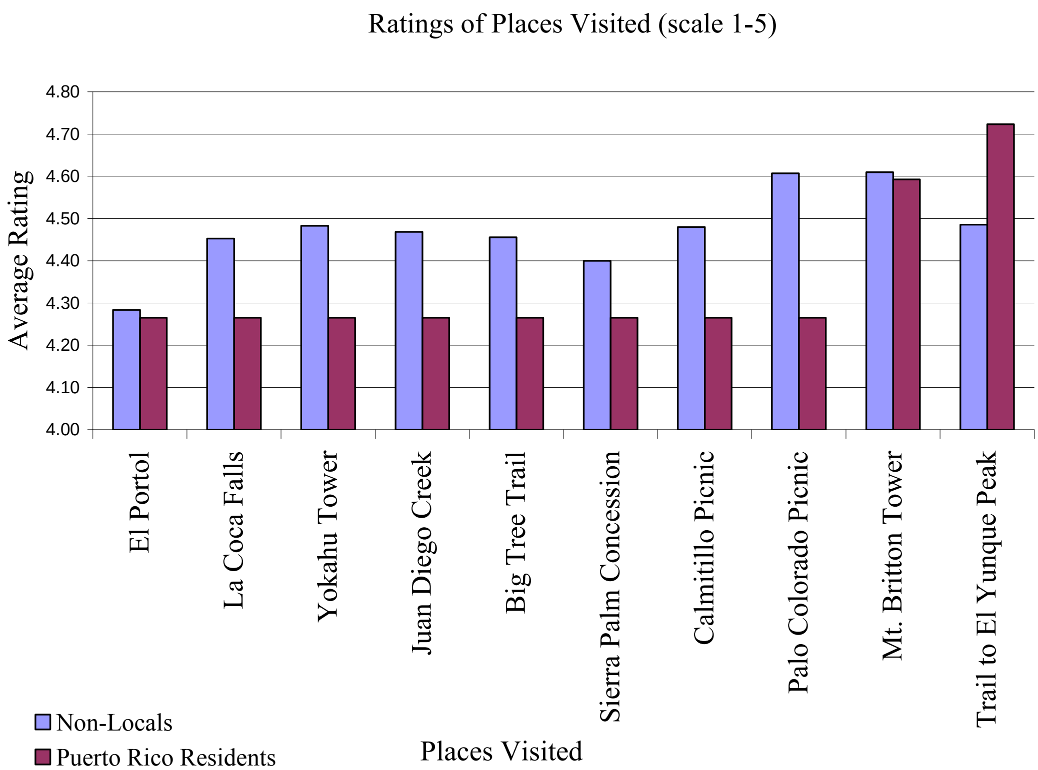


Figure 1-5 Participants rated the various points of interest on a scale of 1-5, one being a "bad" experience and five being "very good." The average rating for each point of interest for Puerto Rico residents and non-locals are demonstrated.

Comments:

The survey provided multiple outlets for participant comments. The fourth question of the survey asked, "Were your expectations of El Yunque National Forest met during your visit, how so/not?" The next survey question asked: "If you are not a Puerto Rico native, how did your El Yunque National Forest experience compare to visiting a forest in your native land? Will the difference have an effect on you returning (in a positive or negative way)?" Also, participants were provided space to write comments within the section of the survey that asked for ratings of various points of interest. The response rate was high for the fourth question, regarding participants' expectations of the forest, but lower throughout the rest of the survey. The high response rate for the fourth question is most likely due to the simple and specific nature of the question. Respondents were overwhelmingly positive about their experience, and could easily express it by commenting "yes" and providing a positive attribute of the forest.

Again, comments provided were overwhelmingly positive; participants felt that their expectations were exceeded and many participants elaborated using descriptors such as "beautiful" and "amazing" in reference to their experience of the forest. The few negative comments sighted a lack of clear trail signage and places to park, and issues of cleanliness pertaining to restrooms and litter.

DISCUSSION

With the increased volume in forest visitors, and the increased percentage of visitors from outside of Puerto Rico, the pressures of tourism upon the forest should increase and change. Some of these changes can be predicted by comparing the values and activities of the types of users within the four parameters of the survey.

Purpose:

The findings of this study, that residents of Puerto Rico come to the forest for different purposes than tourists from outside of the region, are affirmed by a similar, previous studie conducted at EYNF. The results for the question "What was the purpose of your visit to the forest?" were consistent with the findings of the 1992 study, *Front-end and formative evaluation of El Portal de El Yunque Visitor Center*, which stated that the main activity of local visitors was picnicking and river swimming, while non-locals came to the forest to walk, hike, backpack and sightsee (Pizzini et al. 1992).

Results of the present study indicate with a p-value of 0.0000 that sightseeing is an activity chosen by non-residents more than residents, and that the same is true of exploring nature (p=0.0132) and photography (p= 0.0052). Meanwhile, resident Puerto Ricans cited more often that their purpose for coming to the forest was to picnic (p=0.0287), visit with friends and family (p=0.0495), and for isolation (p=0.0516). Based upon the comments of the 1992 study's participants, who placed an emphasis on tranquility and fresh air, one could also infer that residents who participated in the present study would have chosen tranquility and fresh air if the option had been given.

Responses of participants when asked for the purpose of their visit to the forest were very much in line with the information presented by Pizzini et al.; most visitors who are residents of Puerto Rico come from the urban and coastal places for fresh, cool air and to escape the city and lowland heat (1993). The desires of Puerto Rican residents are reflected in the survey responses of the present study; more residents wanted to picnic, visit with their friends and family and find isolation than did non-residents (Figure 1-1 and 1-2).

In 1993, Pizzini wrote that visitors from the Continental United States came to the forest from hotels in rented vehicles or on tour buses from cruise ships (Pizzini et al. 1993). Although the present study did not ask participants for their mode of travel to the forest, the data indicates a similar profile; overall, non-residents wanted to sightsee, explore nature and take photographs significantly more than residents did. These activities are common "tourist" activities for visitors.

Although there are significant differences among the two groups discussed, there are also some important similarities. A similar percentage of both residents and non-residents cited bird watching, hiking, swimming, relaxation and identifying rare species as a purpose for their visit.

Swimming was selected as a purpose of visit by equal proportions of residents and non-residents (Figure 1-1). This data is interesting since it is an activity previously associated with residents who come to the forest to picnic. From this data, forest planners should feel confident in their ability to please both Puerto Rico residents and non-residents by making improvements to the river swimming infrastructure.

The similar response of swimming as a purpose of visit for both Puerto Rico residents and non-residents may indicate that the profiles of visitors are changing, and that more visitors from Puerto Rico are acting as tourists and/or more non-resident visitors are spending more time in the forest and adding river swimming to their sightseeing adventure. It is also possible that fewer residents were picnicking during the administration of the survey, which is why the numbers for swimming are so similar (further discussion in "Limits to the Study" section).

Hiking was another selection that was similar for both residents and non-residents of Puerto Rico. Thirty-two percent of non-residents and 29% of residents disclosed hiking as one of their purposes of visiting the forest. This common ground between the groups should be taken into consideration by forest planners since so many visitors would be pleased with improvements to hiking opportunities.

Ratings:

Although the purposes for visiting the forest differ between residents and non-residents, both groups seem to be satisfied with their experience of the forest. Though the differences in ratings given to features of the forest between the two groups were not statistically significant, the subtle differences in the way in which the two groups rated these features may still communicate a difference in values between the two groups especially when studied alongside the previously described differences in the two groups' purposes for visiting the forest.

The most striking feature of the data (Figure 1-5), is the overall higher ratings given by non-locals. Forest planners and managers should take this into consideration since a higher proportion of visitors are coming from outside of Puerto Rico. It is also important to ask why residents of Puerto Rico gave lower ratings than non-locals. This overall lower level of satisfaction should be more deeply explored and understood.

In the case of the Palo Colorado picnic area and information center, non-locals gave this facility an average rating of 4.61 while locals gave it an average rating of 4.27 (Figure 1-5). This difference could be due to the value that non-local people have placed on having an accessible information center. Alternatively, the difference could be due to the fact that the goals of non-locals (sightseeing and experiencing natural features as opposed to socializing) were satisfied at that location.

Also, the non-locals rated all of the interest points higher than residents, with an average rating of all points being 4.47, 0.13 higher than the average rating of residents, 4.34. This might be due to the excitement that non-locals bring to the forest, since many of them have never been to EYNF. The higher rating may also indicate that the forest caters more to the desires of non-locals than residents. The forest has many facilities for sightseeing. Non-locals who come to explore and see something new may have experienced the facilities more positively than non-residents looking to relax and picnic with friends and family.

Another interesting aspect of the rating data is the high evaluation given for the trail to El Yunque Peak. Residents of Puerto Rico rated the trail 4.72, the highest rating given to any interest point for either group. The non-locals' average rating for the trail was also high at 4.49. It is unclear why residents gave the trail the highest rating since a large proportion of both residents and non-residents indicated hiking as a purpose of visiting the forest.

Forest Values:

The values of a visitor will greatly affect the ways in which they use the forest. Some of the statistically significant differences between values of non-residents and residents of Puerto Rico (Figures 1-3 and 1-4) correspond to the findings of the 1992 study *Front-end and formative evaluation of El Portal de El Yunque Visitor Center*. In the *Front-end Evaluation*, a hierarchical system was designed for quantifying the value visitors placed on forest attributes. The study found that values of international visitors were focused on the forests' benefits to visitors, its importance for Puerto Rico, the general importance of forests to the world, and the beauty and uniqueness of El Yunque. Local visitors stressed the value that the forest has as part of their homeland and the value of its uniqueness, wilderness, clean air, rainfall and provision of relaxation, therapy and leisure (Pizzini et al. 1992).

In the *Front end* evaluation, major distinctions between the groups include the locals' emphasis on fresh air and patrimony and the international visitors' emphasis on the beauty and importance of the forest. These distinctions correspond with findings of the present study, which indicates that Puerto Rican residents place a higher value on nature, tranquility and fresh air, while non-residents placed a higher value on atmosphere and adventure.

The present study found that both groups of visitors placed nearly equal emphasis on the values of (in order of greatest to least mentioned) conservation, infrastructure, education, family togetherness, exercise, and Puerto Rican pride. The latter four categories were a very small percentage of the values mentioned, but conservation and infrastructure were mentioned as values ten and five percent of the time respectively. Since both conservation and infrastructure were attributes of the forest that both residents of Puerto Rico and non-locals valued, forest planners should consider ways to further foster and develop these attributes.

For both groups, ten percent of the comments in reference to forest values were directed at conservation and preservation of the forest. Respondents stated "the forest should be kept the way it is" and "preserving the forest is paramount" among other similar comments. One way in which forest planners can foster in visitors an assurance that the forest is being preserved is to provide up-to-date information for visitors regarding ongoing conservation projects at El Yunque.

Forest planners should also consider the emphasis placed on infrastructure by both Puerto Rico residents and non-locals. Improvements to restroom facilities, parking availability and trail signs should increase visitor satisfaction.

Comments:

The comments made on the surveys were consistent between residents and those from outside Puerto Rico, and both groups' comments were consistent with the assessment of visitor satisfaction from the National Visitor Use Monitoring project. Overall, visitors are satisfied with their experiences of the forest. The two main points of dissatisfaction among both residents and non-residents are confusion with trail signs (unclear or non-existent in places where they are desired) and persistent litter.

Participants in the survey mentioned litter during survey collection. It may be the most negatively distracting aspect of the forest. Forest planners should consider making more trash receptacles available, posting signs urging visitors to use trash receptacles, and assign a staff person to maintain areas with higher incidents of litter.

LIMITS TO THE STUDY

Challenges to the study include seasonal variation in visitor profiles in turn affecting the interest points where participants were found. The study took place in August, after students returned to school from summer vacation. Because of this, the volume of local picnickers was reduced. A further lessoning of picnickers surveyed is due to the length of the survey period. Surveys were conducted over a three week period, limiting the surveying of picnickers to three weekends. Since this type of visitor is very common in the summer and during the weekends, a key demographic may have been overlooked. Although there was, statistically, a significantly greater amount of local visitors surveyed who came to the forest to picnic, the disparity between groups may be greater than represented by this study.

The lack of picnickers surveyed should also have an effect on the survey results in respect to attributes of the forest most valued by visitors and time spent in the forest. A visitor who comes to picnic is less likely to be concerned about hiking and more likely to be concerned with the facilities utilized for picnicking: restrooms, picnic shelters, swimming accessibility and grills. Furthermore, having less data from picnickers most likely decreases the mean time that the visitors who were surveyed spent in the forest, thus deemphasizing the knowledge base of respondents. Finally, a lack of picnicker responses could have an effect on the values of ratings given by visitors. It is possible that picnickers are more or less satisfied with certain interest points, such as the picnic areas and swimming holes, than is indicated by the study.

CONCLUSION

Concluding Recommendations:

It is necessary for forest planners to consider the effects of the dramatic increase in yearly forest visits (discussed in the "Background" section). This section provides some recommendations for forest planners in light of the increasing visits and information provided by the present study.

The problem of reducing tranquility in the forest due to increased visitation may be mitigated by a traffic reduction program. Many National Parks, such as Grand Canyon National Park and Zion National Park use buses to shuttle visitors around the park. In this way, less development of sites would be needed because the need for parking would decrease. Also, the tranquility could be maintained with the reduction of vehicles quickly passing up and down the mountain; reducing stress of traffic, parking and emissions. El Portal Visitor Center, since it is near the entrance to the park and has a large parking area, would be an ideal location for visitors to park, plan their trip and board a bus.

Forest planners must consider how the forest can support increased numbers of visitors. As previously mentioned, local and non-local visitors gave high ratings to interest points that involved hiking. One way the forest could support more visitors and satisfy the desires of increasing numbers of visitors would be to encourage the use of existing trails and create more trail hiking destinations with varying levels of difficulty. This would pull more tourists out of the busy central locations and create the necessary space for experiencing the natural environment.

An idea for encouraging non-local visitors to spend more time in the forest is to bring in concessionaires to offer a picnic service to tourists who do not have grilling supplies, etc. for such an event with them on vacation. The concessionaires could offer everything a group would need to have their own picnic. This picnic service would not only help with overcrowding, since visitors could fill all the picnic shelters (moving them away from crowded, central locations), it would encourage non-local visitors to experience Puerto Rican culture and foster community between the two groups.

Another possible action for forest planners is to help make visitors aware of present and upcoming preservation and conservation efforts. This could increase visitor satisfaction since so many survey participants indicated a concern for conservation of the forest.

Finally, forest planners could increase visitor satisfaction by finding ways to reduce litter in the forest. This could be done by providing more trash receptacles, posting signs urging utilization of said receptacles and even by assigning a staff person to maintain areas with high incidents of litter.

Final Comments:

Keeping in mind the differences between residents and non-residents, current trends and future scenarios portend a rising conflict of interest. For example, with the increase of non-resident forest visitors desirous of sightseeing and new experiences and the increase in forest visitors in general will also come higher levels of traffic and vehicle emissions. The residential visitors may have difficulty finding the tranquility and fresh air they seek.

Furthermore, one trend that should be considered is population increase. As the population of Puerto Rico and the United States increase, so will tourist pressure on the forest. The U.S. Census Bureau found that the population of Puerto Rico increased 3.5% from 2000 to 2007 and the population of the United States increased 7.2% during the same years. These population increases indicate Puerto Rican residents will be impacting the tranquility of the forest as well as non-residents (U.S. Census 2008).

Another future scenario to consider is Global Climate Change (GCC). Globally, the surface temperature is predicted to increase between 1.4 to 5.8°C from 1990 to 2100 (Gitey et al. 2001). This temperature rise might reduce the amount of forest visitors coming from cooler climates outside of Puerto Rico (United States, Canada, Europe, South America) and increase the volume of Puerto Rican resident visitors heading to the rain forest for cooler temperature, fresh air, and rainfall. This would be a reversal of the current trend of the increase in percentage of non-local visitors. Important research to consider for the future should include both the impact of GCC on visitor numbers, and also how the increasing volume of visitors will affect visitor satisfaction.

The aim of this study was to consider the differences and similarities between two types of visitors to El Yunque National Forest: residents and non-residents of Puerto Rico. Although residents largely come to visit with family and friends and relax and the majority of non-residents come to sightsee and explore nature, both groups seem to have an overall positive experience of the forest, indicating that, at present, forest managers are successfully satisfying the culturally diverse visitors.

CHAPTER TWO:

CLIMATE CHANGE AND VARIATION IN THE EL YUNQUE NATIONAL FOREST OF PUERTO RICO

CHAPTER SUMMARY

The linear and seasonality trends of the monthly surface air temperature and precipitation in Puerto Rico were studied using the ARIMA model for the period of 1955 through 2008. The amplitude of precipitation variation was also examined using the coefficient of variation.

Auto Regressive Integrated Moving-Average (ARIMA) modeling verified that a warming trend is dominant over the majority of the studied areas. El Verde station, located at the El Yunque National Forest, and a majority of stations used for the study have shown strong warming trends in the monthly temperature with a maximum at El Verde (0.14 °F (0.078 °C) /year) and seasonality of 4-6 months. Cooling trends have been observed at a few stations including Aibonito, Cayey, Dos Bocas, Guayamas and Manati. The results of the linear trend analysis and variations of precipitation did not show any significant change in the rainfall over the same period.

INTRODUCTION

El Yunque National Forest (EYNF) in northeastern Puerto Rico is administered by the USDA Forest Service and covers 11,491 hectares. Evaluating the ecological and hydrological responses to climate change in EYNF is well established through the use of downscaled global model simulations (Scatena, 1998). To our knowledge, no weather pattern analysis has been done using the meteorological observation data from the regions. This study aims to assess climate change and variations in EYNF as well as the entire region by examining the seasonality and linear trends of the monthly precipitation and temperature data collected from 20 weather stations. A management tool to take these climate change responses into account will be presented in Ch. 3.

METHODS

Study site

Puerto Rico (18º 15' N, 66º 30' W) displays a wide variety of topography and climate in the tropical moist regions. The annual average temperature is 82.4 °F (28 °C) throughout the year with a dry season from November to May and a rainy season from June to November. The temperature in the south is usually a few degrees higher than the north, while temperatures in the central interior mountains are always cooler than the rest of the island. The climate of Puerto Rico is mainly typified as a tropical marine climate and has very little seasonal temperature variations.

Average rainfall varies from area to area, ranging from 161 inches (1,550 mm) in the north to 36 inches (910 mm) in the south. El Yunque National Forest averages 180 inches (457.2 cm) of rainfall yearly while the city of Ponce (southern part of the island) averages 40 inches (101.6 cm) a year.

Figure 2-1 Locations of the 20 climate stations used for the data analysis

Data

Climate data were obtained from the website of Luquillo Experimental Forest Long-term Ecological Research Project (http://luq.lternet.edu/) and the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html). Climate data consists of daily surface maximum and minimum temperatures and daily rainfall measurements from 20 stations.

The territory covered in the study extends in latitude from 17.97 º N to 18.47 º N and in longitude from 65.91 º W to 67.16 º W. 20 stations were selected based on a shared recorded time period for all stations: Aguirre, Aibonito, Cayey, Coloso, Corozal, Dorado, Dos Bocas, Guayamas, Gurabo, Isabela, Juncos, Lajas, Magueyes Island, Manati, Mayaguez city, Ponce, Rio Piedras, San Juan, Trujillo Alto, and El Verde. Data recorded before January 1955 was excluded from this study due to limited and sporadic availability. The locations of these stations with recorded years are provided in Table 2-1.The data for each station were averaged monthly using Microsoft Excel and arranged with time sequence IDs.

The credibility of the precipitation and minimum and maximum temperature data was addressed by identifying outliers using an adapted Z-test. To discard extreme outliers in temperature datasets, stations located at the highest elevation, lowest elevation, highest latitude, and lowest latitude were selected, their monthly mean averaged, standard deviation calculated, and the Z-test performed to generate maximum and minimum values to filter all datasets. The Z value was determined as three times standard deviation, subtracted from a mean value for minimum value, and added to a mean value for maximum. The method used here is considered to be highly conservative since the lowest of the lowest and highest of highest data points were used to identify and eliminate outliers.

Table 2-2 displays two charts with four stations chosen based on criterion described above. In the set of maximum monthly temperature, Dorado (the station at both the lowest elevation and lowest latitude) shows the highest value of 96.15 °F while Aibonito (at the highest elevation) displays the lowest value of 68.63 °F. Only one data point from Aibonito was found as an outlier below 68.63 °F. In the case of minimum monthly temperature, Aguirre station at the lowest latitude yielded the highest temperature value 80.08 °F while the smallest value 55.12 °F was obtained from Aibonito station at the highest elevation. As a result of filtering out outliers, one point each from stations Coloso, Junco, and Cayey was removed from the data set.

S no.	Station name	Latitude (°N)	Logitude(°W)	Elevation(FT)	Recorded years
1	Acquirre	17.97	66.22	25	1955-2008
2	Aibonito	18.13	66.26	2370	1955-2008
3	Cayey	18.11	66.15	1370	1955-2008
4	Coloso	18.38	67.16	40	1955-2008
5	Corozal	18.33	66.36	650	1955-2008
6	Dorado	18.47	66.31	5	1955-2008
7	Dosbocas	18.34	66.67	200	1955-2008
8	Guayamas	17.98	66.09	72	1955-2008
9	Gurabos	18.26	65.99	160	1955-2008
10	Isabela	18.46	67.16	420	1955-2008
11	Juncos	18.23	65.91	213	1955-2008
12	Lajas	18.03	67.07	90	1955-2008
13	Magueyes	17.97	67.95	12	1955-2008
14	Manati	18.43	66.47	250	1955-2008
15	Mayaguez	18.19	67.14	74	1955-2008
16	Ponce	18.03	66.53	70	1955-2008
17	Rio Piedras	18.39	66.05	92	1955-2008
18	San Juan	18.44	66	9	1955-2008
19	Trujillo Alto	18.33	66.02	115	1955-2008
20	El verde	18.2	65.49	1148	1975-2008

Table 2- 1 List of stations in the study area

(a) Maximum temperature

	Station	Latitude (°N)	Elevation (FT)	Longitude(°W)	Mean	SD	Z	Min	Max
Lowest Latitude	Aguirre	17.96	25	66.22	87.69	1.84	5.53	82.16	93.22
Highest Latitude	Dorado	18.47	5	66.31	85.36	3.6	10.79	74.57	96.15
Lowest Elevation	Dorado	18.47	5	66.31	85.36	3.6	10.79	74.57	96.15
Highest Elevation	Aibonito	18.13	2370	66.26	78.42	3.26	9.79	68.63	88.21

(b) Minimum temperature

	Station	Latitude	Elevation	Longitude	Mean	SD	Z	Min	Max
Lowest Latitude	Aguirre	17.96	25	66.22	70.35	3.24	9.73	60.62	80.08
Highest Latitude	Dorado	18.47	5	66.31	69.83	2.68	8.03	61.8	77.86
Lowest Elevation	Dorado	18.47	5	66.31	69.83	2.68	8.03	61.8	77.86
Highest Elevation	Aibonito	18.13	2370	66.26	64.34	3.07	9.22	55.12	73.56

Table 2-2 Criteria used to identify outliers: total mean, standard deviation, Z value, Minimum and Maximum data points

Precipitation

Autoregressive Integrated Moving Average (ARIMA) modeling was applied for the monthly averaged precipitation time series. This method was used to determine whether statistically significant differences exist from month to month, to look for seasonality, and also to examine the entire 53-year period for a linear trend. The ARIMA model was built without taking account of the moving average (MA) component, which merely smoothes averages out based on random lag by user selection. The auto regressive (AR) function finds the best time lag of each station by looking at the seasonality pattern that is most evident.

The first model was constructed and examined to find linearity in each station independently of any effects of seasonal variation. Results of this model show a weak linear trend. Figure 2-2 shows a weak linear trend found in the Coloso and Aguirre stations by ARIMA modeling.

To examine whether distinctive seasonality exists in precipitation patterns, negative autocorrelation coefficient values exceeding the confidence level were used to find the most significant time lag. Correlation is the mutual relationship between two or more random variables, which can be utilized as a practical mathematical tool for analyzing time domain signals. Unlike correlation, autocorrelation is the correlation of a signal with itself, using the same time series twice (Parr 1999). It is useful in finding similarities between a given time series and a lagged version of itself over successive time intervals. Since datasets are arranged by time IDs representing each month, the time lag found here indicates seasonality in units of months. Figure 2-4 demonstrates how seasonality can be detected by looking at negative feedback in a partial autocorrelation plot in the Coloso and Aguirre stations.

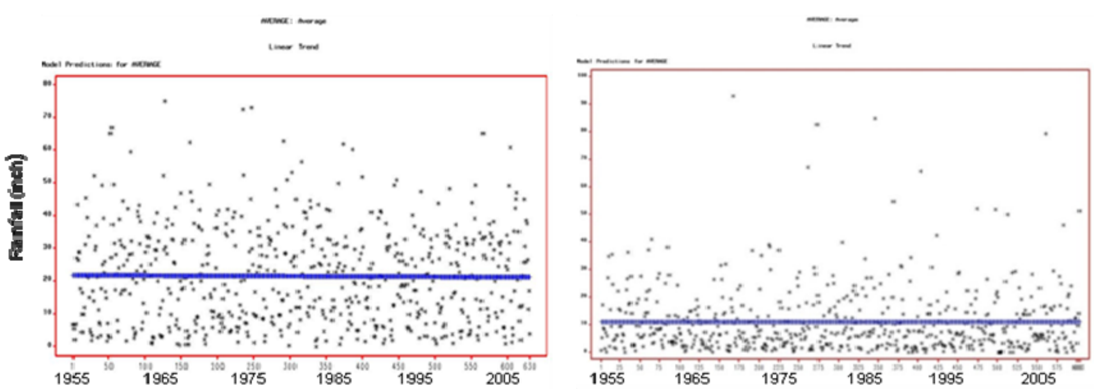
Finally, based on Akaike information criterion, the best fitting ARIMA model was built with the most significant known time lag and examined in conjunction with the linear trend shown in Fig 2-4. Results show a difference between the model that was only tested with the linear trend and the model that also takes account of seasonality with P-values and slope estimates.

The fittingness of the models was checked with P-value, R square, a correlation coefficient (slope estimate), and categorized to be statistically significant if the P-value was less than 0.05 and recorded in conjunction with the slope and R square values. Table 1 in Appendix

2.1 shows how statistical values improved by taking account of seasonality with linear trend analysis in chosen stations.

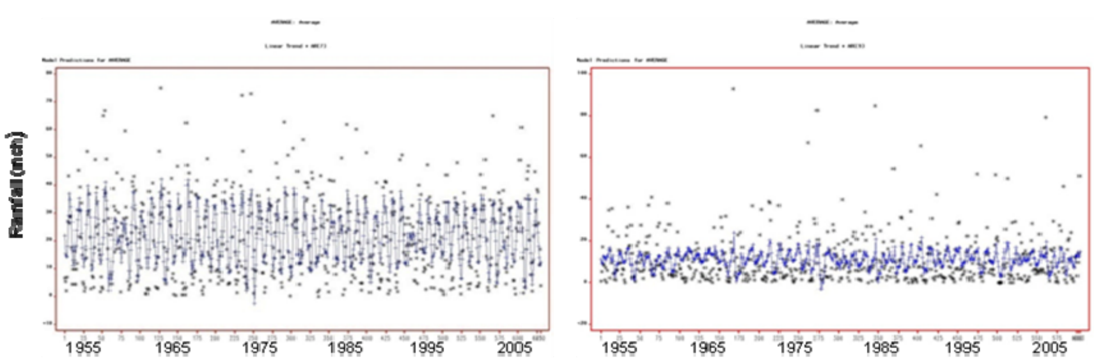
As an indicator of climate variation as opposed to climate change, coefficient of variation (CV; i.e., standard deviation standardized by the mean) of monthly precipitation was computed. Then it was converted to a linear representation with the ARIMA procedure by taking the time variable over the x-axis and examined to demonstrate whether there has been change in variation of monthly precipitation during the study period. Graphs of the linear trend of CV found in the stations are displayed in the result section.

Presentation of equations and tests are not provided as it goes beyond the scope of this paper.



