ACTA CIENTÍFICA

Una revista transdisciplinaria de Puerto Rico y el Caribe

VOL. 32(2), 2021

ISSN: 1940-1148

ACTA CIENTÍFICA
Una revista transdisciplinaria de Puerto Rico y el Caribe

VOL. 32(2), 2021
ISSN: 1940-1148

PORTADA

***Scolopendra subpinipes* depredando a *Osteopilus septentrionalis*.**

Los eventos de depredación en el campo ocurren rápidamente y en lugares (y horas) de difícil acceso para el observador, lo que pudiera explicar lo limitado de su documentación en la literatura científica; más raro aún son los eventos que involucra a un artrópodo y un anfibio. La foto tomada en la Laguna Cartagena (Lajas, suroeste de Puerto Rico) el 13 de febrero de 2021, a las 11:00 am, muestra a un subadulto (ca. ~6 cm de largo) de la Rana Cubana, *O. septentrionalis*, siendo devorada por el ciempiés *S. subpinipes* (~10–12 cm de largo) desde la rama de un Samán (*Samanea saman*) a ca. 6 m de altura (localización del árbol [WGS84]: 18.012525°, -67.108101°; 14 m s. n. m.). La rana aún conservaba su coloración natural en vida, ojos claros, y tejidos frescos, indicativo de haber sido capturada por el ciempiés poco antes de fotografiarla. Aunque en Puerto Rico se ha documentado la depredación de ranas (*Lithobates catesbeianus* o Sapo Toro) y sapos (*Rhinela marina* o Sapo Común) por ciempiés (a veces llamados alacranes en otras partes de la isla), la misma involucra al ciempiés gigante, *S. alternans*. Por el contrario, la interacción capturada en la foto representa el primer caso de depredación de un anfibio por el ciempiés *S. subpinipes* y el primer caso para la Rana Cubana, siendo depredada por un ciempiés, en toda su extensión geográfica en el Caribe y EE. UU. Todas las especies de ranas aquí mencionadas han sido introducidas en Puerto Rico al menos hace 70 años (algunas hace más de 160 años), y aunque son introducidas, esta interacción sugiere que ya han sido incorporadas localmente en los procesos ecológicos relacionados a ciclaje de nutrientes, carbono y energía por medio de relaciones presa-depredador.

Fotografiado por Neftalí Ríos López;
árbol identificado por Eugenio Santiago Valentín.

CONTENIDO

ACTA CIENTÍFICA

Una revista transdisciplinaria de Puerto Rico y el Caribe

EDITOR

Neftalí Ríos López
Universidad de Puerto Rico en Humacao
Call Box 860
Humacao, Puerto Rico 00792
neftali.rios@upr.edu

JUNTA EDITORIAL

Oscar J. Abelleira Martínez
Universidad de Puerto Rico,
Recinto Universitario de
Mayagüez, PR

Humfredo Marcano Vega
USDA-International Institute
of Tropical Forestry,
Río Piedras, PR

Amelia Merced Alejandro
USDA-International Institute
of Tropical Forestry,
Universidad de Puerto Rico,
Recinto Universitario de
Río Piedras, PR

Tamara Heartsill Scalley
USDA-International Institute
of Tropical Forestry,
Río Piedras, PR

Ernesto Medina
IVIC, USDA-International
Institute of Tropical Forestry,
Río Piedras, PR

Wilmer O. Rivera De Jesús
Escuela Secundaria
Universidad de Puerto Rico,
Recinto Universitario de
Río Piedras, PR

Tania López Marrero
Universidad de Puerto Rico,
Recinto Universitario de
Mayagüez, PR

Elvia J. Meléndez-Ackerman
Universidad de Puerto Rico,
Recinto Universitario de
Río Piedras, PR

Elsie Rivera Ocasio
Universidad de Puerto Rico,
Recinto Universitario de
Bayamón, PR

Ariel E. Lugo
USDA-International Institute
of Tropical Forestry,
Río Piedras, PR

Pablo A. Méndez Lázaro
Universidad de Puerto Rico,
Recinto Universitario de
Ciencias Médicas, PR

Minnuette Rodríguez Harrison
Escuela Especializada en
Ballet Julián E. Blanco,
Santurce, PR

Yaniria Sánchez de León
Universidad de Puerto Rico,
Recinto Universitario de
Mayagüez, PR

Mariangie Ramos Rodríguez
Universidad de Puerto Rico,
Recinto Universitario de
Utuado, PR

Pablo A. Llerandi Román
USDA-Forest Service
El Yunque National Forest,
Río Grande, PR