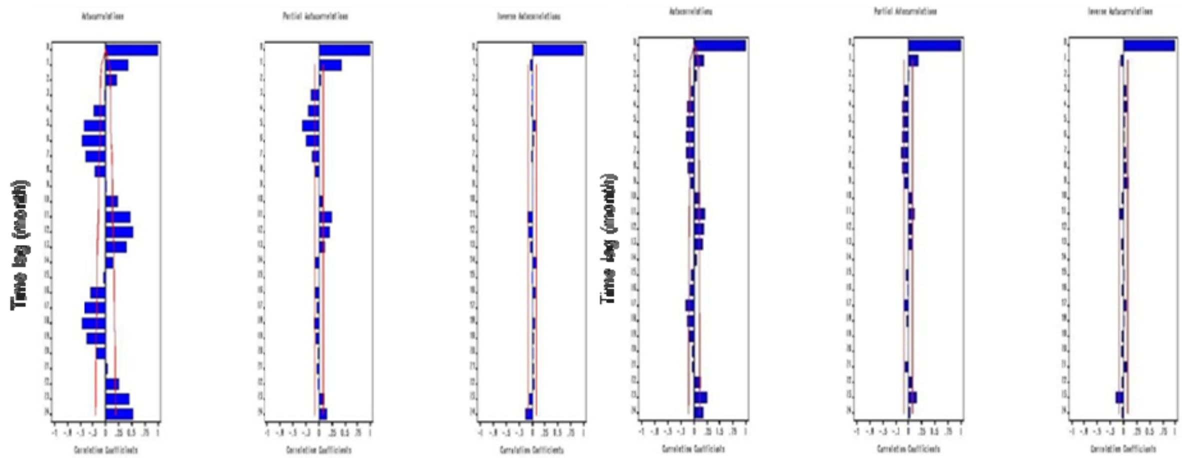
(a) Coloso (b) Aguirre

Figure 2-2 Non significant linear trend of mean monthly precipitation found in Aguirre and Coloso



(a) Coloso (b) Aguirre

Figure 2-3 ARIMA model predictions for a linear trend in combination with seasonality



(a) Coloso (b) Aguirre

Figure 2-4 Seasonality as a function of negative feedback found in autocorrelation plot found

.no	Station	Linear trend	Slope	P-Value	r-sqd	Linear & seasonality	Slope	P-value	r-sqd
1	Acquirre	None	0	0.9865	0	None	-0.0003	0.8537	0.106
2	Coloso	None	-0.0009	0.7704	0	None	-0.0013	0.4475	0.369

Table 2- 3 Linear trend and seasonality found in precipitation data of each station with statistical values

Minimum and Maximum Temperature

Positive linearity as a sign of global warming

'Linear trend,' as a measure of increase or decrease in long term temperature, was estimated using the Autoregressive Integrated Moving Average (ARIMA) procedure. ARIMA was applied for the monthly averaged precipitation time series. This method was used to determine whether statistically significant differences existed from month to month, to look for seasonality, and to examine the entire 53-year period for a linear trend. As it is essential to solely examine linear trends independent of effects of seasonal variation, a simple ARIMA model was first constructed without taking account of an autoregressive (AR) component. Figure 2-5 shows a strong increasing trend found in Dorado and El Verde. The relationship was determined to be significant if the P-value was less than 0.05 and recorded in conjunction with slope and square root values.

Seasonality showing shift in temperature depending on seasons

To examine whether distinctive seasonality exists in precipitation patterns, negative autocorrelation coefficient values that exceeded confidence levels were used to find the most significant time lag. Since datasets are arranged by time ID representing each month, time lag found here indicates seasonality in units of months. Figure 2-7 demonstrates how seasonality can be detected by looking at negative feedback.

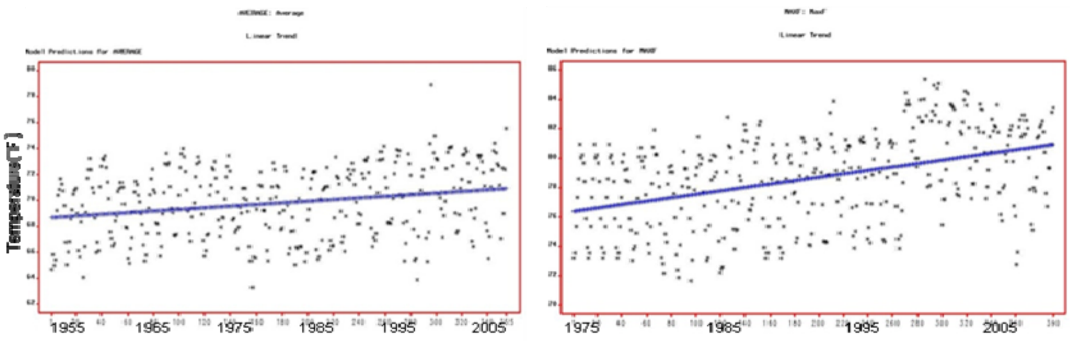
Linearity and seasonality; relating climate change to seasonal pattern

The most prominent time lag in combination with a linear trend was tested with the ARIMA model to find the best fit model of data based on Akaike's information criterion (AIC). Results show a difference between the model that was only tested with a linear trend and the model that takes seasonality into account (Figure 2-6).

The fittingness of the models was also checked with P-value, R-square, and a correlation coefficient (slope estimate), and then categorized based on statistical significance and recorded in conjunction with slope and R square values. More reliability was given to model predictions constructed with both linearity and seasonality. Seasonal variation is a major force driving climatic pattern in Puerto Rico and therefore it is important to predict warming trend in relation to it.

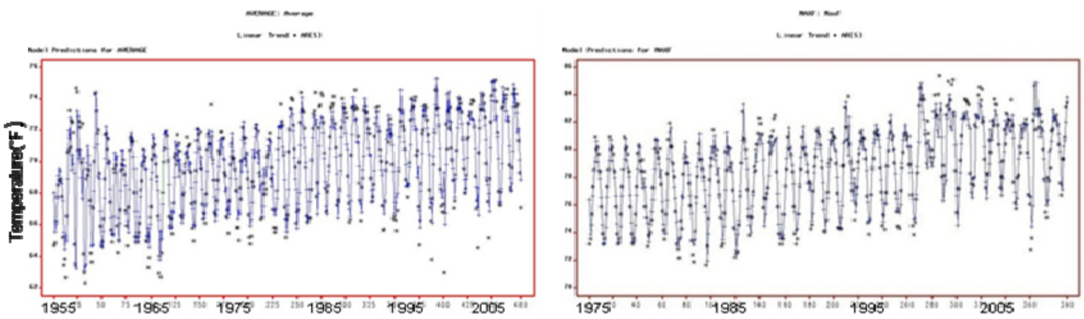
Again, the moving average (MA) component of ARIMA was excluded from model construction because the purpose of the study does not require averages to be smoothed based on random lag by user selection. The auto regressive (AR) function finds the best time lag of each station by looking at the seasonality pattern that is most evident

Presentation of equations and tests are not provided as it goes beyond the scope of this paper.



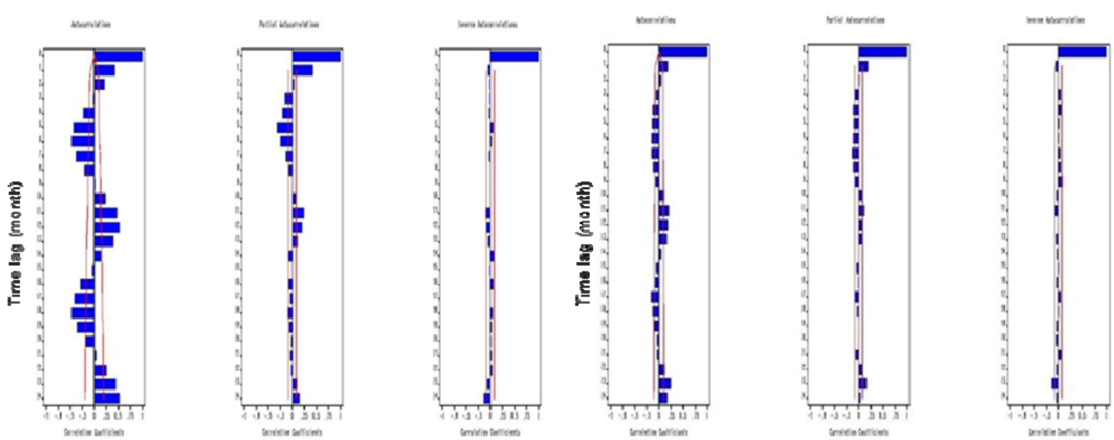
(a) Dorado (b) El Verde

Figure 2-5 Strong linearity found in Dorado and El Verde



(a) Dorado (b) El Verde

Figure 2-6 ARIMA model predictions for a linear trend in combination with seasonality



(a) Dorado (b) El Verde

Figure 2-7 Seasonality as a function of negative feedback found in autocorrelation plot

RESULTS

Linear and Seasonal trends of precipitation

Analysis of precipitation revealed neither statistically strong linear trends nor seasonality (Figure 2-11). Yet, over the whole of Puerto Rico, precipitation shows increasing trends (13 stations increasing and 7 stations decreasing). Table 1 in Appendix 2.1 shows how the slope of regression equation, P-value, and R-square value changed from station to station, and how the R values were strengthened by taking account of seasonality into linearity.

Coefficient of variation of the monthly mean precipitation

Coefficient of variation is expressed as the ratio of standard deviation of the average daily temperature to the monthly mean, which expresses the amplitude of precipitation variation by month. Opposed to several authors and studies who have predicted increasing climate variation resulting from global warming (Karl et al. 1995; Groisman et al. 1999; Easterling et al. 2000) observation data in 10 stations showed a negative coefficient of variation, including stations with non significant P-values (Table3 in Appendix 2.1). Among statistically significant stations, those with negative trends (Magueyes, Ponce and El Verde) are all at the edge of the island El Verde station located on the El Yunque National Forest showed the lowest CV value of -0.09.

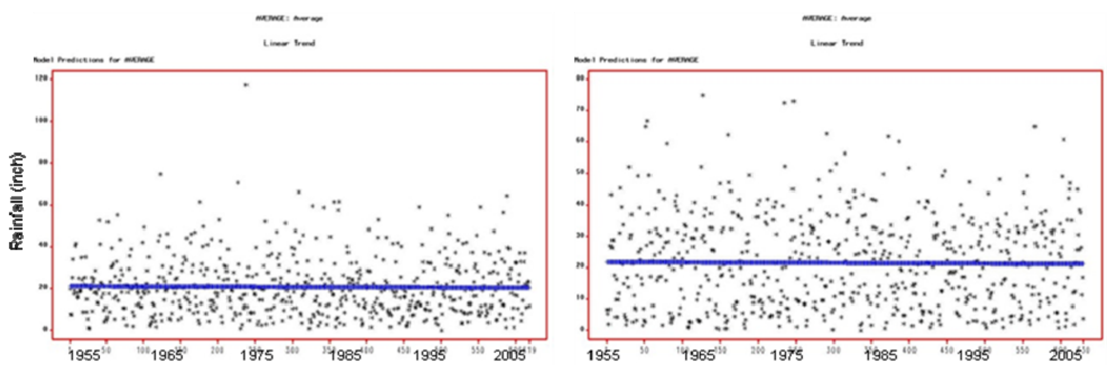
Linear and Seasonal trends of temperature

Analyses of the temperature series show that mainland Puerto Rico has experienced statistically significant warming during the study period. Fourteen stations are found with strong warming trends of minimum monthly temperature with an average of 0.0419 °F /year and a maximum of 0.1034 °F /year found at Juncos, while the other six stations are not statistically significant . The linear rates of maximum temperature show an increase over the island during the study period about 0.0093 °F /year for the monthly mean, and a maximum 0.1403 °F /year at El Verde. Five stations show negative linear trends and the other six showed no significance Climatic trends of mean monthly maximum and minimum temperatures with corresponding slope values are shown in Table 2-4.and 2-5. Most of these warming trends are higher than the observed global warming during the recent decades, which is 0.216 °F (0.12 °C) /decade. There are more stations with increasing trends in monthly mean minimum temperatures than there are with monthly mean maximum temperatures (Table 3 and 4 in Appendix 2.1).

Cooling trends have been observed in datasets of maximum monthly mean temperature at five stations: Aibonito, Cayey, Dos Bocas, Guayamas and Manati. The maximum cooling trend was found at Dos Bocas at -0.06792 °F/year with an average of -0.057048 °F/year.

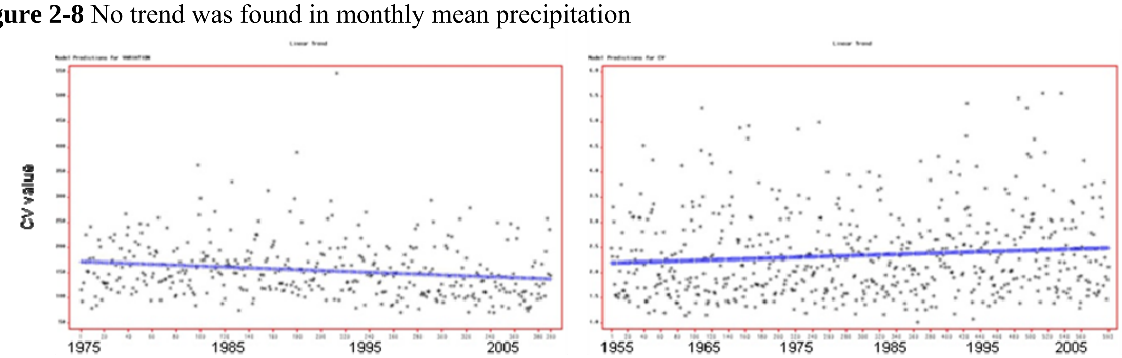
When the ARIMA model calculated linear trends taking seasonality into account, increases in R-square values were reported in almost every station. At El Verde, it increased nearly tenfold from 0.07 to 0.827 in minimum temperature and 0.177 to 0.803 in maximum temperature. Most of the stations showed seasonality at a lag of 4-6 months ($p<.05$).

More reliability was given to model predictions constructed with both linearity and seasonality. Seasonal variation is a major force driving climatic pattern in Puerto Rico and therefore it is important to predict warming trends in relation to it.



(a) Dos Bocas (b) Coloso

Figure 2-8 No trend was found in monthly mean precipitation



(a) El Verde (b) Magueyes

Figure 2-9 Linear trends of coefficient of variation in precipitation

Discussion and Summary

Compared with the global average, a warming trend is dominant over most of the stations in the study area (Figure 2-11). Global average temperatures on both land and sea have increased by 1.4 °F (0.8°C) around the world since 1880, while the global warming rate in the last 25 years has risen to 3.6 °F (2°C) per century according to NOAA (National Oceanic and Atmospheric Administration).

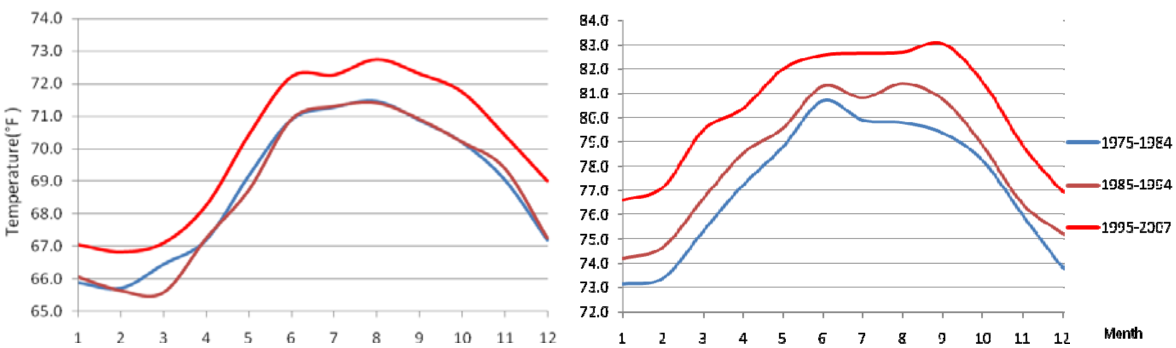
Given that land temperatures have historically increased about twice as fast as ocean temperatures and that sea surface temperatures (SSTs) drive the atmospheric temperatures, as can be expected on a relatively small island such as Puerto Rico, warming trends observed in Puerto Rico are noteworthy.

From the analysis of individual stations, it is revealed that El Verde exhibits a strong warming trend at the rate of 0.6804 °F /decade for the minimum temperature and 1.4028 °F /decade during the study period (1975-2008), which is significant at the 99 % level. As Tables 2-4 and 2-5 show, most of these warming trends are higher than the observed global warming trend (0.216 °F (0.12 °C) /decade) during recent decades. . The yearly temperature profile of El Verde shows a significant increase in temperature from the first study period, from 1975-2008, to the last period, from 1995-2008, as shown in Figure 2-10.

Consistent with the IPCC's Third Assessment Report, minimum temperatures increased more rapidly than maximum temperatures (0.4193 vs. 0.0929 °F /decade) from 1955–2008. As tables 2-4 and 2-5 show, there are 14 stations with increasing patterns in minimum temperature while only 9 stations with maximum temperatures showing warming trends. It is predicted that anthropogenic modification of the biosphere is projected to result in increased variability in precipitation as well as diminished variability in extreme temperatures, but with a higher number of occurrences (Karl et al. 1995; Groisman et al. 1999; Easterling et al. 2000). Global circulation models predict, and numerous observations confirm, that anthropogenic climate change has altered high-frequency climate variability (Drake, 2005).

Nevertheless, results of this study suggest that the increasing temperature does not always result in less rainfall, or a higher coefficient variation of precipitation, as many people expected. A number of authors reported that both precipitation and potential evapotranspiration must be considered when referring to the moisture conditions of land surfaces. Further, the impacts of climate variation and change on hydrology and water resources are far more complicated, and they extend beyond the scope of this study (S.Wu et. al., 2006). Monthly mean maximum and minimum temperature, monthly mean precipitation, and coefficient of variation were plotted against longitude, latitude, and elevation. Regression analysis showed no statistically significant relationships among these variables.

The existence of 'exceptional areas' is probably because the linear regression trends of these stations are influenced greatly by one or two extreme values and the changing trend is not significant, or possibly because they are caused by the complicated and probably nonlinear relationships among climate factors. Further, careful research is necessary.



(a) El Verde: Minimum temperature (b) El Verde: Maximum temperature

Figure 2-10 Increasing trends in El Verde over three decades

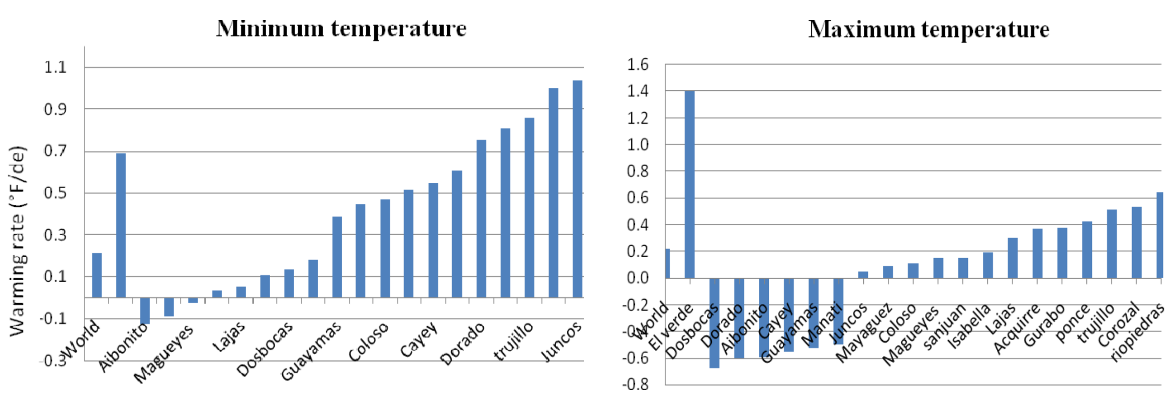


Figure 2-11 Warming trends found in minimum and maximum temperature

Conclusion

The causes of warming are attributed mainly to radiative forcing due to increased Greenhouse Gases (GHG). Local changes such as urbanization, land-use changes, forest fragmentation and industrialization have also had impacts on the thermal regime. Strong warming in cities like San Juan is due to rapidly expanding urbanization in such areas. Cooling in some localities may be due to negative forcing caused by local land-use changes and increases in atmospheric aerosols.

Assessing long-term climatic changes and variations remains a difficult task. Climate can be extremely variable, both spatially and temporally.

Past climatic records indicate that the LEF has become considerably drier, and will most likely continue to do so. These changes can affect local water budgets, distribution of forest vegetation, and possibly result in complete replacement of many unique components in the LEF such as the montane cloud forest and contribute to the extinction of animal and plant species whose migration rates cannot keep up with climate change rates and new species interactions. Changes in the surface temperature of 1 to 2 °F and fluctuations in annual rainfalls of 11 to 33 % could dramatically alter the distribution of forest vegetation within the El Yunque Experimental Forest (EYNF) of Puerto Rico (FN. Scatena, 1998). Because a 1.8°F (1C) increase in surface temperature can cause a 1250 FT (375 m) change in the heating level of condensation of the trade winds that pass over the LEF (Malkus et al. 1953), changes in the distribution of tree species within the LEF are unavoidable.

With an intermediate to large reported temperature increase, consequences could be significant. The increasing temperature trends at El Verde station particularly suggest it is one of the most sensitive areas responding to global climate change. The results of this study can be used to suggest guidelines on climate change and variability research without highly sophisticated statistical analysis, and to recommend important considerations in planning for future development in the area.

CHAPTER 3:

A MANAGEMENT TOOL FOR ADDRESSING GLOBAL CLIMATE CHANGE: MAPPING BIOLOGICAL VULNERABILITY TO CLIMATE CHANGE

CHAPTER SUMMARY

To date the US Forest Service has not explicitly included specific strategies for adapting to climate change in any of their LRMPs. This chapter focuses on the provision of a management tool that will allow EYNF managers to take climate change into account when making management decisions. This tool was developed via GIS analysis and shows the spectrum of biological vulnerability to climate change across the forest (Figure 3-2, Appendix 3.3).

Biological vulnerability to climate change was approximated by the presence of sensitive vertebrate species living within the forest with each species given a vulnerability weight. These weights were based on three factors: rarity, endemism, and whether or not global climate change is considered a threat to species viability. The map was spatially validated *in situ* to assess correlation with various habitat quality indicators.

Examples of management uses are provided with the recommendation that any usage of the map be accompanied by field validation of the location(s) in question. Additionally, replication of the methods for use by other land management agencies can be easily achieved and is encouraged if the map proves useful.

INTRODUCTION

The USDA Forest Service is in need of strategies to mitigate and adapt to climate change in order to preserve the ecological and economical value of their land holdings. Due to the unique and varied climate regimes in tropical montane cloud forests, EYNF is expected to be particularly sensitive to climate change effects (WWF 2003). As discussed in Chapter 2, climate change is indeed observable at the local scale of EYNF. Particularly noteworthy is the increasing warming rate observed at El Verde field station that already exceeds the average global warming rate (Figure 2.11).

The purpose of this section of the project is the provision of a management tool that will allow forest managers to take into account the possible effects of climate change when making management decisions. This management tool has been designed using spatial analysis concepts and techniques via ESRI's ArcGIS to provide a map of EYNF that shows ratings for biological vulnerability to climate change (by virtue of weighted habitat of sensitive vertebrate species) across the entire forest at a 15 m resolution.

It is not unprecedented that analyses such as these be used to prioritize areas for adaptation measures or facilitate other management decisions (Javed 2005, Gould/IITF 2005, Jankowski and Nyerges 2001). Gould et al. (2005) recently completed the Puerto Rico Gap Analysis Project (PRGAP), which utilizes vertebrate habitat models created using GIS methods that are then used in targeting certain species and locations for conservation attention.

The final product of this project is a map (Figure 3-2, Appendix 3.3) as described above that can be used by EYNF managers to aid in locating and/or prioritizing locations within the forest for management actions. Specific ideas and examples of possible management uses are described in the final section of this chapter.

Vulnerability Concept

Vulnerability to climate change defined as it is currently used in literature primarily refers to social community risk and the ability of communities to cope with predicted climate change effects. In this sense, spatial analysis techniques have been used previously to map vulnerability to climate change in India (Javed 2005). Here, we focus on the much smaller scale of the EYNF political boundaries. We also focus on just biological as opposed to social vulnerability because the scale and nature of EYNF as an entirely federally owned and governed piece of land does not lend itself to social vulnerability measures; few if any people live within the forest boundaries and the surrounding community has little influence on forest management.

In general, vulnerability consists of two aspects: an external risk (the actual shock to which the area is subjected- generally measured by current climate factors) and an internal risk (the ability to cope with the changes) (Javed 2005). Given the uncertainty of climate change effects at this small scale, external risk is manifested here by applying higher ratings for those species for which global climate change is considered a threat to species viability (termed "GCC Threat" throughout this paper, source: IUCN Redlist). The internal risk is accounted for in this analysis by the rarity and endemism qualities of already at-risk species. Thus, the habitat models were each given species-specific weights for three factors (GCC threat, rarity, and endemism) to produce a cumulative map of biological vulnerability to climate change.

METHODS

GIS Map Creation Methods

The descriptive (as opposed to predictive) presence of sensitive species was used as an indicator of biological vulnerability; that is, species habitat models were based on the current extent of the habitat rather than predicted future extents. To acquire this information, habitat models for fifteen vertebrate species were created, weighted, and combined to produce the final map. The particular fifteen species were chosen because they represent all vertebrates that both (a) have habitat within the forest and also (b) were listed by local, state, or international data sources as rare or threatened (USDA FS 2004, Puerto Rico DNER, PRGAP, IUCN Redlist, NatureServe) . These species consist of four birds, one reptile (*Epicrates inornatus*), one mammal (*Stenoderma rufum*), and nine coqui frogs (*Eleutherodactylus spp.*) (Table 3-1). Note that even though it has not been recorded since 1976, *E. karschmidti* was included in the analysis since it was also included in the USDA Forest Service Monitoring and Evaluation Report for [El Yunque National Forest], 2004.

Scientific Name	Common Name	Type
Accipiter striatus venator	Puerto Rican Sharp-shinned Hawk	Bird
Amazona vittata	Puerto Rican Parrot	Bird
Buteo platypterus brunnescens	Puerto Rican Broad-winged Hawk	Bird
Dendroica angelae	Elfin-woods Warbler	Bird
Eleutherodactylus eneidae	Eneida's Coqui	Frog
Eleutherodactylus gryllus	Cricket Coqui/Green Coqui	Frog
Eleutherodactylus hedricki	Hedrick's Coqui/Treehole Coqui	Frog
Eleutherodactylus karlschmidti	Web-footed Coqui	Frog
Eleutherodactylus locustus	Warty Coqui	Frog
Eleutherodactylus portoricensis	Upland Coqui	Frog
Eleutherodactylus richmondi	Ground Coqui	Frog
Eleutherodactylus unicolor	Burrowing Coqui	Frog
Eleutherodactylus wightmanae	Melodious Coqui/Wrinkled Coqui	Frog
Epicrates inornatus	Puerto Rican Boa	Snake
Stenoderma rufum	Desmarest's Fig-eating Bat/Red Fruit Bat	Bat

Table 3-1 List of species used in this analysis. Species inclusion was based on two criteria: (a) habitat includes land managed by El Yunque National Forest; and (b) species was listed by local, state, or international data sources as rare or threatened.

Vertebrates were chosen as opposed to other organisms due to the wealth of habitat information available (particularly due to the recently completed Puerto Rico GAP Analysis, IITF), and the analysis was limited to the most sensitive species because specific habitat information for more common species is much less well documented and available (Karl et al. 1999).

Descriptive habitat parameters for each species were determined from data compiled by literature review of all species. Current species presence was given precedence over historical species presence in situations where the sources indicated that species distribution is currently different than historic distributions. Primary sources of habitat information included IUCN Redlist, NatureServe, PRGAP (Bill Gould, IITF), various US Forest Service EYNF management documents, Joglar (1998), and Schwartz and Henderson(1991). See Appendix 3.2 for sources and habitat information that justified each element of each habitat model.

ESRI's ArcGIS software was used to create the habitat models and the resulting biological vulnerability map. Each habitat model consisted of raster values that ranged from 0-100 where 0=no presence of the species and 100=most likely presence of the species. The primary spatial data layers used to construct the habitat models are described in Appendix 3.1.

Habitat Weighting Process

After habitat model construction, the model for each of the 15 species was weighted according to three factors: rarity; endemism; and climate change as a high risk factor (GCC threat). Each nominal rating was given a numerical correlate on a scale from 0-100. Specific ratings for each category and species are provided in Table 3-2, Table 3-3, and Table 3-4.

Rarity Ratings

Overall rarity ratings were determined from an average of five separate sources (Table 3-2). Sources ranged in scope from local (an EIS conducted by EYNF managers in 2004) to global (IUCN Redlist, NatureServe).

USDA Forest Service EIS 2004		**PR GAP Occurrence**		**Puerto Rico DNER**		**IUCN Redist**		**NatureServe Conservation Status**	
ENDANGERED	100	Rare	100	CR	100	CR	100	GH	100
SENSITIVE	50	Uncommon	50	VU	50	EN	75	G1	80
not listed	0	Common	0	DD	25	VU	50	G2	60
				none	0	NT	30	G3	40
						LC	10	G4	20
								G5	0

Table 3-2 Nominal conservation status indicators and corresponding numerical codes from five separate sources. Explanation of acronyms: PR DNER - CR (Critically Endangered), VU (Vulnerable), DD (Data Deficient); IUCN Redlist Categories - CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern; NatureServe - GH: Possibly extinct/presumed eliminate, G1: Critically imperiled, G2: Imperiled, G3: Vulnerable, G4: Apparently secure, G5: Secure

Endemism Ratings

Endemism status was based on habitat modeling and literature review provided in the PRGAP (Gould, IITF 2005). The purpose of including endemism ratings was to develop a gradient such that species that relied solely on the land within EYNF were considered to be of highest importance while those that only used EYNF as one of several possible migratory destinations were rated the lowest. Note that none of the species that were included qualified as either a “Breeding Resident” or a “Migratory Resident.” These ratings were included for scaling of the numerical codes and future use as necessary.

Endemism Extent	Abbreviation	
Habitat does not extend outside of El Yunque National Forest	Endemic to EY	100
Habitat does not extend outside of main island of Puerto Rico	Endemic to PRmi	75
Habitat does not extend outside Puerto Rico's political boundaries	Endemic to PR	50
Habitat does not extend outside of Puerto Rico and the Virgin Islands	Endemic to PRVi	40
Breeding Resident of Puerto Rico	BR	30
Migratory Resident of Puerto Rico	MR	10

Table 3-3 Nominal and corresponding numerical codes for rating each species by endemism. See **Table 3-5** and **Appendix 3.2** for application of these ratings to each species.

Global Climate Change (GCC) Threat Ratings

GCC threat ratings were based on IUCN Redlist species assessments. Species were given "Indirect" ratings if threats included natural disasters (since tropical cyclone intensity is expected to increase with climate change (IPCC 2007)) or habitat loss (due to aforementioned natural disasters or loss of habitat due to invasive species action, which could be facilitated by climate change (IPCC 2007)). Information on the indirect threats came from a variety of sources. GCC was considered a direct threat (IUCN Redlist) to all *Eleutherodactylus spp.*, an indirect threat (various sources- see Appendix 3.2) to *A. striatus venator, B. platypterus brunnescens, A. vittata,* and *Dendroica Angelae*, and not a threat to *E. inornatus* and *S. rufum*.

GCC Threat Rating	
YES	100
Indirect (natural disasters/habitat loss)	50
NO	0

Table 3-4 Nominal and numerical ratings for assessment of whether or not Global Climate Change (GCC) is considered a threat for each species. See **Table 3-5** and **Appendix 3.2** for application of these ratings to each species.

Species Name	Rarity	Endemism	GCC Threat	Combined
Accipiter striatus venator	100.0	75	50	**75.0**
Amazona vittata	96.0	100	50	**82.0**
Buteo platypterus brunnescens	100.0	75	50	**75.0**
Dendroica angelae	54.0	75	50	**59.7**
E. eneidae	80.0	75	100	**85.0**
E. gryllus	31.3	75	100	**68.8**
E. hedricki	42.0	75	100	**72.3**
E. karlschmidti	83.3	75	100	**86.1**
E. locustus	58.0	75	100	**77.7**
E. portoricensis	31.0	75	100	**68.7**
E. richmondi	58.0	75	100	**77.7**
E. unicolor	70.0	100	100	**90.0**
E. wightmanae	23.0	75	100	**66.0**
Epicrates inornatus	70.0	75	0	**48.3**
Stenoderma rufum	50.0	40	0	**30.0**

Table 3-5 Weight ratings by type and species. See **Table 3-2**, **Table 3-3**, and **Table 3-4** for explanation of numerical weights for each category. The "Combined" rating is simply the average of the 3 other ratings. Each rating system was used to weight spatial habitat models in the construction of a map showing cumulative biological vulnerability (**Figure 3-1**)

For comparison purposes, five different maps (15 meter resolution) of biological vulnerability were produced, each using a different type of indicator: (1) unweighted (merely a sum of the 15 habitat models), (2) weighted by rarity only, (3) weighted by endemism only, (4) weighted by GCC threat only, and (5) one that combined (averaged) the three weights (Figure 3-1). [Note: since GCC was not predicted to be a threat to either *Stenoderma rufum* or *Epicrates inornatus*, the habitat models for these species were not included in the GCC threat indicator calculation] To compensate for uncertainty in the spatial data, each of the five raster maps were smoothed via ArcGIS Spatial Analysis "focal mean" operation, which gives each cell the mean value of the 9-cell square that surrounds it. Raster values were extracted from each map for each of the field site points (described below).

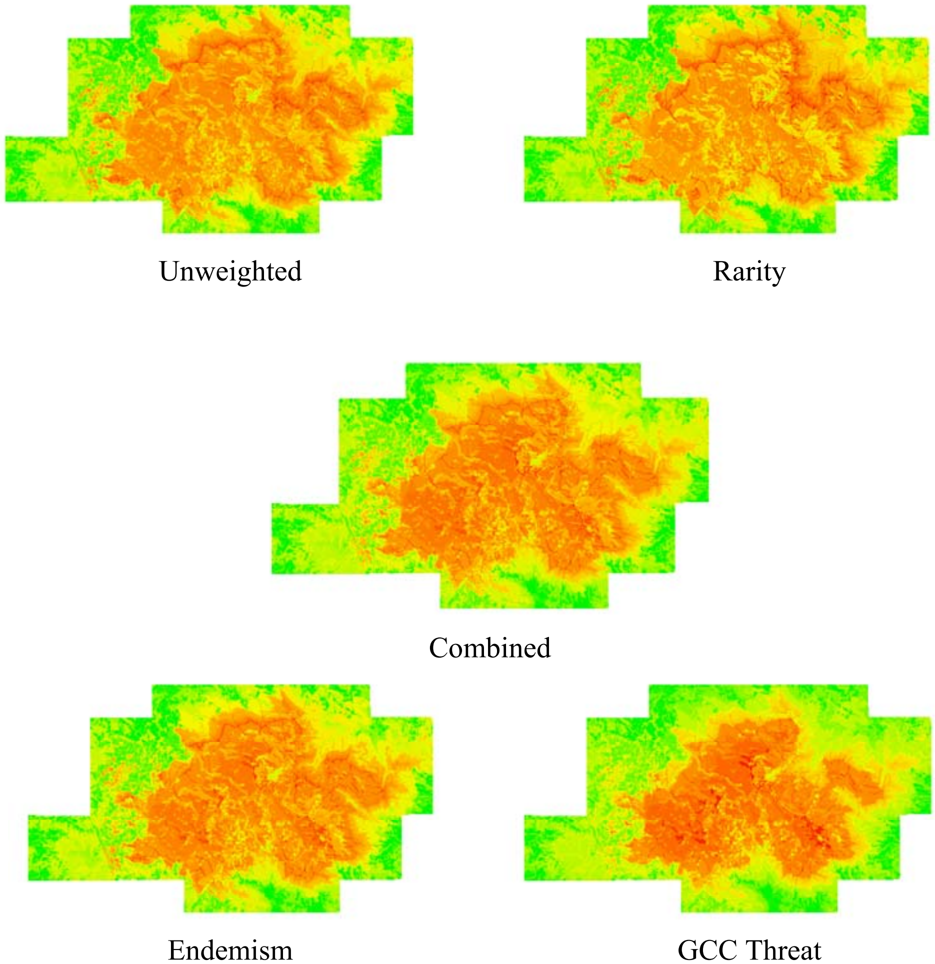


Figure 3-1 Compiled species habitat models using five different weighting systems. Values range in relative likelihood of sensitive species presence (taking respective weightings into account) from high (red) to low (green). Weightings for each species and system are given in **Table 3-5**.

Field Validation Methods

Field validation was conducted for the purpose of lending additional substantiation and authentication to the biological vulnerability map (as derived ultimately from literature as described above) by determining possible correlations between weighted sensitive species habitat (as determined via the GIS analysis described above) and *in situ* habitat quality.

We expected that field indicators of high habitat quality would correlate with the weighted presence of sensitive vertebrate species (Welsh, in press). To determine habitat quality, data was collected for various indicators of biological productivity, diversity, and other indicators of habitat quality (described below). However, it must be noted that many indicators are species specific, which tempered any expectations that any one habitat quality indicator would prove to be correlated with cumulative biological vulnerability. For instance, high percentage canopy cover is an indicator of high quality habitat for many amphibian species (Welsh and Lind 1996, deMaynadier and Hunter 1999), but not necessarily for bird species that prefer dense shrub habitats (Bell and Whitmore 1997).

Selection of field sites for validation was spatially randomized. Due to limited time for field data collection, a subset of the sites closest to roads and trails were selected to facilitate convenience and speed of field data retrieval. Thus, the randomized field sites were then clipped to the subset of 34 sites that were closest to roads or trails. The randomized field sites represented a fairly even distribution of biological vulnerability levels as determined from a prototype map that had been completed before field site selection.

Field data was collected 11 August to 23 August 2007 within the boundaries of El Yunque National Forest. Materials for data collection included DBH tape, transect tape, digital camera, compass, clinometer, and a Garmin Forerunner 301 GPS unit. Field sites were located using the GPS unit and compass. Plots extended in a 10 x 10 m square following the cardinal directions with the predetermined site point serving as the NE corner.

Within these plots the following data was collected: digital photographs at all 4 cardinal directions as well as directly up from the ground; the number of individual trees (> 5 cm dbh); the number of tree species; the DBH and height of the 3 largest trees; the slope, aspect, and elevation of the site; canopy density (% complete); visual observation of undergrowth density (low to high); visual observation of landslide evidence (low to high); visual observation of vegetation damage/herbivory (low to high); additional notes (e.g. whether a site appeared 2nd growth or not); and weather conditions.

From the measures of DBH and height of the 3 largest trees, a "biomass" measure was calculated ($\pi*(0.5*dbh)^2 * height$) and averaged across each site. The visual indications of undergrowth, landslide evidence, and vegetation damage were given numerical codes (none = 0, low =1, med = 3, high= 5) to facilitate statistical data analysis. In addition, a numerical indicator of "overall habitat quality" was generated from a combination of the comments about the site, the digital photographs, and visual observations. This parameter took into account such a combination of factors: diversity of vegetation; diversity of vertical forest structure; evidence of vegetation damage/pest presence; proximity to public roads; forest age (2nd growth vs. old growth); and biological productivity relative to nearby areas.

RESULTS

Data Analysis

The numerical vulnerability values associated with the coordinates of each field site were extracted for each of the five differentially weighted maps. Each of these values was tested for statistical correlation with 12 parameters derived from the field data (Table 3-6).

Parameter	Description
Res. Log Av. Biomass	Biomass (average of 2 * pi* dbh * height), log transformed, and normalized against elevation
Res. Log Tot. Biomass	Biomass (as above) * # of individuals in the plot
Res. Log Av. Biomass, no outliers	As above, outliers removed
Res. Log Tot. Biomass, no outliers	As above, outliers removed
# Individuals	Number of woody plant individuals (>5cm dbh) in plot
# Species	Number of woody plant species (>5 cm dbh) in plot
# Individuals/Species	Individuals/species (indicator of species evenness)
Landslide evidence	Numerical code indicating evidence of landslides in the plot
Vegetation Damage	Numerical code indicating degree of vegetation damage by insect/disease/weathering
Undergrowth	Numerical code indicating density of undergrowth
Canopy (%)	Percent closure of canopy, visual estimate
Overall habitat quality	Numerical code indicating site quality from visual observation by field tech

Table 3-6 Parameters derived from field data that were tested via linear regression analysis for correlation with biological vulnerability (weighted sensitive species presence) values as derived from the GIS maps shown in Figure 3-1.

	Unweighted	Rarity	Endemism	GCC	Combined
Res. Log Av. Biomass	*	*	*	*	*
Res. Log Tot. Biomass	*	*	*	*	*
Res. Log Av. Biomass, no outliers	*	*	*	*	*
Res. Log Tot. Biomass, no outliers	*	*	*	*	*
# Individuals	*	*	*	*	*
# Species	*	*	*	**(-)12.4**	*
Species Evenness	9.3	*	11.4	**18.6**	**15.4**
Landslide Evidence	*	*	*	*	*
Vegetation Damage	*	*	(-)10.5	**(-)13.8**	**(-)12.7**
Undergrowth Density	*	*	*	*	*
Canopy (%)	*	*	*	*	*
Overall Habitat Quality	**28.9**	**17.7**	**29.8**	**34.2**	**32.2**

Table 3-7 Results of regression analyses between five differentially weighted vulnerability indicators and field data. Numbers indicate r^2 values. Asterisks (*) indicate no significant correlation. Orange indicates $p < 0.10$, red indicates $p < 0.05$, and magenta indicates $p<0.01$. “(-)” indicates negative correlation.

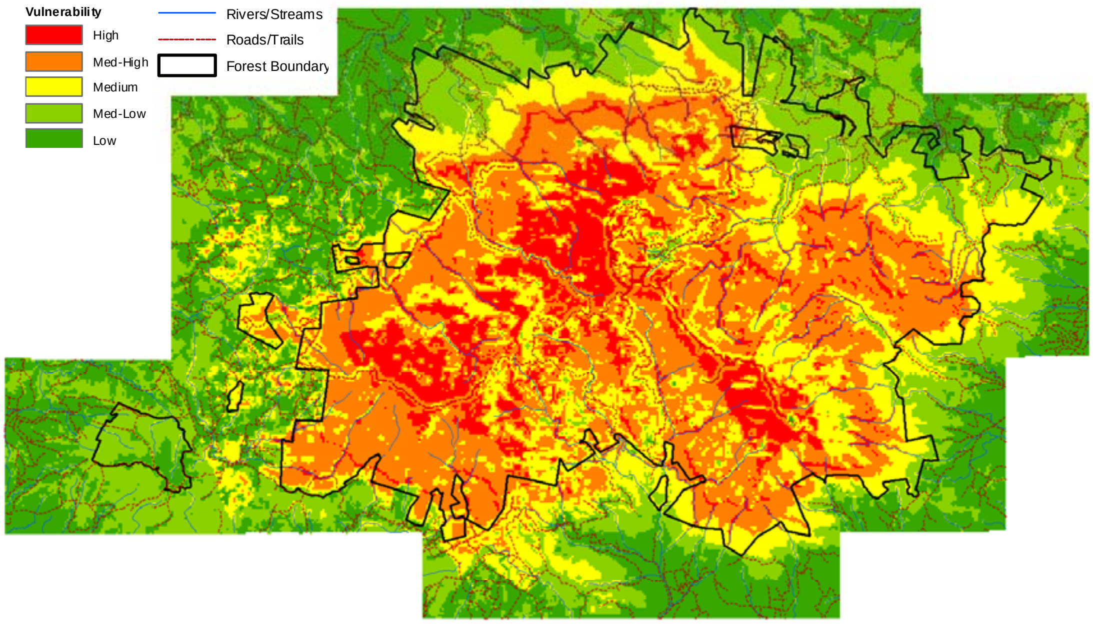
Regression analysis showed that none of the five vulnerability indicators are significantly correlated with biomass data or number of individuals per plot (Table 3-7). The GCC threat vulnerability indicator showed a negative correlation with woody plant species per field plot. All indicators except for the rarity indicator show significant correlation with species evenness, although only GCC Threat and Combined were significant at $p<0.05$. Endemism, GCC, and Combined indicators were significantly negatively correlated with vegetation damage. All indicators were significantly and positively correlated with the "overall habitat quality" parameter.

DISCUSSION

Interpretation of Data Analysis: Implications for Map Usage

While the GCC Threat indicator was significantly correlated with the highest number of field data parameters, the negative correlation with species number goes against the general expectation that diversity levels would be correlated among all organisms. The "overall habitat quality" was the only field data parameter for which all vulnerability indicators were correlated.

The high correlation of the vulnerability map with "overall habitat quality" parameter is a very useful finding. For instance, when using this map as a resource in making management decisions (see next section), it is highly recommended that this map not be used without field validation of the management area in question to confirm vulnerability as indicated by the map. Using a simple visual assessment of habitat quality for field validation, while potentially highly subjective, is nonetheless rapid and based on the regression results is also apparently effective in estimating biological vulnerability. For further discussion on this subject, see the "Future Areas of Research/Improvement for the Map" section.



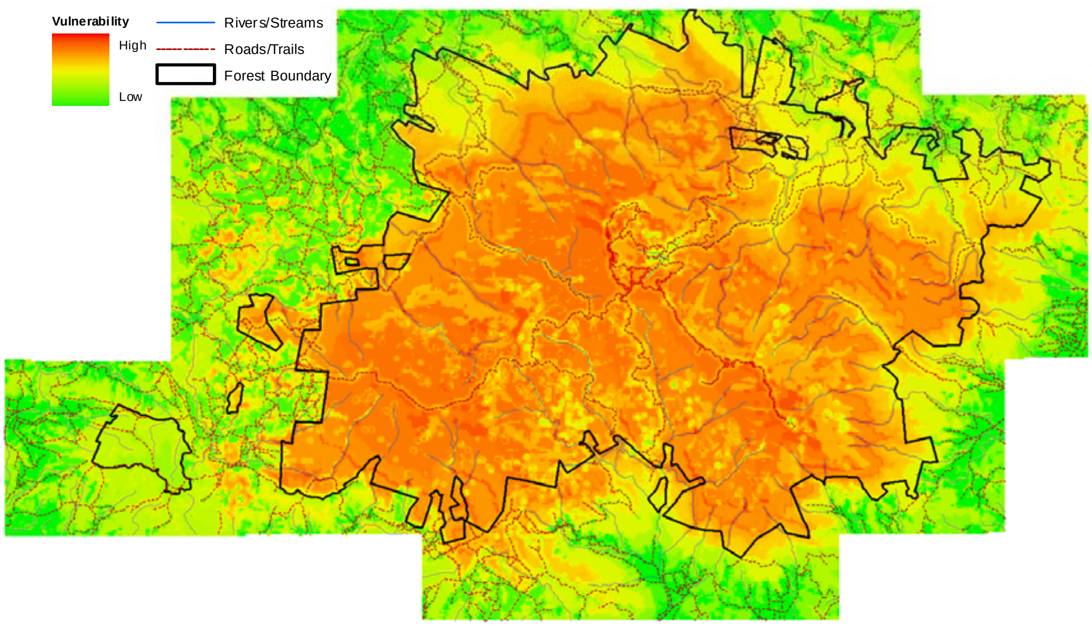


Figure 3-2 Biological vulnerability to climate change (via weighted presence of 15 sensitive vertebrate species) in El Yunque National Forest, Puerto Rico. Habitat models of each species were weighted by three factors: rarity, endemism, and GCC threat (see text for further explanation). Lower map shows raw vulnerability values while the upper map shows vulnerability values as classified into five categories (high to low) for enhanced distinction between values. Forest boundary, roads/trails, and stream/rivers layer are included for spatial reference. Maps created by Michael Billmire, University of Michigan School of Natural Resources and the Environment, 2008.

Biological Vulnerability Map Limitations

The biological vulnerability map is limited in the long-term by the fact that climate change is expected to greatly alter suitable ranges and distributions of species. As climate and global change effects are realized, the map will become increasingly obsolete. Thus, if possible it ought to be updated as necessary to reflect changing species distributions. The author suggests an update interval of ten years.

Additionally, the map is limited in validity by the fact that some subjective methods were unavoidable for various steps in the map making process. In the interest of full-disclosure and acknowledgement of the limitations of the map, the following steps in the map making process are identified as at least partly subjectively determined:

1. Choosing to use watershed data to represent forest regions (i.e. "north-central" forest) in habitat models (effects habitats of *A. striatus venator*, *B. platypterus brunnescens*, and *E. inornatus*).

2. Determination of numerical ratings for rarity, endemism, and GCC threat categories (see Table 3-2, Table 3-3, and Table 3-4). Since the highest ratings in each category were given 100 and the lowest were given 0, the only source of contention should come in the ratings given to the middle categories.

3. Determination of effective buffer distances for roads/trails layer. This followed Gould (PRGAP 2005), who used 30m buffers to determine forest edge habitat in constructing habitat models for PRGAP. Ortega and Capen (1999) suggest that habitat quality for certain bird species is reduced within 150m from roads, so the distances used may be fairly conservative. Certainly species specificity is also a concern here as bird species would be expected to use a greater range of habitat than *Eleutherodactylus spp.*

4. Determination of effective buffer distances for streams layer. As above, actual effective buffers distances are going to be species specific. In addition, streams are particularly difficult to buffer using traditional spatial analysis techniques since stream width changes continuously.

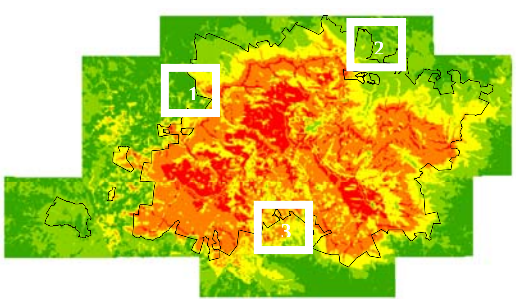
5. "Overall habitat quality" parameter from field data, discussed above.

Biological Vulnerability Map Usage: Management Ideas/Examples

The present section will provide ideas and examples for usage of this map by EYNF managers. The author stresses that the degree to which this map is used is at the full discretion of EYNF managers. No *specific* management recommendations will be made because the author will not assume knowledge of the many factors that go into each specific management action. Further, it is not intended that this map *alone* should be used to justify any management decision, but should instead be used in combination with all other management considerations. All other management variables being equal, this map can be used to either target areas for management action or to prioritize areas for management action. That said, what follows are five examples of how this map might be used by EYNF managers with specific decisions left to the EYNF managers.

Management Example #1: Prioritizing Acquisition of new land

Since the "proclamation" boundary (the blocky outer boundary in the maps) represents the entire area of all land that is purchasable by the USDA Forest Service for management by El Yunque National Forest, one way in which to use this map is to help prioritize locations for land acquisition if funds/resources are limited and managers must choose between several properties available for acquisition.



In the following hypothetical scenario, three properties (see left) are up for sale and the USDA Forest Service, thanks to a very generous anonymous donor, has enough available funds to acquire one of them.

The close-up examples of each property (Figure 3-3) show that property #3 contains the most orange/red (med-high to high vulnerability) and is thus the most valuable by virtue of containing habitat of vulnerable biological species.

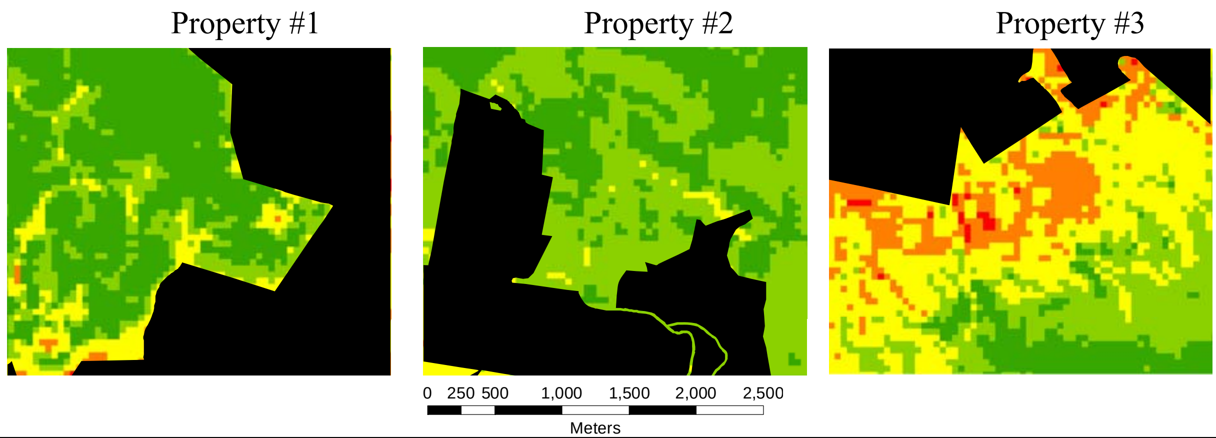


Figure 3-3 Close-ups of the three properties in the theoretical scenario described above displayed by biological vulnerability (weighted presence of sensitive species) rating. Land already owned by EYNF is blacked out for clarity. Red represents higher vulnerability while green values represent low vulnerability.

Using the example above, a list of priority property acquisition locations based solely on this map might include: the western portion of the private "island" in the northwestern part of the forest; along the current southern boundary of the forest; and along the western boundary between the "mainland" forest and the closest western "island" (Figure 3-4).

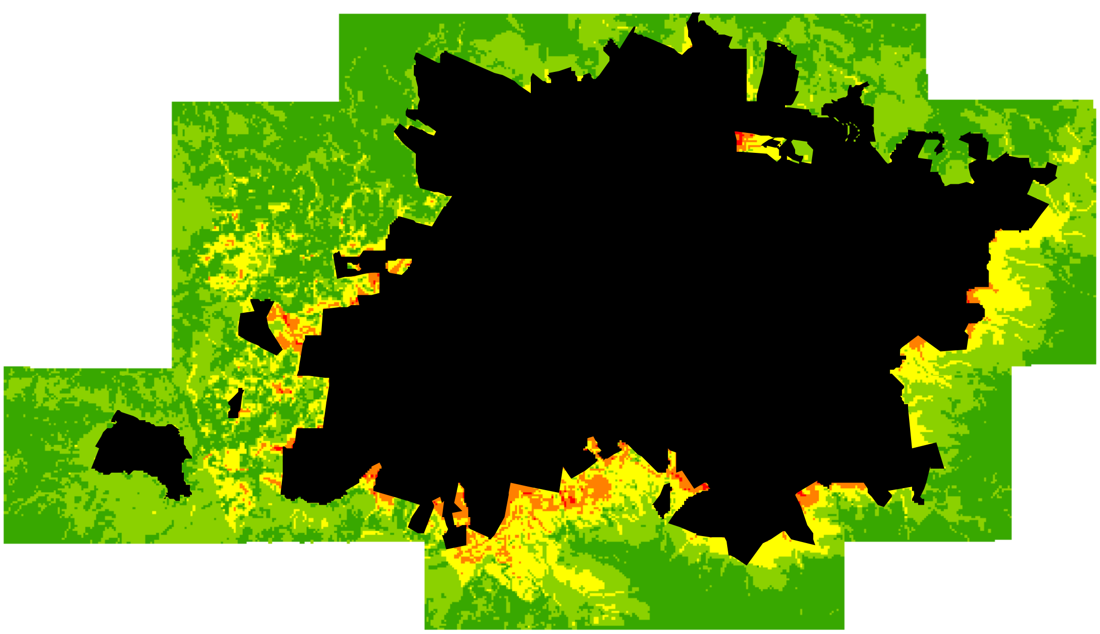


Figure 3-4 Classified biological vulnerability map (as shown in **Figure 3-2**, red: high vulnerability, green: low vulnerability) formatted for use in identifying properties for acquisition. Land currently owned/managed by the USDA Forest Service is blacked out to accentuate the relevant land area. Biological vulnerability is

approximated by weighted habitat of sensitive species. Red/orange indicates high vulnerability while green indicates low vulnerability.

Management Example #2: Prioritizing additional areas of conservation/protection

In 2005, 10,000 acres comprising the bulk of western El Yunque National Forest were designated as a federal Wilderness area (El Toro Wilderness Area). It is proposed that this biological vulnerability map be used as a resource to target/prioritize additional areas that could be placed under stricter conservation protection.

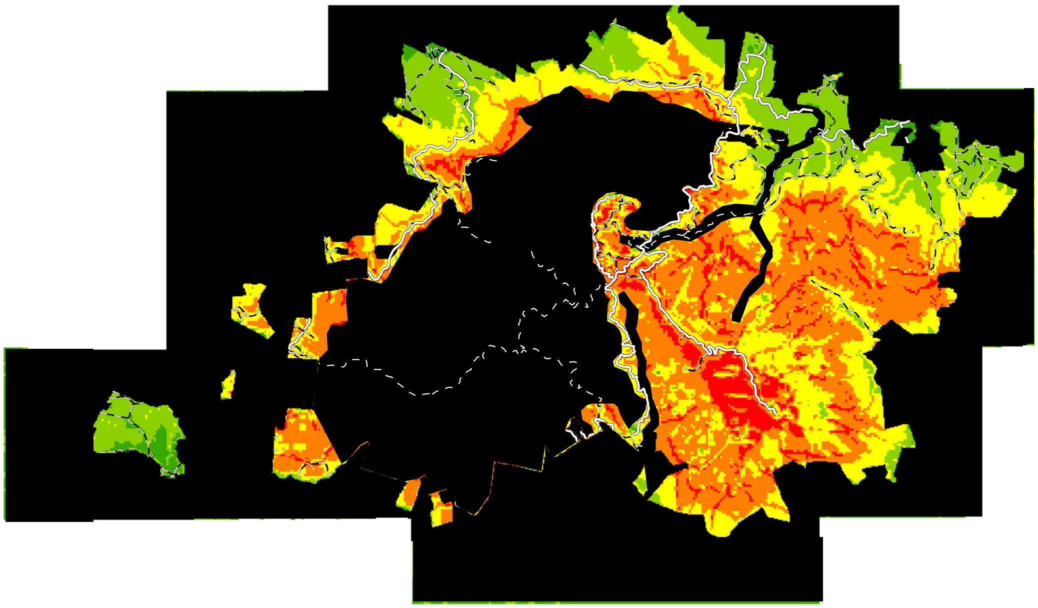


Figure 3-5 Biological vulnerability map (red: high vulnerability, green: low vulnerability) modified to highlight areas currently owned by forest and not under special conservation protection. Areas that are either outside of the forest boundary or already under strict conservation protection (Wilderness or W&S Rivers) are blacked out to accentuate the area of focus. Paved road (solid white lines) and dirt road/trail (dashed white lines) layers are included for spatial reference.

From Figure 3-5, it is apparent that the area currently not protected with the highest degree of biological vulnerability (weighted presence of sensitive species) is the area southwest along East Peak Road (the road that extends from roughly the center of the map to the south eastern corner).

Management Example #3: Prioritizing proposal of additional Wild and Scenic Rivers

In December 2002, the reaches of Rio Mameyes, Rio de la Mina, and Rio Icacos that are within the current EYNF boundary were designated as part of the National Wild and Scenic River System (NWSRS 2008). If EYNF managers consider proposing additional rivers for designation in the future, while actual aquatic species will be the top priority, this map can still be used to aid in selecting/prioritizing which rivers are proposed (Figure 3-6)

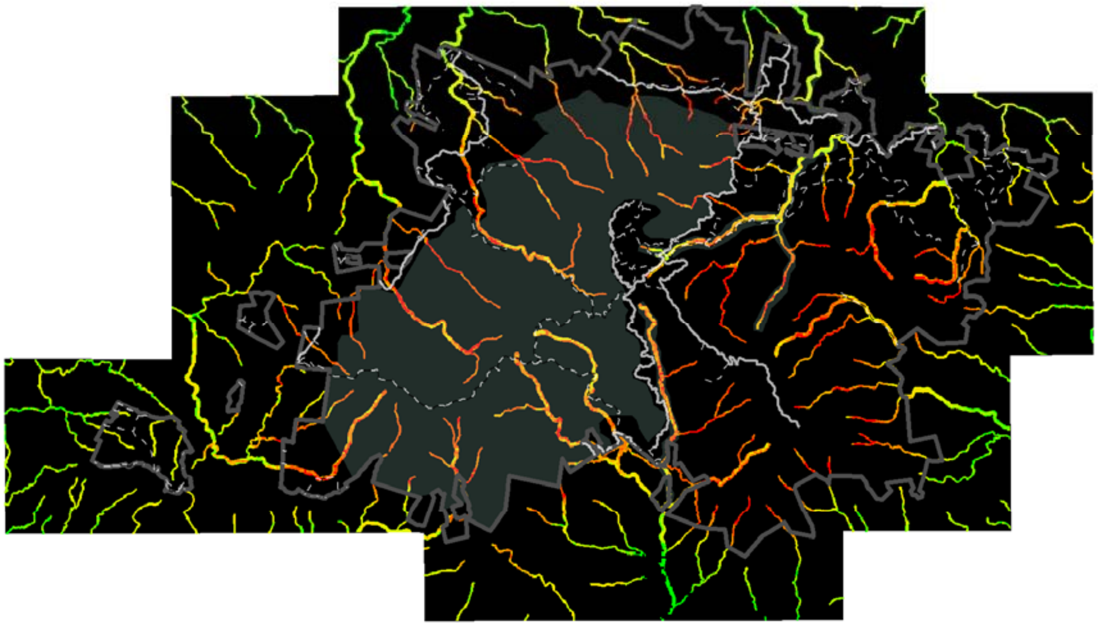


Figure 3-6 Biological vulnerability to climate change (weighted presence of sensitive species) for streams/rivers in El Yunque National Forest. Red represents higher vulnerability while green represents lower vulnerability. Forest boundary (thick gray lines), road (solid white lines), and trail (dashed white lines) layers are included for spatial reference. Shaded area represent area already having Wilderness or Wild and Scenic River designation.

Management Example #4: Prioritizing placement/construction of future roads/trails/structures

The author proposes that this map can be used as a helpful resource for any management decisions involving the planning, construction, accessibility, or removal of trails, roads, or structures. In planning, this map could be used to avoid proposed construction in particularly vulnerable areas. With proposed construction projects, the map could be used to set higher standards for low-impact structures in areas of higher vulnerability. EYNF managers may also choose to use this map to identify and justify removal of structures currently within highly vulnerable areas.

For setting accessibility guidelines, managers could decide to restrict/open-up access to areas of the forest based (partly) on the vulnerability of the areas in question. For example, public access is currently restricted for East Peak Road, and managers may choose to use this map as partial justification for continued restricted access due to the highly vulnerable area on the south side of the road (Figure 3-2).

Management Example #5: Prioritize locations of management concern for action

The biological vulnerability map can also be used to target and prioritize areas of management concern. Such areas may include known colonies of invasive species whereby the colonies can be prioritized for removal based on their relative biological vulnerability values.

Finally, the author would like to reemphasize that this map is not intended to be used as the sole resource/justification for any one management decision, but rather as a resource to consult and use only to the degree to which the managers feel appropriate given all other management considerations. It is recommended that any decisions made using this map be accompanied by field validation of the management areas in question to at least visually confirm habitat quality (as described at the end of the "Interpretation of Data Analysis" section).

Future Areas of Research/Improvement for this Map

If this map proves to be a useful management resource for El Yunque National Forest managers, additional spatial analyses like this can be employed for the USDA Forest Service and other land management agencies as a method/tool as a way to address climate change in land management. Given the availability of the basic spatial data layers described in Appendix 3.1, the exact methods described here are applicable to any other land area.

In terms of improving the map, the biological vulnerability map should be updated as necessary (the author suggests once every ten years) to include new information on the habitats of the fifteen rare species. In addition to habitat information, the map should be updated to include new information on both the spatial data used to create the habitat models (Appendix 3.1) and the conservation status indicators given to each species.

Further improvement in the value of this map as a resource to help manage the forest for climate change could be made by including all vertebrate species for which GCC is considered a direct threat. Assuming this only includes all amphibians (due to their sensitivity to moisture and temperature changes), then this would involve the very manageable task of adding roughly five more species to this analysis.

While the field validation that was performed confirmed the correlation of the biological vulnerability indicator with habitat quality (as mentioned in the "Interpretation of Data Analysis") the author suggests that when using this map as a management resource, it should not be used without field validation of the management area in question to confirm vulnerability as indicated by the biological vulnerability map.

Given the correlation of the "overall habitat quality" parameter as determined from the field data (see "Interpretation of Data Analysis" section), it is also suggested that a rapid assessment checklist be developed based on the factors that were included in this parameter. This checklist should then be tested for regression against the combined biological vulnerability indicator as described in the "Data Analysis" section. If regression results prove significant, the checklist will be usable for rapid assessment in conjunction with management actions that utilize the biological vulnerability map.

For reemphasis and possible future use, **overall habitat quality** (as determined in the field) included general observations of: diversity of vegetation; diversity of vertical forest structure; evidence of vegetation damage/pest presence; proximity to public roads; forest age (2^{nd} growth vs. old growth); and biological productivity relative to nearby areas.

CHAPTER 4:

INVASIVE PLANTS MANAGEMENT STRATEGY: EL YUNQUE NATIONAL FOREST, PUERTO RICO

CHAPTER SUMMARY

Managing invasive species in El Yunque National Forest requires careful consideration of ecological distinctions between the continental U.S. and the U.S. territory of Puerto Rico. Since sociopolitical and cultural distinctions are inextricably linked to the U.S. Forest Service's (USFS) management of El Yunque ecosystems, such less salient considerations cannot be ignored to successfully minimize the spread and damage caused by invasive species. Ideally at each U.S. National Forest, natural resource management frameworks are tiered from both national (i.e. Forest Service Washington Office) and regional (i.e. Forest Service Southern Region) regulatory guidance. However, the ecology of the only tropical United States National Forest and political institutions of the Estado Libre Associado de (or Commonwealth of) Puerto Rico create unique context for implementing such conventional invasive species management programs.

Forest Service national and regional invasive species guidance may appear out of synch with El Yunque, given a long history of exotic species introductions, less pronounced seasonality, and weather driven by steep Luquillo Mountains and ocean patterns. Additionally, relationships between the federal government and the Commonwealth of Puerto Rico may further complicate implementation of a continental invasive species management paradigm. Nevertheless, El Yunque National Forest (and other potential partner agencies/organizations) should and can meet the challenges and opportunities for addressing terrestrial invasive plants presented in this chapter. To maintain the integrity of this Puerto Rican symbol of *patria* (homeland), USFS will need to take a hard look at both the particular tropical island biology and existing institutional capacity.

Here I review ecological factors relevant for adapting appropriate invasive species management techniques. I draw out strategies for managing terrestrial invasive plants that could apply to El Yunque from regional and national USFS guidance. Next, I document the current status and trends of institutional capacity for managing terrestrial invasive plants. I

also describe the invasive species inventory and monitoring capacity building I carried out in August 2007. Lastly, I suggest partnership opportunities to minimize the spread and reduce ecological and economic damage of invasive terrestrial plants in El Yunque National Forest.

BACKGROUND

Weeds in Paradise

Invasive plants in El Yunque National Forest can cause economic, environmental, and human health impacts. Recreational visits to El Yunque account for close to $500 million directly or indirectly to Puerto Rico's GDP (USDA Forest Service 2006). Nature-focused tourism remains a significant contribution to the Puerto Rican economy (See Chapter 1). Physical and/or visual degradation at the expense of invasive species could potentially reduce value of El Yunque as a major tourism attraction. Vitousek et al. (1997) showed that heavily visited islands are invaded more intensely than larger land masses or low traffic islands. Prompt and coordinated containment and eradication results in more cost savings and less resource damage than longer term monitoring and control efforts (USDA Forest Service 2004b).

The tropical climate and prolonged growing season can be conducive to vigorous growth of nonnative invasive species. Proliferation of invasive plants and the displacement of native vegetation can alter nutrient and energy dynamics, as well as vegetation community composition (Dale et al. 2001, Vitousek and Walker 1989, Vitousek et al 1997). The invasive tree *Syzigium jambos* has been shown to establish abundant populations in parts of El Yunque that were previously under cultivation. Where *Syzigium* was most dominant, plant community diversity was reduced (Brown et al. 2006). Ecosystem homogenization by nonnative species can also decrease resiliency – the ability to recover from disturbances – whether anthropogenic, natural, or combination (Olden et al. 2003).

Some invasive species facilitate erosion or increase sedimentation since they do not retain soil structure as well as native vegetation (Gordon 1998, Pimentel et al. 2005). These impacts can lead to human health hazards related to landslides, and degrade water quality for municipal water sources.

Climate change may threaten native plant communities in tropical forests if we presume that 1) long-term climate stability contributes to high species richness, and 2) a significantly lower intrinsic rate of species migration than in temperate ecosystems (or at least along an elevation gradient in Puerto Rico) (Malcolm and Markham 2000). As the USFS evaluates its direction for adaptation to climate change, managing the risks of invasive species will be crucial. This chapter identifies both challenges and opportunities for managing terrestrial invasive plant species in El Yunque National Forest in time to be considered for revision of the El Yunque National Forest Land and Resource Management Plan; the general Forest-level guidance was last completed in 1997 and amended in 2004 (USDA Forest Service 1997, 2004a).

El Yunque National Forest management history

El Yunque (formerly Caribbean) National Forest, part of the U.S. Forest Service National Forest system, is coterminous with Luquillo Experimental Forest (LEF). The USFS research unit, International Institute of Tropical Forestry (IITF) coordinates research within LEF.

El Yunque NF covers only about 28,000 acres (relatively small compared to most National Forests), yet the number of tree species in El Yunque is greater than that of all other National Forests combined (USDA Forest Service 1997, 2007). El Yunque is located in the steep Sierra de Luquillo Mountains of eastern Puerto Rico and has a long history as a protected forest.

USFS traces El Yunque's roots as a protected area to a timber reserve under the Spanish crown in established in 1876. Yet in fact, the upper slopes of El Yunque, which include dwarf cloud forest, colorado (*Cyrilla racemiflora*) forest, and sierra palm (*Prestoea montana*) forest, have been under some form of protection since Europeans arrived in Puerto Rico in 1494. The lower elevations of modern day El Yunque, consisting of palo colorado forests and tabonuco (*Dacryodes excelsa*) forests, were at times selectively logged, cultivated for shade coffee, and subsistence agriculture (USDA Forest Service 2004, 1997). Foresters had a role in trying to establish some non-native trees in El Yunque, since the historic forest management model included trying to establish timber species from other tropical forests, including Asia and Africa (Aide et al. 2000, Francis and Liogier 1991, Marrero 1950).

Past forest managers were responsible for remarkable reforestation rates from the late 1940s to 1970s, despite Puerto Rico's rapid population growth during the same decades (Francis and Matrantonio 2001). Abandoned pastures, originally forests, were reclaimed as secondary forests by planting hundreds of thousands seedlings of the native *Tabebuia heterophylla* tree (Zimmerman et al. 1995). Shade coffee trees (*Inga vera*) and other species that grew in abandoned coffee plantations (*Inga laurina* and *Guarea guidonia*), were harvested for charcoal production under the auspices of the Forest Service in the 1940s (Zimmerman et al. 1995).

Studies have shown the species richness and diversity of forests regenerated from old Luquillo Mountains pastures and coffee plantations were similar to species richness and diversity of nearby relatively undisturbed stands (Thompson et al. 2002, Zimmerman et al. 1995). However, the composition of species differed depending on land use history (Zimmerman et al. 1995).

Ecosystem services provided by El Yunque include: buffering hurricane impacts, supplying municipal water sources, sustaining cultural values (including the Common Coquí frog, *Eleutherodactylus coqui*, an unofficial national symbol of Puerto Rico) (USDA Forest Service 1997, Crother 1999).

The Role of Rain

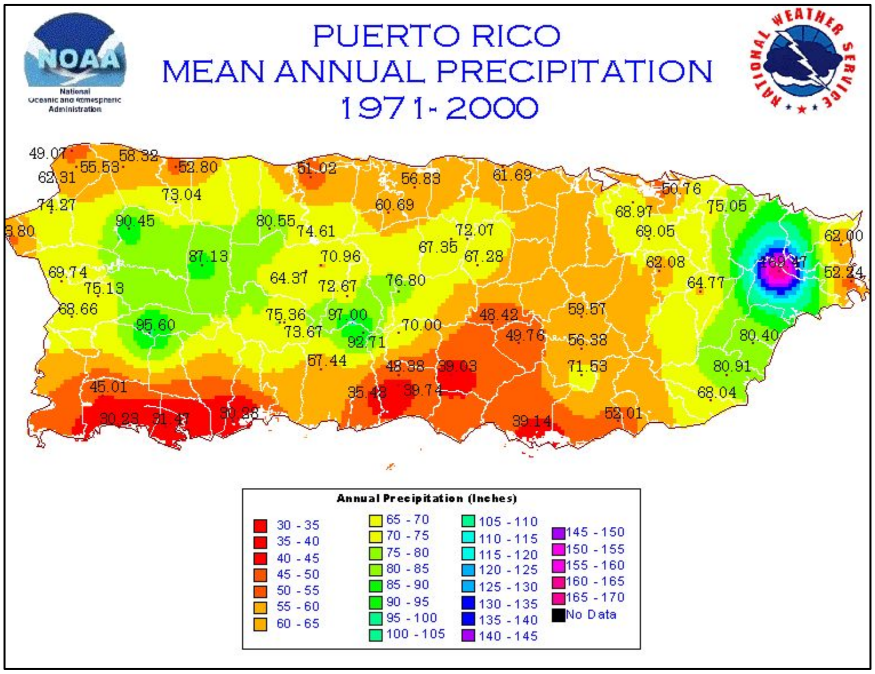


Figure 4.1 El Yunque is clearly receives more rain the other parts of the island.

Driven by topography, rainfall patterns influence the distribution of the above four forest types along an elevation gradient (citations, vegetation, meterology). The sharp rises of the Luquillo Mountains induce convective forcing of moist air from prevailing easterlies. This convection results in orographic rain almost year round with heavier cloud formation in the summer over this rainforest. Annual rainfall in El Yunque ranges from 2300 mm at 100 m to 4700 mm at 700 m elevation. Seasonal variation in temperature and precipitation are much more subtle in El Yunque than the other National Forests (see Figures 4.2 and 4.3, see Chapter 2) (Carter, Elsner, and Bennett 1997). Furthermore, global processes can directly influence El Yunque's precipitation and temperature regimes (Scatena 1998). For example, North African draughts, glacial retreat in the Andes, El Niño Southern Oscillations (ENSO) patterns have all been correlated to Caribbean hurricane frequency and rainfall variation (Prospero and Nees 1985, Rogers 1988, Reading 1990, and McDowell et al. 1994).

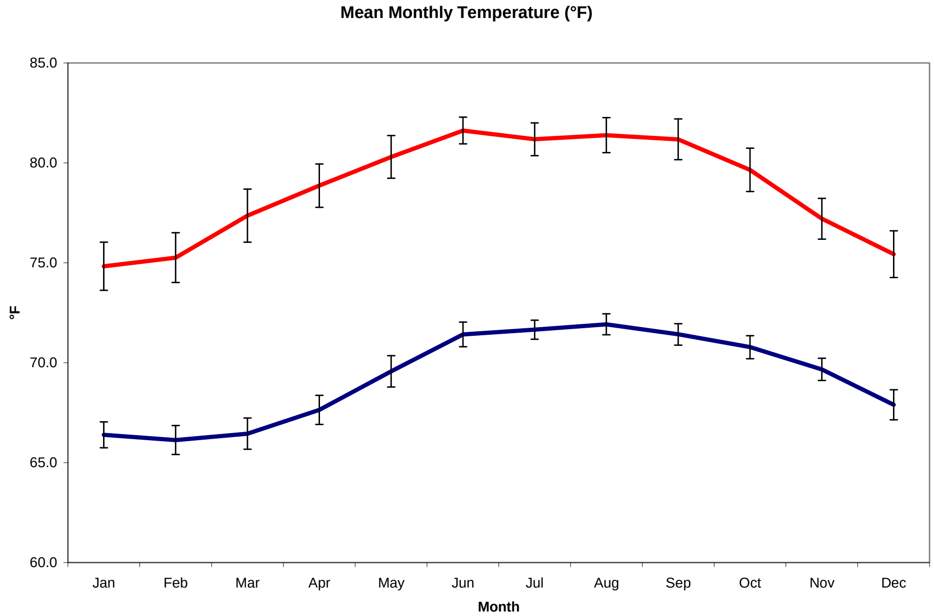


Figure 4.2 Mean monthly maximum (red) and minimum (blue) temperature at El Verde station, 1975-2007. Standard error bars shown. (Luquillo LTER – ITES University of Puerto Rico and USDA Forest Service IITF).

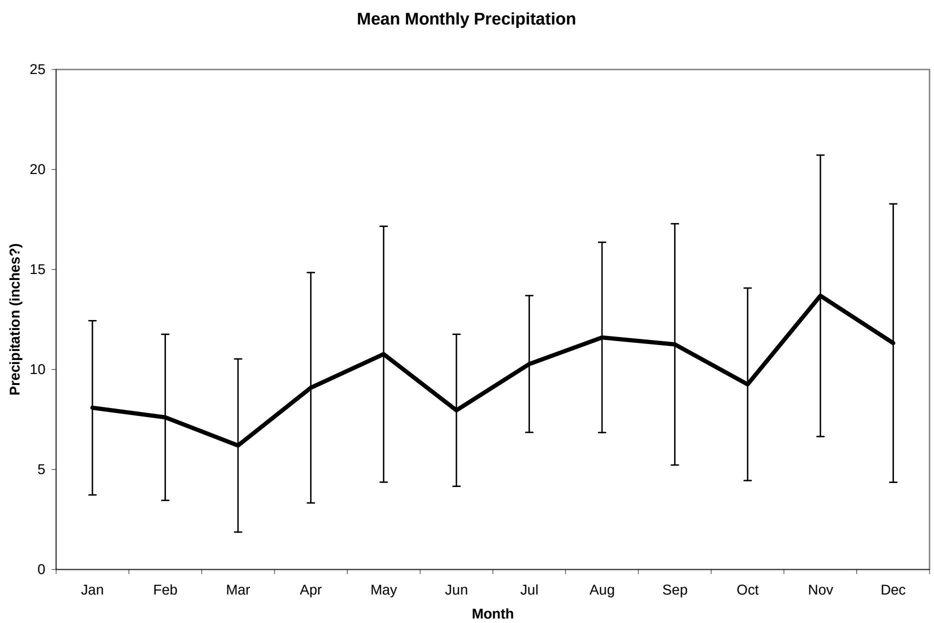


Figure 4.3 Mean monthly precipitation temperature at El Verde station, 1975-2007. Standard error bars shown. (Luquillo LTER – ITES University of Puerto Rico and USDA Forest Service IITF).

Climate Change Effects

Landslides

El Yunque, along with the rest of Puerto Rico has seen a dramatic deficit of rain water since 1990. During the 1990's, annual rainfall accumulation was the lowest of the entire 20th century (USGS 1999). This, along with the reported increasingly severe rainfall during monsoon season impacts the Forest. While the loss in total rainfall could stress more native vegetation communities and reduce forest productivity, increased rainfall fluctuation will raise the risk of landslides, and cause loss to biodiversity (IPCC, 2007).

Rainfall intensity and duration are key predictors of landslides. In Puerto Rico, storms with a total precipitation of 100-200 mm, about 14 mm of rain per hour for several hours, or 2-3 mm of rain per hour for about 100 hours can all trigger landslides (Larsen & Simon 1993). Average annual precipitation in parts of El Yunque can exceed 4000 millimeters, compared from less than 1000 millimeters, along the southern coast of the island. Landslides were shown to be five times more likely to occur within 85 m of highways than areas beyond than 85 m away from highways in EYNF (Larsen and Parks 1997). Many known invasive species infestation sites within El Yunque NF are at landslides and eroding road cuts (L. Rivera pers. comm.).

More frequent and more severe extreme rain events and droughts are likely to trigger more landslides. Intense rains and periodic hurricanes trigger landslides both annually and following periodic extreme storms. Landslides provide suitable disturbed areas that then become open for rapid establishment of invasive plant species. The ongoing and anticipated climate change effects of altered temperature and precipitation, as well as increased disturbances (i.e. both increased tropical cyclone intensity and buffer zone development pressures exacerbated by sea-level rise) could push the human population closer inland towards El Yunque. The impacts make El Yunque highly susceptible to displacement and loss of natural flora and fauna by non-native species and reduction of biophysical stability (increased landslides) (Dale et al. 2001, Scatena 1998).

Development pressures

The direct climate change impacts are compounded by development pressures on the periphery of El Yunque. Such development can create reservoirs for invasive species populations, which can be difficult to control due to jurisdiction across various land ownerships. Neighboring urbanization provides not only a source of invasive species, but also conduits such as roads (von der Lippe and Kowarik 2007). Urbanization also changes the deterministic functioning of how rain forms in El Yunque. As concrete and asphalt replace natural and/or cultivated vegetation, urban heat islands influence the local air temperatures. Increased local air temperatures in turn impact the formation of clouds and rain further up the mountains. So, existing forest vegetation communities that vary by elevation-dependent temperature and moisture regimes may face a shift in their determining ecological patterns.

Shifting species distributions

Scatena (1998) found that through geologic time, current tree species distributions do not necessarily represent historical species distributions with respect to the elevation gradient in El Yunque. Remnant 600 years old Palo Colorado (*Cyrilla racemiflora*) trees grow at elevations where current temperature and moisture regimes would not support their establishment. So, although there is some evidence of forest species ranges shifting without human-mediated changes in El Yunque, the rate at which anticipated direct and indirect coupled effects of climate change could result in drastic changes in plant community composition.

While fluctuation in atmospheric greenhouse gas concentration and associated temperature changes have occurred throughout the earth's history, the unprecedented rate of carbon dioxide increase and associated warming trends are expected to contribute to species loss in protected area (Malcolm and Markham 1996, 1997). As lower elevations become warmer and drier, existing species distributions will need to shift higher in elevation to find optimal temperature and moisture profiles. Those species that can not migrate as fast as their habitat recedes upward may eventually be lost. So, warming trends are likely to favor "weedier" plants that have high dispersal abilities, including invasive species (Sykes and Prentice 1996, Walker and Steffen 1997). This filtering out of low dispersal species may be especially significant in a tropical forest, since the absence of glaciation would not have selected for highly mobile flora as in many temperate ecosystems (Malcolm and Markham 2000).

Although the resolution of current climate change models may not fine enough to predict precise changes in El Yunque's nuanced climate, there is hydrologic and biological evidence of a warming trend (see Chapter 2) (IUCN Redlist 2004, Global Amphibian Assessment 2005). Increased frequency of hurricanes are likely to lead to lower forest species richness Puerto Rican forests (Vandermeer et al. 2000).

Tropical island invasive plants biology paradigms

Tropical island communities have been shown to be particularly vulnerable to exotic plant species (Denslow 2003, Smith 1984). Geographical isolation often leads to high endemism and low resistance to invading opportunistic species.

On the other hand, some species that are technically exotic (i.e. new to the island) are functioning in existing Puerto Rico ecosystems as beneficial. It has been shown that invasive plants can actually help repair degraded forest soil structure and fertility, restore forest cover, and increase species richness (Lugo 2004). Native pioneer species are not able to establish in the degraded soil, but exotic species are able to facilitate succession from abandoned agricultural land (formerly cleared forest) to more complex mix of multi-tiered vegetation types (Zimmerman et al. 1995).

Generally the majority of introduced species tend to not survive local ecosystem stresses (Williamson 1999). In Puerto Rico's forests, species are adapted to frequent hurricane disturbance. As climate changes, a different mix of introduced species will survive and fail in forests (Dale et al. 2001). This can yield a reshuffled mix of native and non-native species as a novel forest type (Lugo 2007).

Experts have recognized that the impact of exotic tree species on the development of native forest communities depends more on species life history traits than geographic origin of the species (Aide et al. 2000). For example, the non-native *Syzygium jambos* can persist in older forests, inhibit colonization of native species, and reduce plant community diversity (Brown et al. 2006). *S. jambos* successfully invades forests because of seed durability, vegetative reproduction, shade-tolerance, and formation of a light-restricting canopy. On the other hand, the non-native African Tulip-Tree, or Tulipán Africano (*Spathodea campanulata)* readily colonizes abandoned pastures at high densities, but it is replaced by native tree species in secondary forests. *S. campanulata* is shade-intolerant and only lives 30-40 years (Aide et al. 2000).

Who is to say what is "native" with so many introduced and established species over hundreds of years? In fact, several species in El Yunque that impair regeneration of native species have been cultivated crops for many generations (i.e. pana or breadfruit, *Artocarpus altilis* and ñame or water yam, *Dioscorea alata*).

Non-native species that only colonize roadsides may not necessarily reduce native biodiversity. However, allowing such populations to persist could passively condone reservoirs of these species to be transported to areas where they can grow to pest levels.

Invasive plant species spread across land ownerships, jurisdictions, and landscapes. Their nationwide impacts cost the United States public an estimated $138 billion annually (Pimentel et al. 2000). Currently, 42 percent – 400 of 958 – of the federally listed threatened or endangered plant and animal species have been negatively affected by invasive species (Nature Conservancy 1996; Wilcove et al. 1998).

Puerto Rico's long growing season, frequent disturbance, high visitor traffic, and roads contribute to seemingly optimal conditions for biological invasions. On the other hand, consider the existing flora has adapted to frequent hurricane disturbance and has developed some resiliency

METHODS

After consideration of relevant literature influencing invasive species ecology and management, I reviewed the official Forest Service policy guidance and identified national and regional strategies that could apply to El Yunque National Forest invasive plants. I emphasized the strategies that can be adapted to El Yunque rather than strategies that are poor matches for the ecological and institutional realities of El Yunque.

In August 2007, I assessed the status and trends of El Yunque National Forest's institutional capacity for managing invasive plants. I examined the records system used to track infestations and treatments. Then I determined the level of consistency with national USFS invasive plants database protocol. Informal interviews from a variety of Puerto Rican natural resources professionals in federal and commonwealth agencies and a conservation trust provided more holistic context of invasive plants management.

The specialists and field technicians contacted (via in-person, phone, and/or e-mail) represented USDA Natural Resources Conservation Service (NRCS), Puerto Rico Department of Agriculture (DAPR), Puerto Rico Department of Natural and Environmental Resources (DRNA), Fideicomiso de Puerto Rico (Conservation Trust of Puerto Rico), USFS NRIS (Natural Resources Information System), USFS International Institute of Tropical Forestry (IITF), and El Yunque NF.

After being provided with access to El Yunque NF computer systems and field technicians, I developed a streamlined invasive plants data collection and records system. I adapted the national inventory system to better suit El Yunque's capacity to track invasive species, while ensuring compliance with updated national data standards (USDA Forest Service 2005). Modified survey forms and an accompanying Spanish guide were field-tested alongside El Yunque NF field technicians and revised. The infestation monitoring tools I developed included a GIS mapping utility. This GIS data were designed so they could be migrated to the new national database for tracking invasive plants (the *TES Invasives* application in NRIS 2.0). El Yunque National Forest's complete transition to the new invasive species database was on hold, pending regional decision on data standards, during this field work.

Given the overarching national and regional policy guidance, El Yunque National Forest's existing management framework, available ecological science, current involvement of associated agencies and groups, and the invasive species information system, I present options that will enable El Yunque to minimize the risks and costs of invasive terrestrial plants now and into the future.

RESULTS

National framework

In 2004 the US Forest Service Chief identified invasive species as one of the top four threats to forest and rangelands in the United States (USDA Forest Service 2004 – invasive species strategy). The ecological and economic harm caused by invasive species has been referred to as a "catastrophic wildfire in slow motion" (USDA Forest Service 2004 – invasive species strategy). The severity, impacts, and disregard for land ownership boundaries of invasive plants, make this an apt comparison.

The goal of the Forest Service National Strategy and Implementation Plan for Invasive species Management is to "reduce, minimize, and eliminate invasive species across all ownerships and landscapes" associated with 155 National Forests and 22 National Grasslands (USDA Forest Service 2004, 2005). This National Strategy outlines a framework that provides general guidance and a common vocabulary among Forest Service units. It is intended to be a starting point from which Forest Service Regional Offices and subsequently each National Forest develops (or tiers from) more specific strategies. The National Strategy consists of four "program elements":

1. Prevention
2. Early detection and rapid response
3. Control and management
4. Rehabilitation and restoration.

> Following the President's 1999 Executive Order 13112, The National Strategy defines an invasive species as one that satisfies both of the following conditions:
>
> - Is nonnative to the ecosystem under consideration, and
> - Its introduction causes or is likely to cause economic or environmental harm or harm to human health.

This agency-wide position is intentionally general; it leaves it up to individual National Forests and Regions to define what exactly is an intact versus a degraded ecosystem. The national strategy emphasizes the following generalized themes:

1. Partnerships and collaboration
2. Scientific basis
3. Communications and education
4. Organizing for success (i.e. procedural streamlining, funding flexibility with commitment to long term)

Based on the exiting institutional capacity the following actions from the National Strategy are potentially the most applicable to El Yunque National Forest:

Prevention – Keep invasive species out of National Forests

- Communication to the public about risks, identification, things they can do to help through developing environmental education material, such as posters, identification cards, public service announcements, K-12 teacher modules, etc.
- Conduct risk assessment (which will be discussed further in this document) – Documentation of the status and likelihood of an invasive species introduction, the consequences of its establishment as a viable population, and the potential for spread.
- Work with partners to build awareness about invasive species conduits and threats.

Early Detection and Rapid Response (EDRR) – Find new infestations and eliminate them before they become established.

- Map priority ecosystems and habitats that are at risk of invasive species infestation, i.e. areas that have high ecological value as well as high traffic (foot and vehicular).
- Based on risk assessment, rank groups of invasive species; incorporate priority lists into Early Detection and Rapid Response protocol.
- If and when a Forest Service-wide early detection and rapid response emergency fund becomes available, understand protocols to secure funds immediately to respond to new infestations.
- Continue to conduct basic research on priority species to provide scientifically based information.

- Work with partners to develop weed reporting system and cross-jurisdictional rapid response teams in case of outbreaks.
- Invest in translating invasive species literature and materials written in Spanish to English and English to Spanish.

Control and Management – Contain, reduce, and eliminate existing infestations.

- Complete comprehensive risk assessment to prioritize target species or areas for eradication, control, or containment.
- Complete comprehensive inventory and mapping of targeted species, including neighboring areas where appropriate.
- Complete programmatic NEPA analysis.
- Expand technical and financial assistance to Forest Service and partners for on-the-ground management and control activities.
- Monitor long-term invasive species population trends and treatment effectiveness; make this information readily available to stakeholders, public and private.
- Educate resource managers and public about the importance of invasive species control and the effects of various management and user practices.

Rehabilitation and Restoration – Heal, minimize, or reverse the harmful effects from invasive species; promote resistance to infestation of invasive species.

- Compile, highlight, and share information about existing restoration and rehabilitation successes.
- Refine native plant establishment techniques.
- Develop infrastructure and procedures for producing and easily procuring native plant material for restoration.
- Collaborate with organizations like native plant societies and higher education institutions to develop educational outreach materials and demonstration areas that illustrate landscape designs and management techniques that facilitate native species use and resistance to invasive species.

Southern Region Framework (Region 8)

The Southern Region adds five additional general components:

- Leadership and coordination
- Current status and trends
- Partnerships and cooperation
- Research
- Information and Technology

The Southern Region framework also emphasizes Integrated Pest Management (IPM). This includes targeted herbicides during cold, dry periods. El Yunque is not consistently dry enough to apply targeted herbicides as recommended in the Regional Framework.

Restoration

The recent USFS Restoration Framework interprets a model of restoration principles built upon the Society for Ecological Restoration International's (SER) definition of ecosystem restoration (USDA Forest Service 2006).

> Society for Ecological Restoration International's (SER) defines ecosystem restoration as:
>
> *The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.*

This Restoration Framework identified non-native invasive species and climate change as top threats to "long-term health, productivity, and diversity [of National Forests]" (USDA Forest Service 2006). Recommendations from the USFS Restoration Framework that are particularly applicable to El Yunque NF invasive plants management include:

- Make operational decisions at the lowest possible levels in an organization
- Establish objectives for the long term

- Use multiple sources of relevant information, such as historical records, scientific studies, practical experience, and indigenous knowledge
- Recognize that ecosystems are dynamic and that change is inevitable; avoid "static endpoint" thinking.
- Design and implement monitoring as part of restoration.

As outlined in the 1997 LRMP, native vegetation is to be used "as much as possible in watershed restoration and other rehabilitation projects" in order to achieve the Desire Future Condition of maintaining "all native plants" (USDA Forest Service 1997).

Current institutional capacity for weed management

Invasive species tracking and monitoring database

In 2007, there were was effectively no functional information system for tracking invasive species at El Yunque National Forest. Previous efforts encountered technology and human resources limitations. Software and operating system incompatibility, combined with inadequate IT (Information Technology) support, contributed to El Yunque NF's inability to integrate invasive species infestation data into the directed Forest Service-wide database. El Yunque field technicians initially received some standardized training from Regional Office NRIS (Natural Resource Information System) training staff on how to enter infestation data. However, the technicians have not practiced using the system.

NRIS has the capability to be integrated with ArcGIS applications, such that spatial data can be visualized, analyzed, and managed using GIS. However, El Yunque NF personnel currently lack the GIS skills required for utilizing this tool. El Yunque NF staff appear to rely on relationships with IITF researchers for any GIS needs more complex than basic procedures.

Nationally standardized NRIS data collection methods are flawed at El Yunque. The expensive NRIS PDR (Palm Data Recorder) package remains nonfunctional, necessary software applications are not installed, technicians have insufficient training/practice, the GPS antennae is not strong enough for satellite reception under tropical forest canopy, and a newer Bluetooth GPS unit remains untested.

The information about which and where invasive species exist in El Yunque lies primarily in the memories of individual staff members who are familiar with the Forest resources and geography. Several years ago a Forest Service employee on detail assignment from another unit in the continental U.S. created a Caribbean National Forest invasive plants list (L. Rivera, pers. comm.). Caribbean NF's Tropical Vegetation Specialist, Luis Rivera, helped the detailer cross reference a USFS Southern Region (Region 8) invasive species list with species known to be present in El Yunque NF. In 2007 El Yunque did not appear to be actively using this list, nor did their staff seem to readily know how to access it.

Reasons why El Yunque NF's invasive plants database and tracking system was not operating at the level expected by regional and national USFS offices also include: not enough time or employees (FTEs) to actively serve as data stewards, standard operative procedures for regular staff do not involve working with this kind of electronic data collection or record keeping, and limited expertise to use the official technology. These are likely to remain challenges even if El Yunque NF allocated considerably more staff time for current employees to collect, enter, and update invasive species records. In 2008, El Yunque's Ecosystem Management Team was exploring hiring an additional forest biologist.

Capacity building carried out and tools created by the author

1. Exported from NRIS previously edited list of potentially invasive plants (Caribbean National Forest). An important starting point: watch-list of potentially invasive, until proven otherwise spp.
2. Adapted NRIS-ready field data sheet from updated National Invasive Weeds Data Protocol. Compatible with updated data standards (USDA Forest Service 2005). Transition to new even more centralized **TES Invasives** application NRIS 2.0 on hold, pending Regional decision on data standards at press time.
3. Developed a field users guide in Spanish for collecting data.
4. Oriented technicians to relevant data collection procedures.
5. Surveyed Forest landslides and road sites for target species; collected site info and photographs for 13 priority infestations sites (USFS and private); included 6 spp. Selected by tropical vegetation specialist.
6. Inventory system established in MS Excel, while it lacks the sophistication of NRIS, it is easier to use, developed in consultation with NRIS staff, so can be integrated into new centralized system, when operable. Does not require user profile registered by WO NRIS administrator to access or update info.
7. Data entered into GIS, maps created, electronic files provided to EYNF as a pilot.

DISCUSSION

Synthesis

Technical capabilities (GIS and related database skills, on-site IT support, etc.) and institutional capacity (no cooperative weed management councils, lack of coordination between potential partnering agencies, etc.) are less than optimal for managing invasive plants at El Yunque National Forest. Yet, El Yunque does not necessarily appear to have an immediate invasive species crisis – especially considering the high visitor traffic per acre and budget constraints. Reportedly, there has never been a native plant species lost from El Yunque, but the number of plant species (including non-native flora) continues to increase with subsequent surveys (Keel 2005). Has El Yunque yet to cross a threshold that would lead to a spiral of invasive species facilitating more invasive species (invasion meltdown hypothesis) (Simberloff and Von Holle 1999)?

Regardless of the answer, El Yunque National Forest resource managers cannot afford to proceed without making invasive species a top priority. Reasonably foreseeable climate changes and associated feedbacks that affect natural and human systems make forgoing strategic invasive species management particularly risky. The Forest Service could be facing irreversible and undesirable changes.

A wait-and-see approach – assuming El Yunque's biodiversity is invulnerable to impacts of invasive species that are known problems in the continental U.S. – could mean missed opportunities for early detection of problem species. Treatment costs rapidly increase as infestations grow. As an El Yunque National Forest Plan (LRMP) revision process draws near, a window for incorporating new types of invasive species analysis and paradigms is open. Based on the ecology and institutions analyzed in this chapter, I recommend that El Yunque National Forest decision-makers consider the following challenges and opportunities in developing appropriate options for invasive species management.

Challenge: Defining "invasive species" in El Yunque National Forest

The official federal definition (according to Executive Order 13112) of invasive species is relatively general when it comes to deciding whether to treat a particular invasive plant infestation. Interpretability of specific terms is common with federal guidance.

> E.O. 13112 defines an invasive species a one that:
>
> - Is nonnative to the ecosystem under consideration, and
> - Its introduction causes or is likely to cause economic or environmental harm or harm to human health.

This definition does not detail spatial or temporal bounds in what is meant by "nonnative." Such a term could potentially be used to justify treating an invasive plant treatment that is not commonly found in a particular forest type, but is native to Puerto Rico. What scale should we consider in an "ecosystem under consideration"? Should "non-native" only refer to species that were not known to exist in Puerto Rico before 1493? Likewise, definitions "economic or environmental harm" and "harm to human health" are intentionally left up to interpretation on case-by-case basis. The vagueness in definition should not translate to inaction. National guidance interpretability should translate to flexibility by local administrative units.

"Native" species vs. "non-native" species represents a strict binary view of biological community assemblages. This classical paradigm underemphasizes intermediate phases along a spectrum of nativeness. Naturalization and migration occur at varying spatial and temporal scales. Furthermore, some species can become vigorous pests despite being native.

Consider agroecological systems where certain organisms exist at relatively low population levels and are neither causing crop damage, destabilizing food webs, nor disrupting nutrient flows. Then, due to anthropogenic habitat manipulation, a persistent species population increases to a pest level that destabilizes food webs, disrupts nutrient flows, and causes crop damage (Vandermeer 2007). Such a species would clearly be a management concern, but is technically native.

The definition of what constitutes a native species is particularly important on an island with a long history of repeated species introductions. Species ranges expand, contract, and shift both with and without anthropogenic forces.

Challenge: No national performance measures for pretreatment invasives inventory

Unfortunately on the USFS national level, invasive species management success is not measured by the amount of pre-treatment mapping or inventory completed (USDA Forest Service 2007b). However, inventorying and mapping infestations prior to treatment can help prioritize treatment efforts for cost efficiency and effectiveness. National invasive species performance measures quantify outputs, such as the number of acres treated. The amount of area surveyed for invasive species is not reported to national oversight.

Opportunity: Prioritize species through Risk Assessment

El Yunque need not wait for the DRNA (Puerto Rico Department of Natural and Environmental Resources) to revise its outdated list of official invasive plants. Although the 50 states' agriculture or natural resources agencies actively determine and rank noxious weeds by state, the DRNA does not appear they have human resources/institutional capacity to serve in this role. El Yunque National Forest can take the initiative and cooperate with DRNA to prepare an updated list through completing a risk assessment of species. The resulting invasive species list should rank and categorize plants for treatment prioritization and threat level. Ecological factors (i.e. vegetative characteristics, fecundity, shade tolerance, etc.) and economic factors (i.e. cost of effective targeted pesticide application, increasing marginal costs of delaying treatment, etc.) ought to be considered together.

Challenge: Funding for Early Detection and Rapid Response (EDRR)

The National Invasive Species Council – comprised of cabinet level secretaries – has called for permanent, flexible, and available emergency funding for Early Detection and Rapid Response (EDRR) programs (National Invasive Species Council 2001, 2003). However, USFS Washington Office invasive plant specialists did not answer author inquiries regarding the availability or status of an EDRR emergency fund.

According to a GAO report to Congress, *Invasive Species – Obstacles Hinder Federal Rapid Response to Growing Threat*, invasive species that threaten agriculture or livestock are much more likely to elicit rapid response than those that threaten forests or other natural areas (US GAO 2001). In 2001, USDA Agricultural Research Service and

USDA Animal and Plant Health Inspection Service (APHIS) obligated $118.2 million on rapid responses to invasive species. Meanwhile, the USFS obligated $16.1 million on rapid responses to invasive species (US GAO 2001). The costs of invasive species eradication escalate without effective EDRR (USDA Forest Service 2004b).

Opportunity: NISC funded pilot monitoring program

The National Invasive Species Council's new Draft Invasive Species Management Plan mentions initiating systematic pilot monitoring projects (National Invasive Species Council 2007). El Yunque could make a case for a pilot priority monitoring effort. The National Invasive Species Council aims to continue exploring emergency funding for Early Detection and Rapid Response (EDRR) through 2012.

If El Yunque develops an EDRR model, they should focus on small satellite populations over larger founder populations. Satellite populations often rapidly grow until their range exceeds the extent of founder populations (Moody and Mack 1988, Lane 1996). Larger founder populations may be more obvious, but satellite populations can represent greater threats. Funding for EDRR is similar to funding for disaster preparedness. El Yunque NF may not be able to rely solely on the typical budget allocated for invasive plants control if unanticipated needs arise.

Challenge: Understanding the role of novel ecosystems

Island habitats are particularly vulnerable to exotic plant species {Smith 1984}. Puerto Rico is a Caribbean island, and El Yunque is a forested island surrounded by agricultural/urbanization matrix. Despite the lack of documented native plant extinction, the number of non-native plants in El Yunque NF continues to increase (Keel 2005). Lugo (2000) counters the often alarmist points of view about imminent ecosystem degradation triggered by climate change; there are potentially positive effects of alien species facilitating certain landscape developments. New types of ecosystems will be comprised of new combinations of species. After all, 30,000 years of tropical forest ecosystems responding to historic climatic variation must have conveyed some ecosystem resiliency. Still, the increasing urbanization and projected weather pattern changes in toward a warmer and drier Puerto Rico could be triggers for more invasive species outbreaks. This implies that framing of *novel ecosystems* versus irreversibly *degraded ecosystems* can influence forest resources management decisions.

Opportunity: Continue dialog with researchers about the value and definition of native habitat

Some experts have recognized that the impact of exotic tree species on the development of native forest communities depends more on species life history traits than geographic origin of the species (Aide et al. 2000). For example, the non-native *Syzygium jambos* can persist in older forests and inhibit colonization of native species. *S. jambos* successfully invades forests because of seed durability, vegetative reproduction, shade-tolerance, and formation of a light-restricting canopy. On the other hand, the non-native *Spathodea campanulata* readily colonizes abandoned pastures at high densities, but it is replaced by native tree species in secondary forests. *S. campanulata* is shade-intolerant and only lives 30-40 years (Aide et al. 2000).

As manufacturing continues to replace agriculture and as population grows in Puerto Rico, the resulting abandonment of agricultural lands often lead to forest structure recovery (Wu et al. 2006). Yet historical land use changes are also responsible for species invasion, habitat loss, habitat fragmentation, soil degradation, and biodiversity loss (Grau et al 2003). Although logging and coffee and fruit production was abandoned by the 1950s in what is now known as the Luquillo Forest Dynamics Plot, land use legacies still influences the current tree species composition (Thompson et al. 2002). More rare and endemic tree species were found in stands that had less historic human disturbance. The degree of historic human disturbance overshadowed the influences of forest regeneration, natural disturbances, and soil and topographic variation in determining community assemblages (Thompson et al. 2002).

Research should explore comparative studies between other tropical islands, such as the Hawai'ian islands and U.S. Virgin Islands.

Challenge: limited GIS and database management expertise available.

USFS is expected to employ current GIS technology and uniform computer applications across the agency. However, El Yunque National Forest seems to rely mostly on affiliated researchers at IITF for most GIS needs. Database management skills needed to track invasive species infestations in accordance with the national NRIS syste, are lacking. Centralized IT support does not appear to be cost-effective for dealing with computer applications related to invasive species.

Opportunity: Continue technical and human resources capacity building

El Yunque NF can build upon existing invasive species information system including the monitoring protocol, database, and GIS mapping developed in this project. Visiting data stewards from other USFS units can be rotated through detail assignments to help process data and train El Yunque staff. If El Yunque NF Ecosystem Management Team considers increasing its regular biologist staff, responsibilities should include GIS work and managing/modify invasive species information systems.

The federal SCEP (Student Career Experience Program) can be used to hire college student interns that can ultimately be converted into pipeline employees upon graduation. Partnerships with any and all of three Puerto Rican universities with GIS curricula – UPR Rio Piedras, UPR-Mayagues, and Universidad Metropolitana – can achieve university and USFS objectives.

The organization SCA (Student Conservation Association) helps place GIS interns with host agency offices. These students are skilled in GIS and GPS technologies and can be cost effective for USFS.
See: www.thesca.org/Position_Types_&_Fields_of_Study/Opportunities/GIS%10GPS/

Challenge: Building trust among Puerto Rican public

Civic engagement is critical for invasive plants management across jurisdictional boundaries. Resentment of federal control often characterizes local communities surrounding many National Forests. In Puerto Rico, gaining and maintaining trust between stakeholders could be further complicated by political relationships between the United States government and the various Puerto Rican political interests. Legacies of colonization and the spectrum of statehood-commonwealth-independence philosophies warrant special consideration in attempts to engage the public in sustaining El Yunque’s value. It is appropriate to be cognizant of such issues on a face-to-face level when dealing with members of the Puerto Rican public.

Opportunity: Cultivate additional partnerships – both formal and informal.

In order for El Yunque National Forest to foster partnerships for greater awareness and education about invasive species, social capital should to be emphasized. Social capital for cooperative invasive species management depends on relationships. Through cooperative agreements, MOUs (Memoranda Of Understanding), and informal relationships, Forest Service can encourage other agencies, organizations, and individuals to be stewards for Puerto Rican natural heritage.

Some stakeholders may prefer to conduct business and communicate in Spanish, rather than English. So, building bilingual spoken and written capacity will enable Forest Service employees as bridges and change agents. Working beyond the philosophical boundaries of stakeholders, such as recreation versus conservation interests, is just as important as working beyond jurisdictional boundaries (see the following section).

Cooperative Weed Management Council – Forest Service can promote and support a network of agency representative and neighboring land owners that share success stories, common treatment problems, and even pool resources for grant proposals. There may be a possibility of developing a Cooperative Weed Management Council with the support of the head forester at DRNA. IITF recently awarded DRNA a forest health grant (C. Carpenter pers. comm.).

Amigos Del Yunque (i.e. Friends of El Yunque) - An auxiliary non-profit organization can provide donor funding and volunteer labor tied to preserving the biodiversity of El Yunque. It has been suggested that Amigos Del Yunque can spotlight neighboring farmers who practice conscientious Integrated Pest Management (P. Ríos pers. comm.). Following examples of Friends groups in protected natural areas such as Acadia National Park, Amigos Del Yunque could leverage the fiscal flexibility of a non-profit organization (see www.friendsofacadia.org). Other activities could include coordinating volunteer habitat rehabilitation and restoration work parties. Amigos Del Yunque could build financial support and a sense of pride from overseas Puerto Ricans or other visitors.

Challenge: Limitations of administrative boundary

Forest Supervisor, Pablo Cruz, stated “we are limited by what we can do outside the National Forest boundary” (P. Cruz, pers. comm.). Piecemeal encroachment into the National Forest boundary by small private landowners is not unheard of. Furthermore, rectifying cadastral landlines is prioritized by “management needs, such as land acquisition or exchange, trespass, and rights-of-way” (USDA Forest Service 1997). Invasive species infestations know no property boundaries.

Opportunity: Think outside the box for restoration

The Wyden Amendment authorizes expenditure of USFS funds on non-federal lands to promote ecosystem health (P.L. 105-277, Sec. 323). At the time of analysis, this authority had not been exercised by El Yunque NF. Examples of the Wyden Amendment used for restoration projects in other National Forests have been highlighted as exemplary partnerships recognized by top USFS leadership (USDA Forest Service 2005c). Literature supports the potential success of such cross-boundary collaborative ecosystem management endeavors (Wondolleck and Yaffee 2000).

Critical distinctions for El Yunque NF

Despite fundamental ecological, social-economic, and cultural differences between the continental U.S. National Forests and the one in Puerto Rico, there seems to be an implied expectation that natural resource management practices would apply universally. Or alternatively, USFS regional and nationwide policy assumes that since El Yunque NF is so unique, that USFS regional and national offices ignore any attempt at appropriate modifications to natural resource management frameworks for El Yunque NF. This places the onus of adapting invasive species management guidelines to fit El Yunque more heavily on El Yunque NF. The following are examples of El Yunque’s distinctions related to invasive plants management.

Due to the rainfall patterns, El Yunque NF can not rely as much upon targeted herbicides for weed control as suggested by regional guidance. Many areas of the forest do not have extended periods without rain. The tropical forest species are adapted to frequent hurricane disturbance. This vegetation also has high net primary productivity due to intense and cumulatively longer hours of tropical solar radiation throughout the year.

El Yunque NF does not yield commercial timber. Wood extraction for *artesania* (folk woodcarvings) amounts to minimal volume. Therefore, El Yunque NF avoids the weed invasion risks associated with commercial logging. On the other hand, since minimal commodities are extracted from El Yunque NF, stewardship contracting can not be used to support restoration activities. Stewardship contracting is gaining popularity as a mechanism for financing restoration in some National Forests.

A "proclamation boundary" surrounds the National Forest for the purpose of targeting land acquisitions and diminishing deleterious effects of development just outside the National Forest. El Yunque NF has and continues to evaluate land exchanges with willing landowners. This can be complicated and protracted process, especially since legal property lines on maps can be inconsistent boundaries on the ground. There has been Commonwealth legislation to protect Forest periphery lands from development (e.g. Ley Núm 150 de 4 de agosto de 1988 Ley del Programa Patrimonio Natural de PR (PR Natural Heritage Program Law)). Yet buffer zone regulations have not been effective at maintaining natural vegetation land cover (Lugo et al. 2004). Development pressures continue just outside the Forest boundary (USDA Forest Service 1997). Federal legislative proposals to facilitate acquisitions of Forest periphery lands have failed (i.e. H. R. 3365 in the 109th Congress and H.R. 671 in the 110th Congress).

Cooperative agreements with neighboring landowners and partner agencies could potentially engender faster and more efficient invasive plants management. Social relationships and structures are crucial for implementing any biological tools for biodiversity protection (Lane 1996).

Conclusion

It is clear that El Yunque NF is not fully employing all the national and regional normatives for invasive plants management, but El Yunque should *not* be. El Yunque should invest in adapting continental U.S. strategies and employ as appropriate, while creating their own strategies.

The tools developed by this project and my recommendations here are not entirely new concepts. In 1998, Tropical Vegetation Specialist, Luis Rivera, requested Region 8 funding to map, monitor, and control Peacock fern (*Selaginella wildenovii*) through mechanical and cultural methods (i.e. Integrated Pest Management). Yet, it was not until nearly a decade later, when some known *S. wildenovii* infestations were mapped into GIS. Limited human resources, technical capabilities, relationships with potential partnerships, and civic engagement have been the primary constraints for more proactive invasive plants management at El Yunque National Forest.

This work represents compilation of scientific and institutional information about managing invasive plants and contextualizes some of El Yunque's local nuances within USFS nationwide and Southern Region frameworks. There are ample opportunities for El Yunque National Forest to address invasive plants challenges through cooperative agreements, awareness and education, information sharing, community stewardship, and exploration of cross-boundary solutions.

REFERENCES CITED

Introduction

Bosworth 2003 {from invasives chapter) Irizzary et al __ <Colonialism in Puerto Rico>

USDA Forest Service 1997 LRMP {see invasives chapter}

USDA Forest Service. 2004. Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Gitay, H., Suarez, A., Watson, R., and Dokken, D. J., editors. 2001. Technical Paper V- Climate change and biodiversity. IPCC Reports. Retrieved on March 9, 2008 from: http://www.ipcc.ch/pdf/technical-papers/climate-changes-biodiversity-en.pdf.

Chapter 1

National Visitor Use Monitoring Results. 2001. Caribbean National Forests. United States Department of Agriculture, Forest Service, Region 8.

National Visitor Use Monitoring Results. 2007. El Yunque National Forest. United States Department of Agriculture, Forest Service Region 8.

Pizzini, M. V., Latoni, A., and Rodriquiz, V. 1992. Front-end and formative evaluation of El Portal de El Yunque Visitor Center. Department of Agriculture, Forest Service.

Pizzini, M. V., Latoni, A., and Rodriquiz, V. 1993. El Yunque or the Caribbean National Forest? Meaning, management, and culture in the urban-tropical forest interface. Pages 221-233 *in* A. W. Ewert, D. J. Chavez and A. W. Magill, editors. Culture, conflice and communication in the wildland-urban interface. Westview Press, Boulder, Colorado, USA.

Potter, R. B. 1993. Urbanization in the Caribbean and trends of global convergence-divergence. The Geographic Journal. **159** (1):1-21.

United States Census Bureau. 2008. American Fact Finder. Retrieved on March 9, 2008 from: http://factfinder.census.gov/home/saff/main.html?_lang=en.

Chapter 2

Scatena, FN. 1998. Third international symposium on tropical hydrology and fifth Caribbean islands water resources congress: An Assessment of climate change in the Luquillo mountains of Puerto Rico. American water resources association, Herdon, Virginia, USA, pp. 193-198.

Lovejoy, E.T, and L. Hannah . 2005. Climate change and biodiversity. Yale university press, New Heaven, USA, pp. 31-40, 70-74.

Ruhf, R. J. and E. M. C. Cutrim. 2003. Time series analysis of 20 years of hourly precipitation in southwest Michigan. International association of great lakes research 29:256-267.

Wu, S., Y. Yin, D. Zheng, and Q.Yang. 2006. Moisture conditions and climate trends in China during the period 1971-2000. International journal of climatology 26:193-206.

Hugehes, G. L., S. S. Rao, and T. S. Rao. 2007. Statistical analysis and time-series models for minimum/ maximum temperatures in the Antartic Penninsula. Proceedings of the royal society 463:241-259.

Trivedi, M. R., et al. 2007. Projecting climate impacts on mountain snow cover in central Scotland from historical patterns. Arctic, Antarctic and alpine research 39:488-499.

Sammarco, P. W., A. Winter, and J. C. Stewart. 2006. Coefficient of variation of sea surface temperature (SST) as an indicator of coral bleaching. Marine biology 149:1337-1344. Lugo, A. E.

Malmgren, B.A., and A. Winter. 1999. Climate zonation in Puerto Rico based on principal components analysis and an artificial neural network. Journal of climate 12: 977- 985.

Hughes,G., S.S.Rao, and T.S.Rao. 2006. Statistical analysis and time-series models for minimum and maximum temperatures in the Antarctic peninsula. Proceedings of the royal society 463: 241-259.

Malmgren., B.A., and A.Winter. 1998. El Nino southern oscillation and North Atlantic oscillation control of climate in Puerto Rico. Journal of climate 11: 2713-2717.

Greenland, D., and T.G.F. Kittel. 2002. Temporal variability of climate at the US Long-Term Ecological Research (LTER) sites. Climate research 19: 213-231.

Chapter 3

Bell, J. L and R. C. Whitmore. 1997. Eastern Towhee numbers increase following defoliation by gypsy moths. *The Auk* 114(4), p. 708-716

deMaynadier, P. Gl. and M. L. Hunter Jr. 1999. Forest canopy closure and juvenile emigration by pool-breeding amphibians in Maine. *J. Wildlife Management* 63(2), pp. 441-450

Gould, W., Alarcon, C., Fevold, B., Jimenez, M. E., Martinuzzi, S., Potts, G., Solorzano, M., and Ventosa, E. 2007. *Puerto Rico Gap Analysis Project – Final Report.* USGS, Moscow ID and the USDA FS International Institute of Tropical Forestry, Rio Piedras, PR.

IUCN. 2001. *The IUCN Red List of Threatened Species: 2001 Categories and Criteria (Version 3. 1*. IUCN, Gland, Switzerland. http://www.iucnredlist.org/info/categories_criteria2001 accessed 7/07

Jankowski, Piotr, and T. Nyerges. 2001. GIS-supported collaborative decision making: results of an experiment. *An. Assoc. of American Geographers* 91(1), p. 48-70.

Karl, J. W., N. M. Wright, P. J. Heglund, and J. M. Scott. 1999. Obtaining environmental measures to facilitate vertebrate habitat modeling. *Wildlife Society Bulletin* 27(2), p.357-365.

National Wild and Scenic Rivers System. 2008. http://www.rivers.gov/wildriverslist.html#pr Accessed 2/08

NatureServe. 2007. NatureServe Conservation Status: Version 5.0 NatureServe, Arlington, VA. http://www.natureserve.org/infonatura/Lnsstatus.htm accessed July 2007

Ortega, Y. K., and D. E. Capen. 1999. Effects of forest roads on habitat quality for ovenbirds in a forested landscape. *The Auk* 116(4): 937-946.

Puerto Rico GAP Analysis Project (PRGAP). 2006. PRGAP Landcover: USDA Forest Service, International In stitute of Tropical Forestry, Rio Piedras, Puerto Rico

Welsh, H.H. and A.J. Lind. 1996. Habitat Correlates of the Southern Torrent Salamander, Rhyacotriton variegatus (Caudata: Rhyacotritonidae) in Northwestern California. Journal of Herpetology. Vol. 30, No.3 pp 385-396. http://www.rsl.psw.fs.fed.us/projects/wild/welsh/welsh2.PDF accessed 2/08

Welsh, H.H. *Awaiting publication*. Richness of amphibian species in three different forest types. USFS. PSW Redwood Sciences Lab, Arcata, CA

USDA Forest Service. 2006. El Toro Wilderness Factsheet. http://www.fs.fed.us/news/2006/releases/01/cnf-el-toro-fact-sheet.pdf accessed 2/08

USDA Forest Service. 2004. Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Chapter 4

Aide, T. M., J. K. Zimmerman, J. B. Pascarella, L. Rivera, and H. Marcano-Vega. 2000. Forest regeneration in a chronosequence of tropical abandoned pastures: implications for restoration ecology. Restoration Ecology **8**(4): 328-338.

Brown, K. A., F. N. Scatena, and J. Gurevitch. 2006. Effects of an invasive tree on community structure and diversity in a tropical forest in Puerto Rico. Forest Ecology and Management 226: 145-152.

Carter, M., J. B. Elsner., and S. Bennett. 1997. Monthly rainfall climatology for Puerto Rico. SR/SSD 97-40 Technical Attachment. National Oceanic and Atmospheric Administration.

Crother, B. I., ed. 1999. Caribbean Amphibians and Reptiles. Academic Press, San Diego, CA.

Dale, V. H., L. A. Joyce, S. McNulty, R. P. Neilson, M. P. Ayres, M. D. Flannigan, P. J. Hanson, L. C. Irland, A. E. Lugo, C. J. Peterson, D. Simberloff, F. J. Swanson, B. J. Stocks, and B. M. Wotton. 2001. Climate change and forest disturbances. 2001. BioScience **51**(9): 723-751.

Denslow, J. S. 2003. Weeds in paradise: thoughts on the invisibility of tropical islands. 2003. Annals of the Missouri Botanical Garden **90**(1):119-127.

Gordon, D. R. 1998. Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida. Ecological Applications **8** (4):975-989.

Global Amphibian Assessment. 2005. Accessed February 2008. http://www.globalamphibians.org/servlet/GAA?searchName=Eleutherodactylus+coqui

Grau, H. R., T. M. Aide, J. K. Zimmerman, J. R. Thomlinson, E. Helmer, and X. Zou. 2003. The ecological consequences of socioeconomic and land-use changes in postagriculture Puerto Rico. BioScience 53(12): 1159-1168.

Francis, J. K. and H. A. Liogier. 1991. Naturalized exotic tree species in Puerto Rico. GTR-SO-82. USDA Forest Service Southern Forest Experiment Station. New Orleans, Louisiana.

Francis, J. K., and J. L. Matrantonio. 2001. Luquillo Experimental Forest, General Technical Report IITF-14, August 2001.

IUCN. 2004. IUCN Red list of threatened species. Accessed February 2007. http://www.iucnredlist.org/search/details.php/7150/all

Keel, S. 2005. Caribbean ecoregional assessment – Puerto Rico, Terrestrial Biodiversity. The Nature Conservancy. May 2005.

Lane, E. M. 1996. A community-based weed control program for The Nature Conservancy. Masters thesis (practicum) School of Natural Resources and Environment, University of Michigan. Practicum Committee: B. Grese, J. Wondolleck, B. Low, and P. Mohai. June 1996.

Larsen, M. C. and J. E. Parks. 1997. How wide is a road? The association of roads and mass-wasting in forested montane environment. Earth Surface Process and Landforms, John Wiley and Sons, Ltd., Vol. 22, 835-848.

Larsen, M. C. , and A. Simon. 1993. A rainfall intensity-duration threshold for landslides in a humid-tropical environment, Puerto Rico.*Geografiske Annaler* 75A:13-23.

Lugo, A. E. 2007. Novel tropical forests and diverse landscapes: the natural outcome of global warming and climate change. Unpublished manuscript.

Lugo, A. E. 2004. The outcome of alien tree invasions in Puerto Rico. Frontiers in Ecology and the Environment. **2**(5):265-273.

Lugo, A. E. 2000. Book review of *Climate Change and Tropical Forests – Uncertainty and Fear*. 1998. A. Markham (Ed.). Kluwer Academic Publishing, Dordrecht, The Netherlands. In Journal of Environmental Quality 29: 349-350.

Lugo, A. E., T. M. Lopez, O. M. Ramos, and L. L. Velez. 2004. Urbanización de los terrenos en la periferia de El Yunque. USDA Forest Service IITF.

Malcolm, J. R. and A. Markham. 1996. Ecosystem resilience, biodiversity, and climate change: setting limits. Parks **6**:38-49.

_______. 1997. Climate change threats to National Parks and protected areas of the United States and Canada. World Wildlife Fund, Washington, DC

_______. 2000. Global warming and terrestrial biodiversity decline. World Wildlife Fund, Washington, DC.

Mas, E. 2008. Personal communication.

Marrero, J. 1950. Results of forest planting in the insular forests of Puerto Rico. Caribbean Forester **11**:107-147.

Matos, ___. 2008. Personal communication.

Moody, M. E. and R.N. Mack. 1988. Controlling the spread of plant invasions: the importance of nascent foci. Journal of Applied Ecology **25**:1009-1021.

National Invasive Species Council. 2001. National management plan: meeting the invasive species challenge. January 2001.

National Invasive Species Council. 2003. General guidelines for the establishment and evaluation of invasive species early detection and rapid response systems.

National Invasive Species Council. 2007. 2008-2012 National invasive species management plan – draft for public comment. December 2007.

Nature Conservancy. 1996. America's Least Wanted:Alien Species Invasions of U.S. Ecosystems. Arlington,VA:The Nature Conservancy.

Olden, J. D., N. L. Poff, M. R. Douglas, M. E. Douglas, and K. D. Fausch. 2003. Ecological and evolutionary consequences of biotic homogenization. Trends in Ecology and Evolution. **19**(1): 18-24.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. **52** (3):273-288.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and Economic Costs Associated with Non-Indigenous Species in the United States. BioScience **50**: 53–65.

Public Law 105-277, Section 323 as amended by Public Law 109-54, Section 434. United States 105th Congress. October 21, 1998.

Scatena, F. N. 1998. An assessment of climate change in the Luquillo Mountains of Puerto Rico. Third International Symposium on Water Resources. Fifth Caribbean Islands Waters Resources Congress. American Water Resources Association. July 1998.

Simberloff, D. and B. Von Holle. 1999. Positive interactions of nonindigenous species: invasional meltdown? Biological Invasions **1**: 21–32.

Smith, C. W. 1984. Impact of alien plants on Hawai'i's native biota. Pages 180-120 in C. P. Stone and J. M. Scott (Eds.). Hawaii's terrestrial ecosystems: preservation and management. University of Hawaii.

Sykes, M. T. and I. C. Prentice. 1996. Climate change, tree species distributions and forest dynamics: a case study in the mixed conifer/northern hardwoods zone of northern Europe. Climatic Change **34**: 161-177.

Thompson, J., N. Brokaw, J. K. Zimmerman, R. B. Waide, E. M. Everham III, D. J. Lodge, C. M. Taylor, D. García-Montiel, and M. Fluet. 2002. Land use history, environment, and tree composition in a tropical forest. Ecological Applications **12**(5):1344-1363.

U.S. Government Accounting Office. 2001. Invasive species – obstacles hinder federal rapid response to growing threat. Report to Congressional Requesters. GAO-01-724. July 2001.

USDA Forest Service. 1997. Revised land and resource management plan: Caribbean National Forest/Luquillo Experimental Forest, Puerto Rico. Forest Service Southern Region.

USDA Forest Service. 2004a. Environmental Assessment: forest plan amendments - Caribbean National Forest, Rio Grande, Puerto Rico. June 2004.

USDA Forest Service. 2004b. National strategy and implementation plan for invasive species management. FS-805. October 2004.

USDA Forest Service. 2005a. Invasive plant inventory, monitoring and mapping protocol field guide. Rangeland Management Staff. October 2005.

USDA Forest Service. 2005b. U.S. Forest Service recreational activities. http://www.fs.fed.us/recreation/programs/facts/ Accessed February 2008.

USDA Forest Service. 2005c. Memorandum regarding Guidance on Use of Reauthorized Watershed Restoration and Enhancement Agreement (Wyden) Authority. November 5, 2005.

USDA Forest Service. 2006. Ecosystem restoration: a framework for restoring and maintaining the National Forests and Grasslands. Restoration Framework Team. January 2006.

USDA Forest Service. 2007a. Caribbean National Forest website. Available at: http://www.fs.fed.us/r8/caribbean/ Accessed February 2007.

USDA Forest Service. 2007b. USDA Forest Service National Forest System invasive species program – Data recording protocols for invasive species management (inventory and mapping) Version 04.01.07.

USDA Forest Service Washington Office. 2005. Guidance on use of reauthorized watershed restoration and enhancement agreement (Wyden) authority memo to Regional Foresters, Station Directors, Area Director, IITF Director, WO Staff Directors. November 1, 2005.

Vandermeer, J. 2007. Personal communication.

Vandermeer, J. 2007. Agroecology. Unpublished manuscript.

Vandermeer, J., I. Granzow de la Cerda, D. Boucher, I. Perfecto, J. Ruiz. Hurricane disturbance and tropical tree species diversity. 2000. Science. 290 (5492): 788-791.

Von der Lippe, M. and I. Kowarik. 2007. Long-distance dispersion of plants by vehicles as a driver of plant invasions. Conservation Biology. **21** (4): 986-996.

Walker, B. and W. Steffen. 1997. An overview of the implications of global change for natural and managed terrestrial ecosystems. Conservation Ecology 1:2.

Wilcove, D.S., D. Rothstein, J. Bubow, J., A. Phillips, and E. Losos. 1998.Quantifying Threats to Imperiled Species in the United States.BioScience 48(8): 607–615.

Williamson, M. 1999. Invasions. Ecography 22: 5-12.

Wu, W., C.A..S. Hall, and F. N. Scatena. 2006 Modeling the impact of land use change on the stream flows at the meso-scale watershed level in North-Eastern Puerto Rico. Hydrological Processes, in press.

Zimmerman, J. K., T. M. Aide, M. Rosario, M. Serrano, and L. Herrera. 1995. Effects of land management and a recent hurricane of forest structure and composition in the Luquillo Experimental Forest, Puerto Rico. Forest Ecology and Management **77**:65-76.

APPENDICES

Appendix 1.1: Visitor Use Survey

1. Where do you live?

Puerto Rico United States Canada South America Europe

Africa Middle East Australia Mexico Central America Asia

2. What is the purpose of your visit to the forest? (circle all that apply)

Bird Watching Hiking Swimming Site seeing

Passing through Relaxation Isolation Photography

Exploring nature Picnicking Identifying rare species Visiting (with family or friends)

3. What do you value most about a forest visit?

4. Were your expectations of El Yunque National Forest met during your visit, how so/not?

5. If you are not a Puerto Rico native, how did your El Yunque National Forest experience compare to visiting a forest in your native land? Will the differences have an effect on you returning (in a positive or negative way)?

6. Please answer if you participated in the following activities and rate your experience:

5-very good 4-good 3-ok 2-disappointing 1-bad

El Portal Rain Forest Center **Rating ______**
Comments:

La Coca Falls **Rating ______**
Comments:

Yokahu Tower **Rating ______**
Comments:

Juan Diego Creek **Rating ______**
Comments:

Big Tree Trail (La Mina Falls) **Rating ______**
Comments:

Sierra Palm Food Concession and Picnic Area **Rating______**
Comments:

Calmitillo Picnic Area **Rating ______**
Comments:

Palo Colorado Picnic Area/Information Center **Rating ______**
Comments:

Mt. Britton Lookout Tower **Rating ______**
Comments:

Trail to El Yunque Peak **Rating ______**
Comments:

Spanish Translation:
1. ¿En dónde vives?

Puerto Rico Estados Unidos Canada Suramérica Europa

Africa Medio Oriente Australia México América Central

Asia

2. ¿Cuál es la razón que vino al bosque? (Marque las repuestas que aplican)

Ver las aves Caminatas en la montaña Natación Turísmo

Venía de Paso Relajación Aislamiento Fotografía

Explorando la naturaleza "Picnic" Identificar especies raras

De Visita (Con familia o amigos)

3. ¿Qué es lo que más valoras de una visita al bosque?

4. ¿Sus expectativas de el Bosque Nacional El Yunque fueron realizadas? Explique cómo sí o cómo no.

5. ¿Si usted no es residente de Puerto Rico, cómo compara su experiencia en el Bosque Nacional El Yunque con la visita a un bosque en su tierra natal? ¿Cree usted que las diferencias tendrán un efecto sobre su regreso (positivas o negativas)?

6. Si usted participó en la siguientes actividades, indique su experiencia:

5-Excepcional 4-Muy Bueno 3-Bien 2-Mal 1-Decepcionante

El Portal Centro del Bosque Pluvial **Índice ______**
Comentarios:

Cascada La Coca **Índice ______**
Comentarios:

Torre de Yokahú **Índice ______**
Comentarios:

Quebrada Juan Diego **Índice ______**
Comentarios:

Vereda de Arboles Grandes (Cascada La Mina) **Índice ______**
Comentarios:

Area de Pasadías Palma de Sierra y "Yuquiyu Delights" **Índice ______**
Comentarios:

Area Pasadías Calmitillo **Índice ______**
Comentarios:

Centro de Información y Area de Pasadías Palo Colorado **Índice ______**
Comentarios:

Torre de observación Monte Britton **Índice ______**
Comentarios:

Vereda de Pico El Yunque **Índice ______**
Comentarios:

Appendix 2.1: Detailed Statistical Results of Puerto Rico Climate Analysis

S.no	Station	Linear trend	Slope	P-Value	r-sqd	L & S trend	Slope	P-value	r-sqd
1	Acquirre	None	0.0000	0.9865	0	None	-0.0003	0.8537	0.106
2	Aibonito	Increasing	0.0130	0.0021	0.023	Increasing	0.0160	0.0150	0.08
3	Cayey	None	0.0006	0.8745	0	None	0.0006	0.8824	0.068
4	Coloso	None	-0.0009	0.7704	0	None	-0.0013	0.4475	0.369
5	Corozal	Increasing	0.0070	0.0323	0.007	None	0.0072	0.1129	0.053
6	Dorado	None	-0.0026	0.3655	0.001	None	-0.0026	0.3646	0.04
7	Dosbocas	None	-0.0012	0.6967	0	None	-0.0013	0.6079	0.063
8	Guayamas	None	0.0041	0.2115	0.003	None	0.0040	0.2932	0.063
9	Gurabos	None	0.0020	0.4880	0.001	None	0.0019	0.5409	0.072
10	Isabella	None	0.0022	0.3541	0.001	None	0.0022	0.3604	0.052
11	Juncos	None	0.0036	0.2454	0.002	None	0.0035	0.3082	0.076
12	Lajas	None	0.0032	0.1704	0.003	None	0.0031	0.1612	0.101
13	Magueyes	Increasing	0.0064	0.0092	0.012	Increasing	0.0063	0.0082	0.041
14	Manati	None	-0.0004	0.8727	0	None	-0.0004	0.8881	0.021
15	Mayaguez	Decreasing	-0.0113	0.0031	0.015	Decreasing	-0.0116	0.0005	0.288
16	ponce	Increasing	0.0052	0.0359	0.007	Increasing	0.0051	0.0253	0.059
17	riopiedras	Increasing	0.0160	<.0001	0.036	None	0.0165	0.0016	0.091
18	sanjuan	None	0.0008	0.7156	0	None	0.0008	0.6780	0.078
19	trujillo	None	0.0000	0.9997	0	None	0.0000	0.9947	0.049
20	El verde	None	0.0018	0.4844	0.001	None	0.0018	0.5878	0.038

Table 1 Statistical values for linear trend for precipitation by stations

S.no	Station	Trend	Slope	P-Value	r-sqd
1	Acquirre	None	0.0003	0.1316	0.004
2	Aibonito	None	0.0003	0.3253	0.002
3	Cayey	None	0.0002	0.3732	0.001
4	Coloso	None	-0.0001	0.5148	0.001
5	Corozal	None	0.0003	0.0763	0.005
6	Dorado	None	0	0.7782	0
7	Dosbocas	None	0.0002	0.2381	0.002
8	Guayamas	None	-0.0002	0.2861	0.002
9	Gurabos	None	0	0.8605	0
10	Isabella	None	0	0.7276	0

S.no	Station	Trend	Slope	P-Value	r-sqd
11	Juncos	None	-0.0001	0.3348	0.002
12	Lajas	None	0.0002	0.2669	0.002
13	Magueyes	Decreasing	-0.0009	<0.0001	0.027
14	Manati	None	0.0002	0.1594	0.003
15	Mayaguez	Increasing	0.0005	0.0135	0.01
16	ponce	Decreasing	-0.0006	0.0015	0.016
17	riopiedras	None	0	0.7906	0
18	sanjuan	None	0	0.8861	0
19	trujillo	None	-0.0003	0.1765	0.004
20	El verde	Decreasing	-0.0894	0.0004	0.032

Table 2 Statistical values of CV trend by stations

(a) Statistical values of linear and seasonal trends: Minimum temperature, by station

No.	Station name	Linear&Seasonality trend	Slope	P-value	r-sqd	Yearly change	Decedal change
1	Acquirre	Increasing	0.0083	<.0001	0.781	0.0997	0.9972
2	Aibonito	None	-0.0010	0.6232	0.747	-0.0125	-0.1248
3	Cayey	Increasing	0.0046	<.0001	0.769	0.0548	0.5484
4	Coloso	Increasing	0.0039	0.0001	0.756	0.0467	0.4668
5	Corozal	Increasing	0.0015	0.0150	0.842	0.0181	0.1812
6	Dorado	Increasing	0.0063	<.0001	0.668	0.0754	0.7536
7	Dosbocas	Increasing	0.0011	0.0493	0.775	0.0134	0.1344
8	Guayamas	Increasing	0.0032	<.0001	0.745	0.0386	0.3864
9	Gurabo	None	-0.0007	0.4477	0.790	-0.0088	-0.0876
10	Isabella	Increasing	0.0037	<.0001	0.804	0.0444	0.4440
11	Juncos	Increasing	0.0086	<.0001	0.768	0.1034	1.0344
12	Lajas	None	0.0004	0.6904	0.759	0.0052	0.0521
13	Magueyes	None	-0.0002	0.8072	0.701	-0.0022	-0.0224
14	Manati	Increasing	0.0051	<.0001	0.803	0.0606	0.6060
15	Mayaguez	Increasing	0.0067	<.0001	0.694	0.0809	0.8088
16	ponce	None	0.0009	0.1228	0.764	0.0108	0.1082
17	riopiedras	None	0.0003	0.7202	0.802	0.0038	0.0380
18	sanjuan	Increasing	0.0043	<.0001	0.865	0.0514	0.5136
19	trujillo	Increasing	0.0072	<.0001	0.730	0.0860	0.8604
20	El verde	Increasing	0.0057	<.001	0.827	0.0686	0.6864

(b) Summary of Table 4.a

Trend	Station no.	Decadal temperature change over global warming rate	Station no.
Increasing	14	-0.1248< Tem.change <-0.02	3
Decreasing	0	0.00< Tem. change < 0.216	5
Non-significant	6	0.216< Tem.change < 1.0344	12

Table 3 Statistical values of linear and seasonal trends for minimum temperature by station (a) and summarized (b)

(a) Linear and seasonal trends: Maximum temperature, by station

No.	Station name	Linear & Seasonality trend	Slope	P-value	r-sqd	Yearly change	Decedal change
1	Acquirre	Increasing	0.0031	<.0001	0.669	0.0366	0.3660
2	Aibonito	Decreasing	-0.0050	0.0072	0.677	-0.0594	-0.5940
3	Cayey	Decreasing	-0.0046	<.0001	0.756	-0.0556	-0.5556
4	Coloso	None	0.0009	0.2461	0.665	0.0110	0.1101
5	Corozal	Increasing	0.0044	<.0001	0.71	0.0533	0.5328
6	Dorado	None	-0.0050	0.2483	0.712	-0.0600	-0.6000
7	Dosbocas	Decreasing	-0.0057	<.0001	0.723	-0.0679	-0.6792
8	Guayamas	Decreasing	-0.0044	<.0001	0.728	-0.0523	-0.5232
9	Gurabos	Increasing	0.0031	<.0001	0.737	0.0373	0.3732
10	Isabella	Increasing	0.0016	0.0172	0.722	0.0191	0.1908
11	Juncos	None	0.0004	0.5125	0.715	0.0051	0.0509
12	Lajas	Increasing	0.0025	<.0001	0.672	0.0304	0.3036
13	Magueyes	None	0.0013	0.1459	0.701	0.0154	0.1536
14	Manati	Decreasing	-0.0042	<.0001	0.644	-0.0500	-0.5004
15	Mayaguez	None	0.0008	0.3146	0.608	0.0092	0.0915
16	ponce	Increasing	0.0036	<.0001	0.736	0.0427	0.4272
17	riopiedras	Increasing	0.0053	<.0001	0.691	0.0640	0.6396
18	sanjuan	None	0.0013	0.1459	0.701	0.0154	0.1536
19	trujillo	Increasing	0.0043	<.0001	0.643	0.0515	0.5148
20	El verde	Increasing	0.0117	<.0001	0.803	0.1403	1.4028

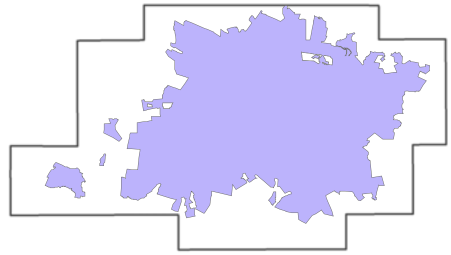
(b) Summary of table 5.a

Trend	Station no.	Decadal temperature change over global warming rate	Station no.
Increasing	9	-0.6704< Tem.change <-0.5004	6
Decreasing	5	00.00< Tem. change < 0.216	6
Non-significant	6	0.216< Tem.change < 1.4028	8

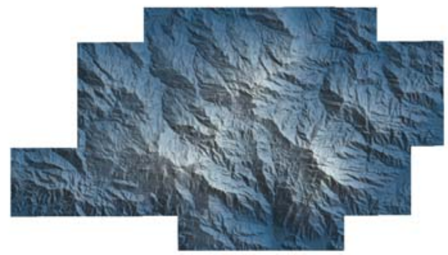
Table 4 Statistical values of linear and seasonal trends: maximum temperature by station (b) and summarized (b)

Appendix 3.1: Metadata for the Spatial Data Used to Create Habitat Models

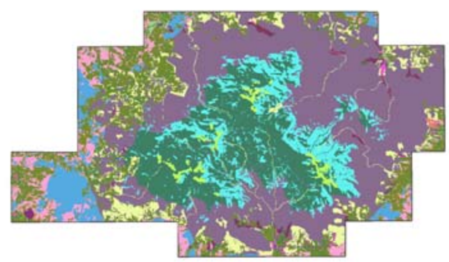
Forest Boundary/Proclamation: Vector layers provided by IITF (courtesy of Olga Ramos) as received by IITF from a 1993 archive. Layers were likely digitized from USGS topography maps. Forest boundary (the inner lavender-shaded area) represents current land owned by the USDA FS. The proclamation (the outer blocky boundary) represents the entire area of land purchasable by the USDA FS .



Digital Elevation Model (10m): Data provided by IITF, originally developed by the USGS. It was used for all habitats that specified elevation ranges.



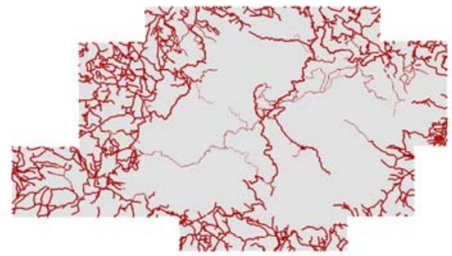
Landcover: 2006 PRGAP Landcover dataset developed by the USDA FS IITF for the PRGAP project from a composite of 18 remotely sensed Landsat TM images taken from 1999-2003. It was used for habitats that specified specific forest type such as "dwarf forest" or "tabonuco forest" or general landcover types such as "all mature moist forests".



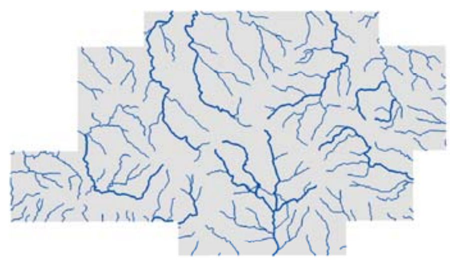
Watersheds: On-screen digitized from watershed map included in EYNF documentation (find eventually). This data was used for habitat that specified certain regions of the forest, such as "north-central forest" or "south-eastern forest".

Roads/Trails: Vector layer was provided by IITF (courtesy of Olga Ramos), as received by IITF from a 1993 archive. Appears to have been digitized from USGS topo maps (1:20,000; EL YUNQUE, ISBN: 978-0-607-46856-4; FAJARDO, ISBN: 978-0-607-46857-1; Version Date, 1982). Modified by the present author (Billmire) based on USDA FS park map as well as field observations for path type and weighting information. All roads outside forest boundary but inside proclamation were given a default weighting (Table ???). It was used for habitats that specified inclusion of "disturbed areas", "open areas", "along roads/trails", "along forest edges."

Type	Buffer Distance (m)
Old Trail	5
Trail	10
Paved Trail	15
Unimproved Road	20
Improved Road	25
Paved Road (partially closed)	30
Paved Road (open to public)	35
Default (outside forest boundary)	30



Streams: Vector layer provided by IITF (courtesy of Olga Ramos), as received by IITF from a 1993 archive. Appears to have been digitized from USGS topo maps (1:20,000; EL YUNQUE, ISBN: 978-0-607-46856-4; FAJARDO, ISBN: 978-0-607-46857-1; Version Date, 1982). Modified by the present author (Billmire) for buffer weighting based on visibility by Landcover dataset (40m buffer if visible in the Landcover data set, 20m buffer otherwise). It was used for habitats that specified "along streams" or "forest edges."



Appendix 3.2: Species Habitat Profiles

The following pages describe the habitat information, translation of habitat information, and weighting information for each species used in the GIS analysis that was used to create the map of biological vulnerability to climate change. The figures for each species profile display the individual habitat model of that species on a gradient of dark orange (most preferred habitat) to light orange (least preferred habitat) to blue-gray (area in which the species is not found).

The primary sources from which weighting information was derived are listed below:

EYNF 2004 EIS:
USDA Forest Service. 2004. Environmental Impact Statement for Revisions to the Land and Resource Management Plan for Caribbean National Forest: Chapter III The Affected Environment: Before and After Alternatives. General technical report.

PR DNR:
Puerto Rico Department of Natural and Environmental Resources. Listing information derived from PR GAP materials, see below

PR GAP:
Gould, W., Alarcon, C., Fevold, B., Jimenez, M. E., Martinuzzi, S., Potts, G., Solorzano, M., and Ventosa, E. 2007. *Puerto Rico Gap Analysis Project – Final Report.* USGS, Moscow ID and the USDA FS International Institute of Tropical Forestry, Rio Piedras, PR.

IUCN Redlist:
IUCN 2006. *2006 IUCN Red List of Threatened Species*. <http://www.iucnredlist.org>. Downloaded various dates July 2007-March 2008

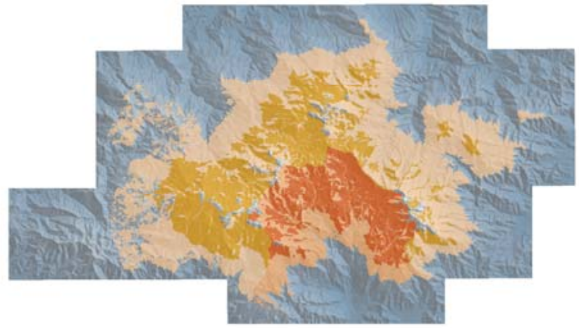
NatureServe:

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura

Accipiter striatus venator

Halcon de Sierra

Puerto Rican Sharp-shinned hawk



Habitat Model Parameters:

Data Type	Weight	Specification	Source
Elevation	100	>400m	Delannoy (1997)
Landcover	100	Palo Colorado	PR DNR 1976, Delannoy
Landcover	50	All other moist forest and shrubland excluding dwarf forest	PR DNR 1976, Delannoy (1997)
	Qualifiers		
Watershed	+ 25%	South central forest: Rio Blanco watershed	Delannoy (1997), USFWS (1994)

Weighting Table

Weighting Factor	Source		*Accipiter striatus venator* Rating	
Rarity	EYNF 2004 EIS	(local)	ENDANGERED	100
	PR DNR	↓	CR	100
	PR GAP	↓	Rare	100
	IUCN Redlist	↓	LC, sub-species not listed	***
	NatureServe	(global)	G5, sub-species not listed	***
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		Indirect	50
Combined Weight:				**75**

Sources

Delannoy, C. A. 1997. Status of the Broad-winged Hawk and the Sharp-shinned Hawk in Puerto Rico. Caribbean Journal of Science, Vol. 33, No. 1–2, 21–33, 1997

Department of Natural Resources (DNR). 1976. The master plan for the commonwealth forests of Puerto Rico. Department of Natural Resources, San Juan, R73EWE0E Ewel, J.J. and J.L.

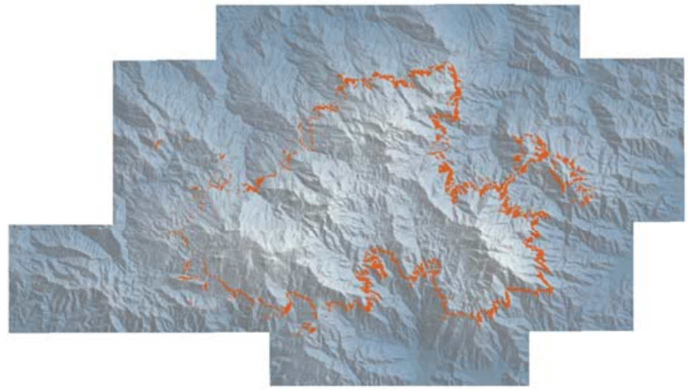
Whitmore. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. U.S. Forest Service, Institute of Tropical Forestry, Research Paper ITF-18. 72 pp.

IUCN Redlist: http://www.iucnredlist.org/search/details.php/49398/all

NatureServe: http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Accipiter+striatus

U.S. Fish and Wildlife Service (USFWS). 1994. Determination of Endangered status for the Puerto Rican Broad-winged Hawk and the Puerto Rican Sharp-shinned Hawk. In: Endangered and Threatened Wildlife and Plants. FWS Report 50 CFR Part 17, RIN 1018-AC12. http://www.fws.gov/endangered/i/b/sab6y.html

Amazona vittata
Cotorra Puertorriquena
Puerto Rican Parrot



Habitat Model Parameters:

Data Type	Weight	Specification	Source
Elevation	100	200-600m	BirdLife International/IUCN Redlist
Landcover	100	Palo Colorado, Sierra Palm	Raffaele 1998

Weighting Table

Weighting Factor	Source		*Amazona vittata* Rating	
Rarity	EYNF 2004			
	EIS	(local)	ENDANGERED	100
	PR DNR	↓	CR	100
	PR GAP	↓	Rare	100
	IUCN Redlist	↓	CR D	100
	NatureServe	(global)	G1	80
Endemism	PR GAP		Endemic EY	100
GCC Threat	NatureServe		Indirect (NS)	50
Combined Weight:				**82**

Sources

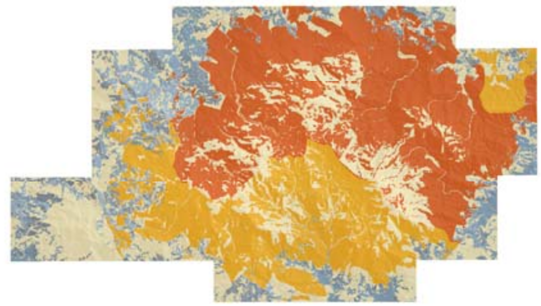
BirdLife International 2006. *Amazona vittata*. In: IUCN 2007. *2007 IUCN Red List of Threatened Species.* <www.iucnredlist.org>. Downloaded on **27 July 2008** .http://www.iucnredlist.org/search/details.php/1069/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: February 27, 2008).

Raffaele, H.A., Wiley, J., Garrido, O., Keith, A., and Raffaele, J. 1998. A Guide to the Birds of the West Indies. Princeton Univ. Press. Princeton.

Buteo platypterus brunnescens

Guaraguao de Bosque
Puerto Rican Broad-winged Hawk



Habitat Model Parameters:

Data Type	Weight	Specification	Source
Landcover	100	Palo Colorado, Tabonuco	Delannoy (1997), Delannoy (1992)
Landcover	50	All other moist forest	Delannoy (1997)
Qualifiers			
Watershed	+ 33%	North-central forest: Rio Mameyes watershed	USFWS (1994), Delannoy(1997)
Watershed	+ 25%	North-central forest: Rio Espiritu Santo, Rio Sabana, Rio Fajardo watersheds	UFSWS (1994), Delannoy (1997)

Weighting Table

Weighting Factor	Source		*Buteo platypterus brunnescens* Rating	
Rarity	EYNF 2004 EIS	(local)	ENDANGERED	100
	PR DNR	↓	CR	100
	PR GAP	↓	Rare	100
	IUCN Redlist	↓	LC, sub-species not listed	***
	NatureServe	(global)	G5, sub-species not listed	***
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	**USFWS** (1994)		Indirect- habitat destruction, anthropogenic disturbance	50
Combined Weight:				**75**

Sources

Delannoy, C.A. 1992. Status Surveys of the Puerto Rican Sharp-shinned Hawk (Accipiter striatus venator) and Puerto Rican Broad-winged Hawk (Buteo platypterus brunnescens). Final report submitted to the U.S. Fish and Wildlife Service as specified in work contract no. 14-19-0004-91-031.

Delannoy, C. A. 1997. Status of the Broad-winged Hawk and the Sharp-shinned Hawk in Puerto Rico. Caribbean Journal of Science, Vol. 33, No. 1–2, 21–33, 1997

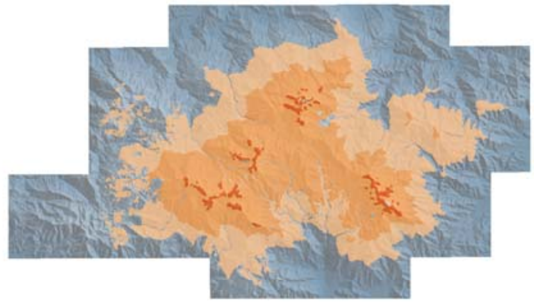
IUCN Redlist: http://www.iucnredlist.org/search/details.php/49429/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007). http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Buteo+platypterus

U.S. Fish and Wildlife Service. 1994. Determination of Endangered status for the Puerto Rican Broad-winged Hawk and the Puerto Rican Sharp-shinned Hawk. In: Endangered and Threatened Wildlife and Plants. FWS Report 50 CFR Part 17, RIN 1018-AC12.

Dendroica angelae

Reinita de Bosque Enano
Elfin-woods warbler



Habitat Model Parameters:

Data Type	Weight	Specification	Source
Elevation	100	> 631m	Kepler and Parkes 1972
Elevation	50	370 – 630m	Cruz and Delannoy 1984,
Landcover	100	Dwarf forest	Waide 1995
Landcover	50	All other moist mature forest types	Cruz and Delannoy 1984

Weighting Table

Weighting Factor	Source		*Dendroica angelae* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	VU	50
	PR GAP	↓	Uncommon	50
	IUCN Redlist	↓	VU D1+2	50
	NatureServe	(global)	G1G2	70
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		NO, BUT storms	50
Combined Weight:				**60**

Sources

Cruz, A. and C. A. Delannoy 1984. Ecology of the elfin woods warbler (Dendroica angelae). I. Distribution, habitat usage, and population densities. Caribbean Journal of Sicence, 20: 89-96.

IUCN Redlist: http://www.iucnredlist.org/search/details.php/6422/all

Kepler, C.B. and Parkes, K.C. (1972). A new species of warbler (Parulidae) from Puerto Rico.The Auk, Vol. 89, pp. 1-18.

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007). http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Dendroica+angelae

USFWS: http://www.fws.gov/southeast/es/pdf/EWW.pdf

Waide, R. (1995). Status and conservation of the Elfin Woods Warbler (Dendroica angelae) in the Luquillo Experimental Forest. Final Report submitted to the U.S. Fish and Wildlife Service.

Eleutherodactylus eneidae

Coqui de Eneida
Eneida's Coqui

Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	303 – 1151m	NatureServe
Roads/Trails	100	Buffer	Rivero 1998
Landcover	66	Moist grasslands, barren, low-density urban	Rivero 1998
Landcover	33	All moist forests, shrubland, and grassland	Rivero 1998, NatureServe

Weighting Table

Weighting Factor	Source		*E. eneidae* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	CR	100
	PR GAP	↓	uncommon	50
	IUCN Redlist	↓	CR A2ae	100
	NatureServe	(global)	GH	100
Endemism	PR GAP		Endemic PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**85**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/7150/all

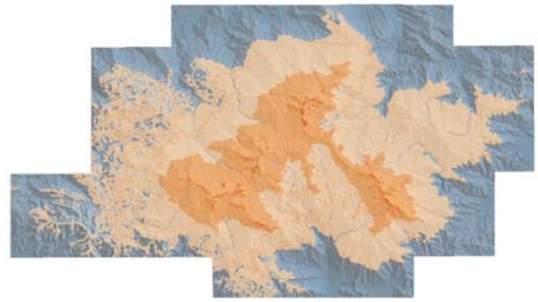
InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007). http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Eleutherodactylus+eneidae

Rivero, J. A. 1998. Los anfibios y reptiles de Puerto Rico/ The Amphibians and Reptiles of Puerto Rico. Segunda ed. Editorial de la Universidad dePuerto Rico, San Juan, Puerto Rico. 510 pp.

USFWS: http://www.fws.gov/endangered/i/c/sac0p.html

Eleutherodactylus gryllus

Coqui grillo
Cricket coqui/Green coqui



Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	>700m	Schwartz and Henderson 1991
Elevation	25	300 – 699m	Joglar 1998
Landcover	100	Dwarf forest	Joglar 1998
Landcover	50	Palo Colorado, Sierra Palm, Tabonuco	
Landcover		30m buffer of forest edges	Schwartz and Henderson 1991

Weighting Table

Weighting Factor	Source		*E. gryllus* Rating	
Rarity	EYNF 2004 EIS	(local)	not listed	0
	PR DNR	↓	not listed	***
	PR GAP	↓	common	0
	IUCN Redlist	↓	EN B1ab	75
	NatureServe	(global)	G2G3	50
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist, Joglar 98		YES	100
Combined Weight:				**69**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/56634/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007)

Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720

USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Eleutherodactylus hedricki

Coqui de Hedrick
Hedrick's coqui/Treehole coqui

Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	>455	Schwartz and Henderson 1991
Landcover	100	60m primary forest interiors	Schwartz and Henderson 1991

Weighting Table

Weighting Factor	Source		*E. hedricki* Rating	
Rarity	EYNF 2004 EIS	(local)	not listed	0
	PR DNR	↓	DD	25
	PR GAP	↓	uncommon	50
	IUCN Redlist	↓	EN B1ab	75
	NatureServe	(global)	G2	60
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**72**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/56648/all

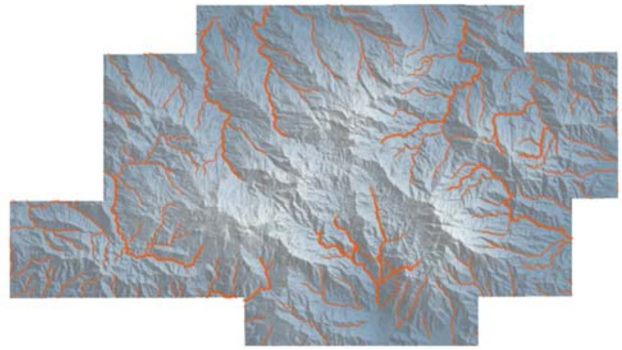
InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007) .http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Eleutherodactylus+hedricki

Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720

USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Eleutherodactylus karlschmidti
Coqui Palmeado
Web-footed coqui



Note: not seen since 1976

Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	45 – 630m	IUCN Redlist, Schwartz and Henderson 1991, Joglar 1998, Hedges 1999
Stream	100	Weighted stream buffer	Schwartz and Henderson 1991, Joglar 1998

Weighting Table

Weighting Factor	Source		*E. karlschmidti* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	none	***
	PR GAP	↓	not listed	***
	IUCN Redlist	↓	CR A2ae	100
	NatureServe	(global)	GH	100
Endemism	PR GAP		Endemic	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**86**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/7146/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007).

Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

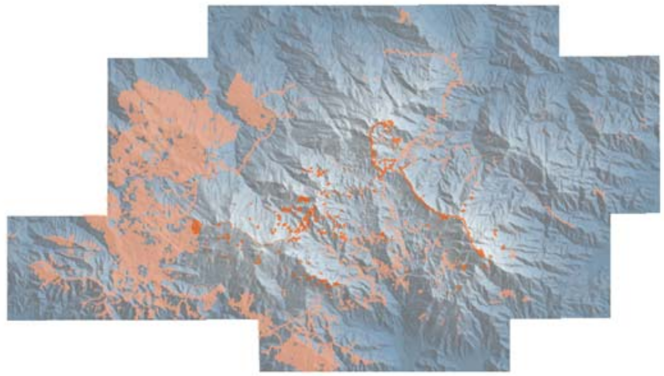
Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720

USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Eleutherodactylus locustus

Coqui Martillito

Warty coqui



Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	>700m	NatureServe, Schwartz and Henderson 1991
Elevation	33	305 – 699m	Rivero and Mayorga 1963
Landcover	100	All unforested types and 30m forest edges	Schwartz and Henderson 1991
Roads/Trails	100	Weighted roads/trails buffer	Schwartz and Henderson 1991

Weighting Table

Weighting Factor	Source		*E. locustus* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	VU	50
	PR GAP	↓	uncommon	50
	IUCN Redlist	↓	CR A4ae	100
	NatureServe	(global)	G3	40
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:			**Total Weight:**	**78**

Sources

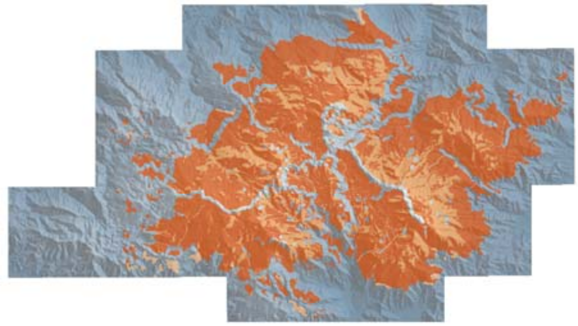
IUCN Redlist: http://www.iucnredlist.org/search/details.php/56725/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007). http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Eleutherodactylus+locustus

Rivero, J.A. and H. Mayorga. 1963. Notes on the Distribution of Some Puerto Rican Frogs with a Discussion on the Possible Origin of Eleutherodactylus Locustus. Carib.J.Sci. 3(2-3):81-86.

Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720

Eleutherodactylus portoricensis
Coqui de la Montana
Upland coqui



Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	>273	Joglar (1998)
Landcover	100	60m interior of all upland forest	IUCN Redlist
Qualifiers			
Landcover	+ 67%	Dwarf, Tabonuco, and Palo Colorado types	Miranda-Castro et al. (2000)
Landcover	+ 33%	Sierra Palm type	Joglar (1998)

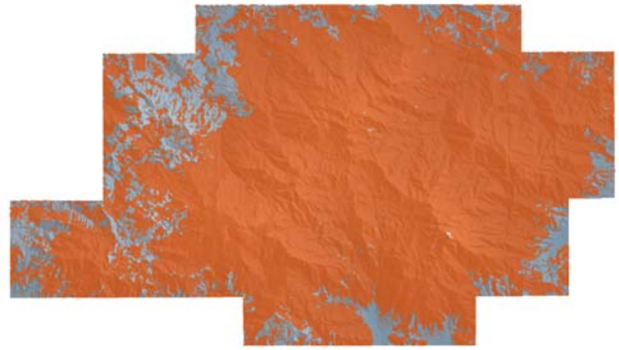
Weighting Table

Weighting Factor	Source		*E. portoricensis* Rating	
Rarity	EYNF 2004 EIS	(local)	not listed	0
	PR DNR	↓	VU	50
	PR GAP	↓	common	0
	IUCN Redlist	↓	EN A4ae	75
	NatureServe	(global)	G3G4	30
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**69**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/56875/all
InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007)
Miranda-Castro, L. et al. 2000. First list of the vertebrates of Los Tres Picachos State Forest, Puerto Rico with data on relative abundance and altitudinal distribution. Caribbean Journal of Science, 36(1-2):117-126.
Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720
USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Eleutherodactylus richmondi
Coqui Caoba
Ground coqui



Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	40 – 1152m	Joglar1998, IUCN Redlist
Landcover	100	All forest types	Joglar1998, NatureServe

Weighting Table

Weighting Factor	Source		*E. richmondi* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	VU	50
	PR GAP	↓	uncommon	50
	IUCN Redlist	↓	CR A3ce	100
	NatureServe	(global)	G3	40
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**78**

Sources

IUCN Redlist: http://www.iucnredlist.org/search/details.php/56914/all

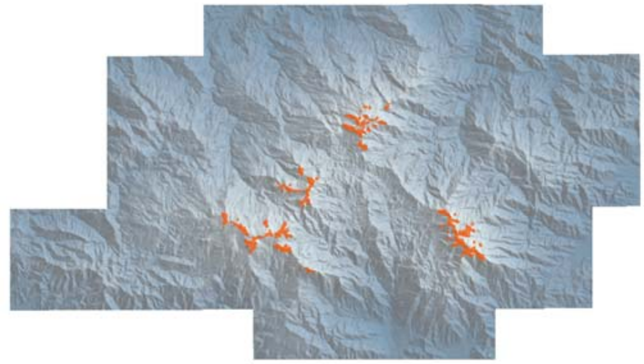
Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007). http://www.natureserve.org/infonatura/servlet/InfoNatura?searchName=Eleutherodactylus+richmondi

Eleutherodactylus unicolor

Coqui Duende

Burrowing Coqui



Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	> 660m	CNF EIS, Rivero 1998, Shwartz and Henderson 1991
Landcover	100	Dwarf forest type	USDA FS 2004, CNF EIS, Rivero 1998

Weighting Table

Weighting Factor	Source		*E. unicolor* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	none	***
	PR GAP	↓	uncommon	50
	IUCN Redlist	↓	CR A3e; B1ab(iii)+2ab(iii)	100
	NatureServe	(global)	G1	80
Endemism	PR GAP		Endemic EY	100
GCC Threat	IUCN Redlist, Joglar, Schwartz and Henderson		YES	100
Combined Weight:				**90**

Sources

USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

IUCN Redlist: http://www.iucnredlist.org/search/details.php/57023/all

Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007).

Rivero, J. A. 1998. Los anfibios y reptiles de Puerto Rico/ The Amphibians and Reptiles of Puerto Rico. Segunda ed. Editorial de la Universidad dePuerto Rico, San Juan, Puerto Rico. 510 pp.

Schwartz, A. and W. R. Henderson 1991. Amphibians and Reptiles of the West Indies. Descriptions, Distributions, and Natural History, Univ. Press Florida, Gainesville, FL. pp. 720

Eleutherodactylus wightmanae

Coqui melodioso
Melodious coqui/Wrinkled coqui

Habitat Model Parameters

Data Type	Weight	Specification	Source
Elevation	100	> 150 m	Joglar (1998)
Landcover	100	All moist forest types	USDA FS 2004, RL, Joglar (1998)

Weighting Table

Weighting Factor	Source		*E. wightmanae* Rating	
Rarity	EYNF 2004 EIS	(local)	not listed	0
	PR DNR	↓	none	0
	PR GAP	↓	common	0
	IUCN Redlist	↓	EN A4ae	75
	NatureServe	(global)	G3	40
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		YES	100
Combined Weight:				**66**

Sources

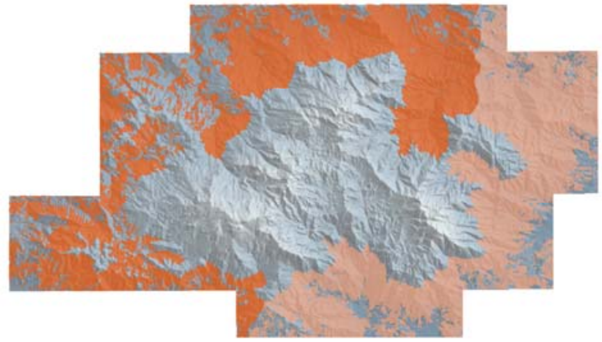
IUCN Redlist: http://www.iucnredlist.org/search/details.php/57056/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007).

Joglar L. R. 1998. Los Coquíes de Puerto Rico, Su Historia Natural y Conservación. Editorial de la Universidad de Puerto Rico. 232 pp.

USDA Forest Service. (2004). Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Epicrates inornatus
Culebron
Puerto Rican Boa



Habitat Model Parameters:

Data Type	Weight	Specification	Source
Elevation	100	0-480m	Wiley 2003
Landcover	100	All forest, shrub	Rivero 1998, Wiley 2003
Qualifiers			
Watershed	+ 25%	North-western forest: Espiritu Santo, Mameyes, and Grande de Loiza watersheds	USDA FS 2004 Boa Surveys

Weighting Table

Weighting Factor	Source		*Epicrates inornatus* Rating	
Rarity	EYNF 2004 EIS	(local)	ENDANGERED	100
	PR DNR	↓	VU	50
	PR GAP	↓	Rare	100
	IUCN Redlist	↓	LR/nt (from '94 categories)	30
	NatureServe	(global)	not listed	***
Endemism	PR GAP		Endemic to PRmi	75
GCC Threat	IUCN Redlist		No	0
Combined Weight:				**48**

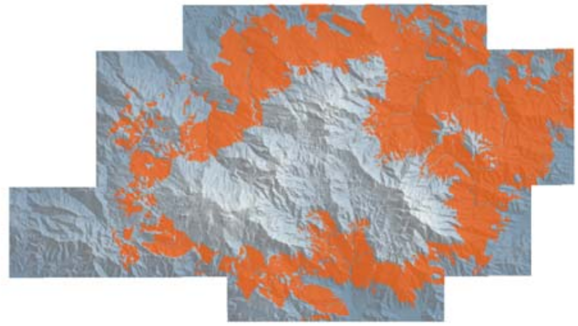
Sources

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007).
IUCN Redlist: http://www.iucnredlist.org/search/details.php/7821/all
USFWS: http://www.fws.gov/endangered/i/c/sac0p.html
Rivero, J.A. 1998. Los anfibios y reptiles de Puerto Rico/The Amphibians and Reptiles of
Puerto Rico. Segunda ed. Universidad de Puerto Rico. Editorial Universitaria, San Juan, Puerto Rico. 510 pp.
Wiley, J.W. 2003. Habitat Association, Size, Stomach Contents, and Reproductive Condition of Puerto Rican Boas (*Epicrates inornatus*). *Caribbean Journal of Science,* Vol. 39, No. 2, p. 189-194
USDA Forest Service. 2004. Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

Stenoderma rufum

Murciélago Rojo Frutero

Desmarest's Fig-eating Bat/Red Fruit Bat



Habitat Model Parameters

Data Type	Weight	Specification	Source
Landcover	100	Tabonuco forest type	CNF Monitoring Report, IUCN Redlist, Genoways and Baker (1972), Gannon et al. 2005

Weighting Table

Weighting Factor	Source		*Stenoderma rufum* Rating	
Rarity	EYNF 2004 EIS	(local)	SENSITIVE	50
	PR DNR	↓	VU	50
	PR GAP	↓	***	***
	IUCN Redlist	↓	VU A1c	50
	NatureServe	(global)	GU	***
Endemism	PR GAP		Endemic to PRVi	40
GCC Threat	IUCN Redlist		NO	0
Combined Weight:				**30**

Sources

USDA Forest Service. 2004. Monitoring and Evaluation Report, Caribbean National Forest. General technical report.

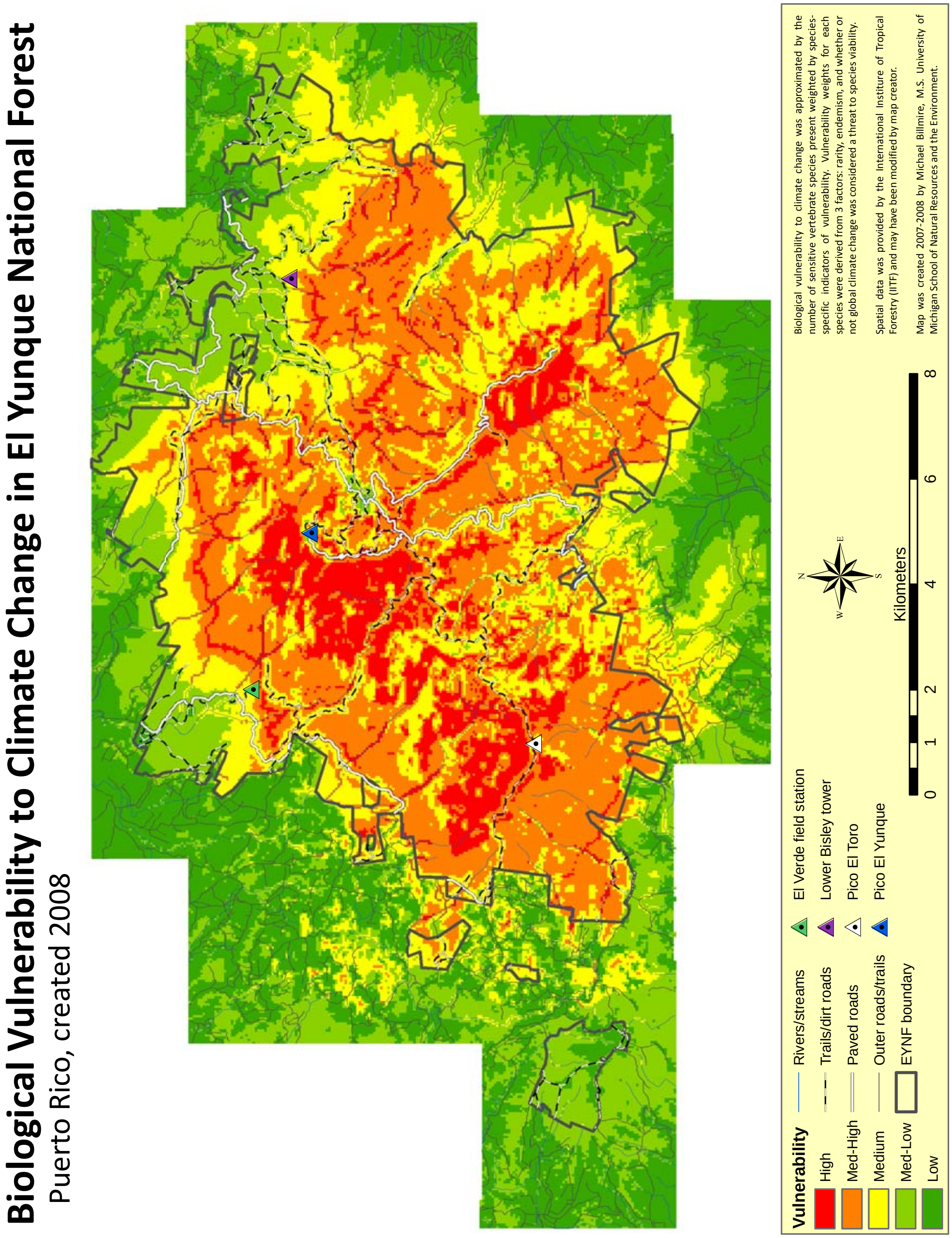
Gannon, M. R., A. Kurta, A. Rodriguez-Duran, and M. R. Willig. 2005. Bats of Puerto Rico. Texas Tech University Press, Lubbock, TX

Genoways, H. H., and R. J. Baker. 1972. Stenoderma rufum. Am. Soc. Mamm., Mammalian Species 18:1-4.

IUCN Redlist: http://www.iucnredlist.org/search/details.php/20743/all

InfoNatura: Animals and Ecosystems of Latin America [web application]. 2007. Version 5.0 . Arlington, Virginia (USA): NatureServe. Available: http://www.natureserve.org/infonatura. (Accessed: July 27, 2007).

Appendix 3.3: Final Map of Biological Vulnerability to Climate Change



Appendix 4.1: Inventory field form

1. General Information

***Infestation ID*: 081601__ __ __ __**	***Date*:**
Project Name: 2007 Invasive Screen	***Ownership*:**
***Examiner (s)*:**	

2. Data Elements

***Target Species Code*:**	**Life Form:**	
Scientific Name:	**Common Name:**	
Phenology:	**Distribution:**	
Infested Area (units):	***% Infested*:**	***Total Area (units)*:**
(Example) 20 m^2	x 75%	= 15 m^2

3. Canopy & Ground Cover

Canopy Cover % (or Cover Code):	**Ground Cover % (or Cover Code):**

4. Associated Species

Target Species Code:	Scientific Name:

5. Comments

____
____
____
____
____
____
____
____
____

Ojo: ***Azul Italico*** = Compulsorio para NRIS

Note: ***Blue Italics*** = Required for NRIS

6. Site Information

Elevation (units):	Aspect:	Percent Slope:	Slope Position:

7. Existing Vegetation Information

Plant Community:		Dominant Life Form:
Dominant Codominant Species		
Plant Code	**Scientific Name**	**Ranking**

8. Reference

Narrative (detailed description of location, directions to site, and sketch of infestation, photo point location, azimuth, and exposure number).

____

____

____

____

____

____

____

____

Appendix 4.2: Inventory field form user guide

Infestation ID: 08 16 01 - ####

Default: Region 8, El Yunque NF, (El Yunque District)

Examinador: escoge un número único en secuencía para cada infestación.

DATE: MMDDAAAA del día que se colecta los datos.

Ownership: Sí hay mas que uno dueño de propiedad, graba el uno que tiene la mayoría de la infestación y nota los otros en **Comments**.

Códijo	Descripción
USFS	U.S.D.A. Forest Service
PRIV	Privada
MGOV	Municipalidad
USFWS	U.S. Fish & Wildlife Service
F&G	DRNA (i.e. state fish & game dept.)
USOT	U.S. Government (other fed lands)
OTH	Other
N/A	Not Applicable

Target Species Code:

Códijo	Nombre Latin	Nombre Comun
ARAL7	*Arctocarpus altilis*	Pana, Panapén, breadfruit
DIAL2	*Dioscorea alata*	Ñame, water yam
DIBU	*Dioscorea bulbifera*	Gunda, air potato
IPSE2	*Ipomoea setifera*	Bejuco de puerco
PUPH2	*Pueraria phaseoloides*	Kudzú, tropical kudzu
SEWI	*Selaginella wildenovii*	Helecho azul, peacock fern

Códijo	Nombre	Descripción

Life Form:

FB	Forb/herb	Vascular plant without significant woody tissue above or at the ground. Forbs and herbs may be annual, biennial, or perennial but always lack significant thickening by secondary woody growth and have perennating buds borne at or below the ground surface.
GR	Graminoid	Grass or grass-like plant, including grasses (Poaceae), sedges (Cyperaceae), rushes (Juncaceae), arrow-grasses (Juncaginaceae), and quillworts (Isoetes).
LI	Liana	Climbing plant found in forests with long, woody, rope-like stems of anomalous anatomical structure. A shrub in the FGDC classification.
NP	Nonvascular	Nonvascular, terrestrial green plant, including mosses, hornworts, and liverworts. Always herbaceous, and often attached to solid objects such as rocks or living or dead wood rather than soil.
SH	Shrub	Perennial, multi-stemmed woody plant that is usually less than 4 to 5 meters or 13 to 16 feet in height. Shrubs typically have several stems arising from or near the ground, but may be taller than 5 meters or single-stemmed under certain environmental conditions.
SS	Subshrub	Low-growing shrub usually under 0.5 m or 1.5 feet tall (never exceeding 1 meter or 3 feet tall) at maturity..
TR	Tree	Perennial, woody plant with a single stem (trunk), normally greater than 4 to 5 meters or 13 to 16 feet in height; under certain environmental conditions, some tree species may develop a multi-stemmed or short growth form (less than 4 meters or 13 feet in height).
UN	Unknown	Lifeform is unknown.
VI	Vine	Twining/climbing plant with relatively long stems, which can be woody or herbaceous.

Phenology (i.e. life stage):

Códijo	Descripción
F1	Forb-Shrub: Pre-flowering (vegetative, rosettes, and bolting)
F2	Forb-Shrub: Flowering
F3	Forb-Shrub: Fruiting
F4	Forb-Shrub: Senescent; dormancy
G1	Graminoids: Leaves partially developed; no heads
G2	Graminoids: Inflorescence inside the sheath (in the boot)
G3	Graminoids: Inflorescence partially or fully exerted from sheath
G4	Graminoids: Seeds maturing or mature
G5	Graminoids: Senescent; dormancy

Distribution:

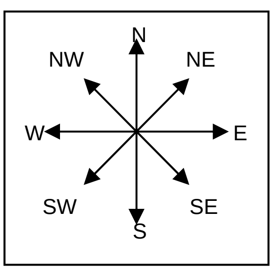
Códijo	Clase
CI	Clumpy
SP	Scattered patchy
SE	Scattered even
LI	Linear

Canopy & Ground Cover:
Use el código *o* porciento

Cover Code Class	Cover	Mid Point
T – Trace	0-1%	0.5%
L – Low	1.1 – 5.0%	2.5%
M – Moderate	5.1 – 25%	15%
H- High	25.1 – 100%	63%

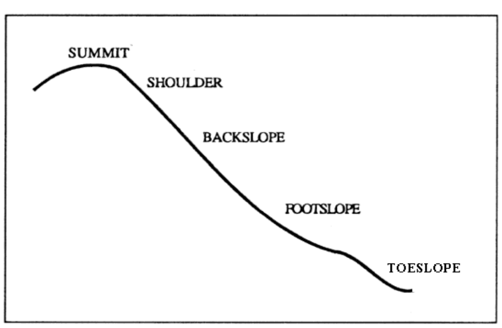
Elevation: use un altimeter (preferido), mapa topographico, o GPS.

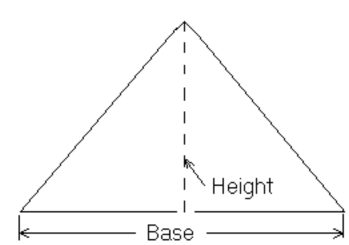
Aspect:



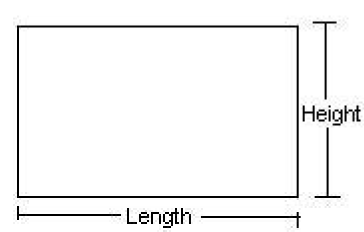
Slope Position:

Códijo	Nombre	Descripción
SU	Summit	The uppermost slope.
SH	Shoulder	The upper slope where material generally moves through creep processes.
BS	Backslope	The steepest portion of the slope where material is generally in transit.
FS	Footslope	The lower portion of the slope where material is generally re-deposited.
TS	Toeslope	The lowermost slope position where material moves generally through alluvial processes.



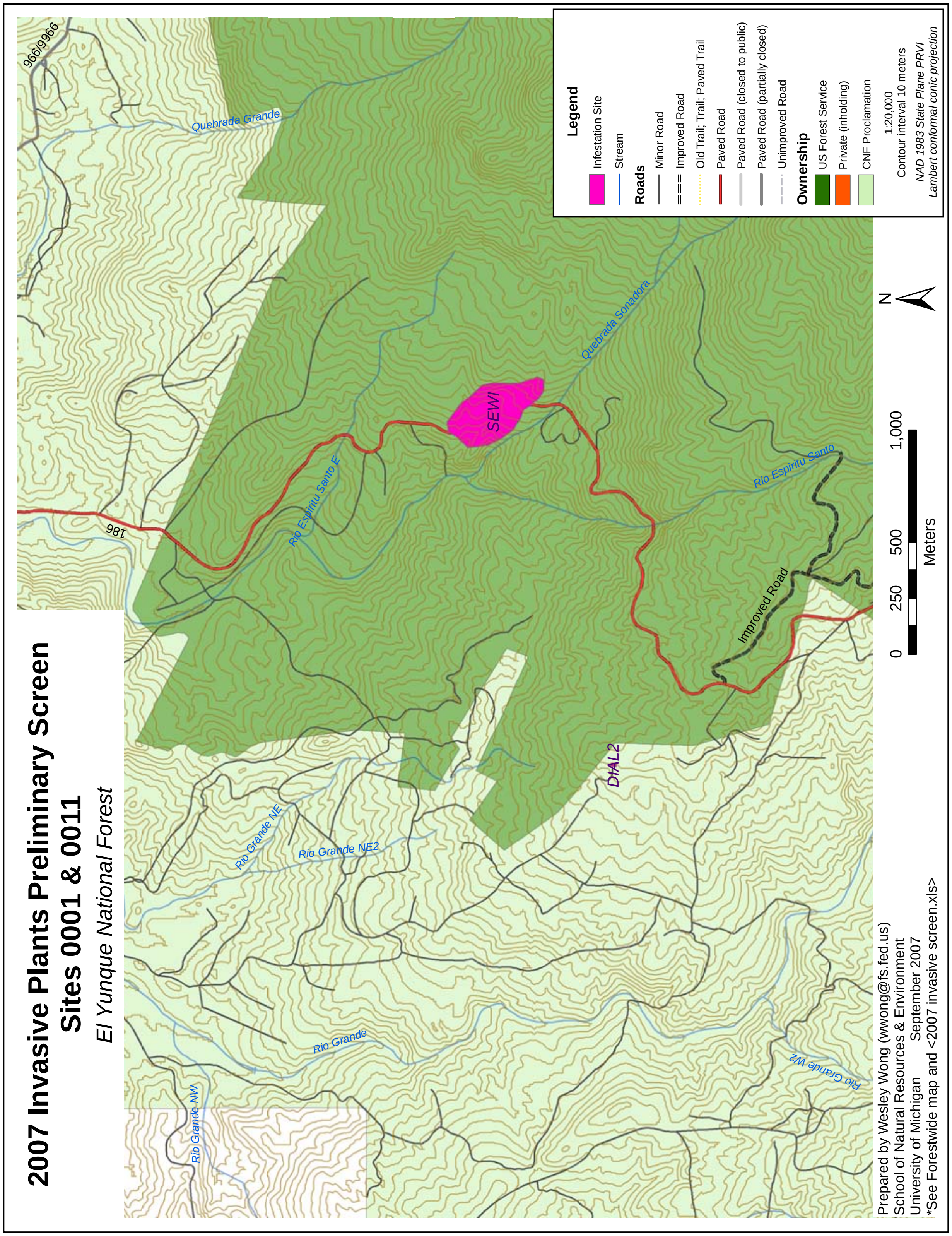


Area = ½ Base x Height

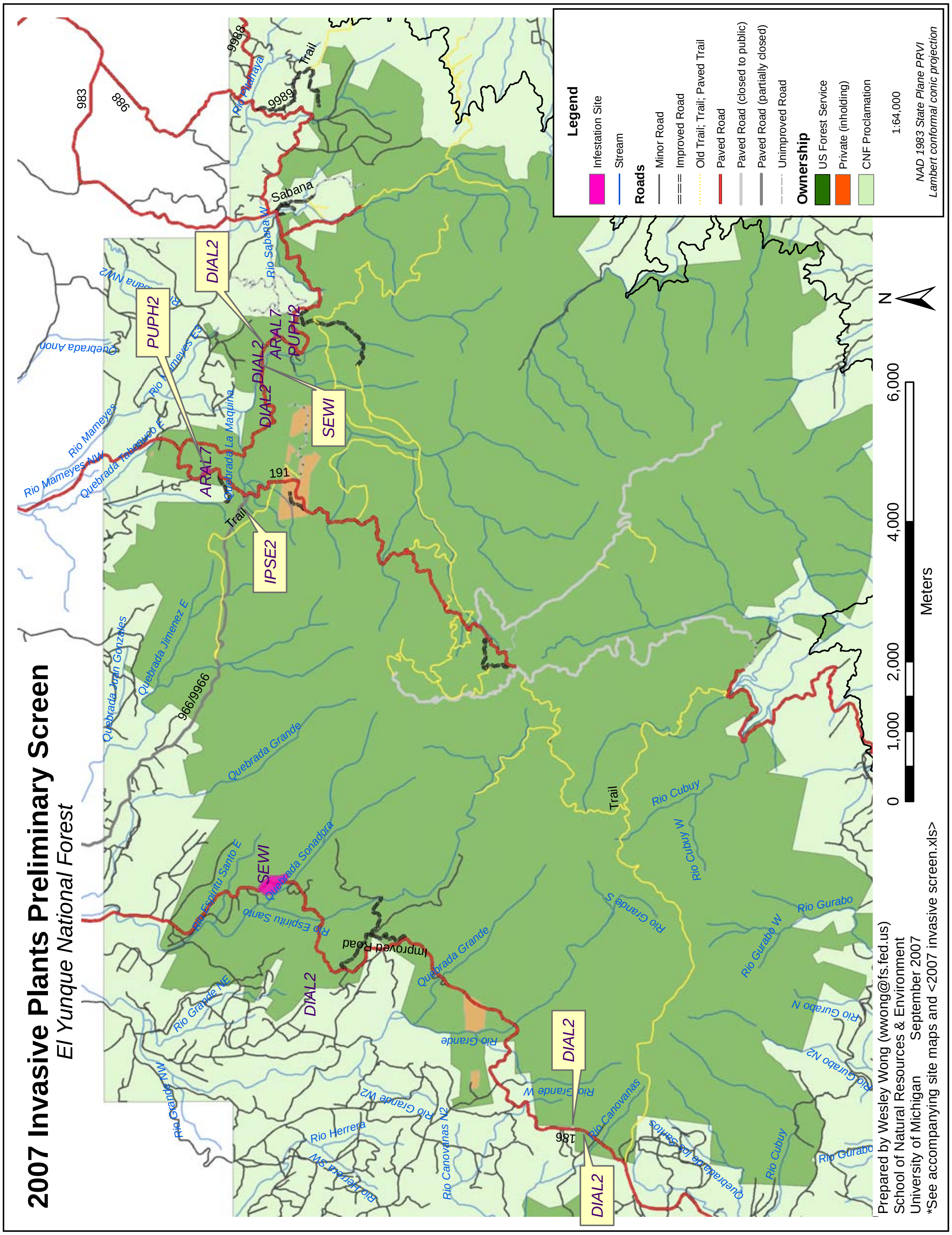


Area = Length x Height

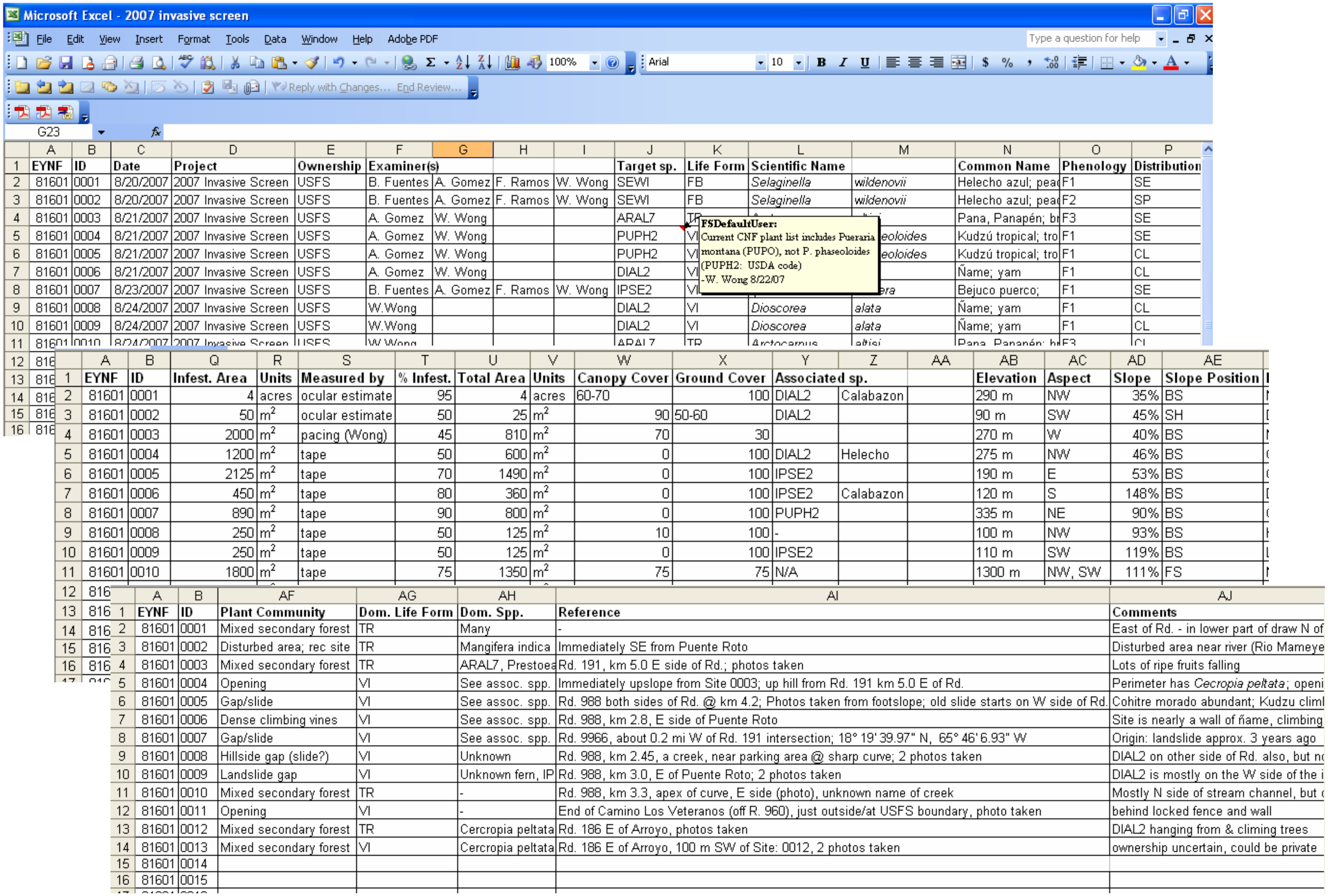
Appendix 4.3: Sample invasive species site map



Appendix 4.4: Forestwide invasive species mapping



Appendix 4.4: Screenshots of invasive species spreadsheet, can be migrated to national (NRIS) Natural Resources Information System.


Microsoft Excel - 2007 invasive screen

EYNF	ID	Date	Project	Ownership	Examiner(s)				Target sp.	Life Form	Scientific Name		Common Name	Phenology	Distribution
81601	0001	8/20/2007	2007 Invasive Screen	USFS	B. Fuentes	A. Gomez	F. Ramos	W. Wong	SEWI	FB	*Selaginella*	*wildenovii*	Helecho azul; pea	F1	SE
81601	0002	8/20/2007	2007 Invasive Screen	USFS	B. Fuentes	A. Gomez	F. Ramos	W. Wong	SEWI	FB	*Selaginella*	*wildenovii*	Helecho azul; pea	F2	SP
81601	0003	8/21/2007	2007 Invasive Screen	USFS	A. Gomez	W. Wong			ARAL7	TR			Pana, Panapén; b	F3	SE
81601	0004	8/21/2007	2007 Invasive Screen	USFS	A. Gomez	W. Wong			PUPH2	VI		*eoloides*	Kudzú tropical; tro	F1	SE
81601	0005	8/21/2007	2007 Invasive Screen	USFS	A. Gomez	W. Wong			PUPH2	VI		*eoloides*	Kudzú tropical; tro	F1	CL
81601	0006	8/21/2007	2007 Invasive Screen	USFS	A. Gomez	W. Wong			DIAL2	VI			Ñame; yam	F1	CL
81601	0007	8/23/2007	2007 Invasive Screen	USFS	B. Fuentes	A. Gomez	F. Ramos	W. Wong	IPSE2	VI		*era*	Bejuco puerco;	F1	SE
81601	0008	8/24/2007	2007 Invasive Screen	USFS	W.Wong				DIAL2	VI	*Dioscorea*	*alata*	Ñame; yam	F1	CL
81601	0009	8/24/2007	2007 Invasive Screen	USFS	W.Wong				DIAL2	VI	*Dioscorea*	*alata*	Ñame; yam	F1	CL
81601	0010	8/24/2007	2007 Invasive Screen	USFS	W.Wong				ARAL7	TR	*Artocarpus*	*altisi*	Pana, Panapén; b	F3	CL

FSDefaultUser:
Current CNF plant list includes Pueraria montana (PUPO), not P. phaseoloides (PUPH2: USDA code)
-W. Wong 8/22/07

EYNF	ID	Infest. Area	Units	Measured by	% Infest.	Total Area	Units	Canopy Cover	Ground Cover	Associated sp.			Elevation	Aspect	Slope	Slope Position
81601	0001	4	acres	ocular estimate	95	4	acres	60-70	100	DIAL2	Calabazon		290 m	NW	35%	BS
81601	0002	50	m^2	ocular estimate	50	25	m^2	90	50-60	DIAL2			90 m	SW	45%	SH
81601	0003	2000	m^2	pacing (Wong)	45	810	m^2	70	30				270 m	W	40%	BS
81601	0004	1200	m^2	tape	50	600	m^2	0	100	DIAL2	Helecho		275 m	NW	46%	BS
81601	0005	2125	m^2	tape	70	1490	m^2	0	100	IPSE2			190 m	E	53%	BS
81601	0006	450	m^2	tape	80	360	m^2	0	100	IPSE2	Calabazon		120 m	S	148%	BS
81601	0007	890	m^2	tape	90	800	m^2	0	100	PUPH2			335 m	NE	90%	BS
81601	0008	250	m^2	tape	50	125	m^2	10	100	-			100 m	NW	93%	BS
81601	0009	250	m^2	tape	50	125	m^2	0	100	IPSE2			110 m	SW	119%	BS
81601	0010	1800	m^2	tape	75	1350	m^2	75	75	N/A			1300 m	NW, SW	111%	FS

EYNF	ID	Plant Community	Dom. Life Form	Dom. Spp.	Reference	Comments
81601	0001	Mixed secondary forest	TR	Many	-	East of Rd. - in lower part of draw N of
81601	0002	Disturbed area; rec site	TR	Mangifera indica	Immediately SE from Puente Roto	Disturbed area near river (Rio Mameye
81601	0003	Mixed secondary forest	TR	ARAL7, Prestoea	Rd. 191, km 5.0 E side of Rd.; photos taken	Lots of ripe fruits falling
81601	0004	Opening	VI	See assoc. spp.	Immediately upslope from Site 0003; up hill from Rd. 191 km 5.0 E of Rd.	Perimeter has *Cecropia peltata*; openi
81601	0005	Gap/slide	VI	See assoc. spp.	Rd. 988 both sides of Rd. @ km 4.2; Photos taken from footslope; old slide starts on W side of Rd.	Cohitre morado abundant; Kudzu clim
81601	0006	Dense climbing vines	VI	See assoc. spp.	Rd. 988, km 2.8, E side of Puente Roto	Site is nearly a wall of ñame, climbing
81601	0007	Gap/slide	VI	See assoc. spp.	Rd. 9966, about 0.2 mi W of Rd. 191 intersection; 18° 19' 39.97" N, 65° 46' 6.93" W	Origin: landslide approx. 3 years ago
81601	0008	Hillside gap (slide?)	VI	Unknown	Rd. 988, km 2.45, a creek, near parking area @ sharp curve; 2 photos taken	DIAL2 on other side of Rd. also, but n
81601	0009	Landslide gap	VI	Unknown fern, IP	Rd. 988, km 3.0, E of Puente Roto; 2 photos taken	DIAL2 is mostly on the W side of the i
81601	0010	Mixed secondary forest	TR	-	Rd. 988, km 3.3, apex of curve, E side (photo), unknown name of creek	Mostly N side of stream channel, but
81601	0011	Opening	VI	-	End of Camino Los Veteranos (off R. 960), just outside/at USFS boundary, photo taken	behind locked fence and wall
81601	0012	Mixed secondary forest	TR	Cercropia peltata	Rd. 186 E of Arroyo, photos taken	DIAL2 hanging from & climing trees
81601	0013	Mixed secondary forest	VI	Cercropia peltata	Rd. 186 E of Arroyo, 100 m SW of Site: 0012, 2 photos taken	ownership uncertain, could be private
81601	0014					
81601	0015					