André R. Sanfiorenzo Gil de Lamadrid
Universidad de Puerto Rico,
Recinto Universitario de
Utuado, PR

DIRECTORIO

Editor en jefe: Neftalí Ríos López
Editor de producción: Pamela Navarro (pamelaapr@gmail.com)
Oficial administrativo: Shirley Prado Sanabria
Revisores de artículos: Alberto R. Puente Rolón, Ariel E. Lugo, Ernesto A. Medina,
Luis J. Villanueva, Neftalí Ríos López
Diseño y diagramación: Pascual Estrada (estrada.pascual@gmail.com)

ISSN: 1940-1148
Río Piedras, Puerto Rico

EDITORIAL

Este segundo número del volumen 32 de 2021 de *Acta Científica: Una revista transdisciplinaria de Puerto Rico y el Caribe* (*AC-PuR&C*) hace realidad el compromiso de publicación de dos números por año, así como proveer de una plataforma constante para la divulgación de contribuciones científicas de y fuera de Puerto Rico. Cuenta con trabajos de colegas científicos de Puerto Rico y Cuba, que suman seis autores que contribuyeron al mismo y los revisores, que sin su trabajo sería imposible esta publicación; nuestras más sinceras gracias a todos. Aquí se incluye contribuciones que cubren tópicos variados desde análisis de lluvia en el contexto de proyecciones de cambio climático para Puerto Rico, ecología de alimentación de ranas en Cuba, y un estudio sobre la influencia de la Rana Cubana sobre ranas nativas en el Caribe y los Estados Unidos.

Este volumen 32, con el que cerramos el año 2021, es posible gracias al servicio de nuestros colegas de Caracas, Venezuela, quienes proveen de la labor técnica y artística para la producción del mismo. La dirección, consejo, apoyo y contribución del Dr. Ariel Lugo a este volumen, así como del Servicio Forestal de los Estados Unidos de América, mantiene sobre ruedas el legado de *AC-PuR&C* y ante esto, ratifico mi más profundo agradecimiento.

Aprovecho para reiterar nuestra cordial invitación a todos los interesados en divulgar sus trabajos, que consideren a *AC-PuR&C* para estos fines y así, anuncio la disponibilidad para recibir sus manuscritos a la brevedad, de cara a la publicación durante el primer semestre, del próximo volumen 33 en el 2022. Gracias por el continuo apoyo a *Acta Científica: Una revista transdisciplinaria de Puerto Rico y el Caribe* durante más de tres décadas como foro de divulgación profesional. Los espero.

Neftalí Ríos López
Caguas, Puerto Rico

ANÁLISIS ESTADÍSTICOS DE LA LLUVIA PROMEDIO DIARIA EN PUERTO RICO ENTRE 1920-2020 NO REFLEJAN DISMINUCIONES EN LA PRECIPITACIÓN ANUAL EN LA MAYOR PARTE DE LA ISLA

Ferdinand Quiñones Márquez

PO Box 3387, Brentwood, TN 37024. Correo e: FQUINON@msn.com

RESUMEN

La precipitación en Puerto Rico es compleja e influenciada por la dinámica de los vientos alisios del este-noreste, corrientes oceánicas y efectos orográficos a nivel local; microclimas generados en respuesta a la microtopografía en zonas montañosas; la estacionalidad en los frentes de frío provenientes del noroeste; fenómenos climáticos tropicales como tormentas y huracanes de mayor magnitud e intensidad a nivel regional, entre otros. En este estudio, examino las tendencias en precipitación a largo plazo para determinar si existen tendencias a disminución o aumento en la precipitación que reflejen los escenarios proyectados de cambio climático para Puerto Rico. Para esto, utilicé datos de precipitación diaria de 41 estaciones meteorológicas existentes e históricas desde 1920 hasta 2020 y disponibles en los archivos de la Administración Nacional Oceánica y Atmosférica. Las estaciones fueron seleccionadas para representar las diversas zonas climáticas y regiones de Puerto Rico e incluir un mínimo de 40 años de datos de precipitación diaria, aunque la mayor parte excede 50 años de datos. Los valores de precipitación diaria se convirtieron en totales mensuales y anuales utilizando las funciones matemáticas de ©Microsoft Excel. Los procedimientos analíticos no-paramétricos estadísticos descritos por Mann (1945), Kendall (1975), y Sen (1968) se utilizaron para determinar las tendencias a largo plazo de la precipitación anual en cada una de las 41 estaciones. Los análisis reflejan que en 28 de las 41 estaciones, la tendencia en los totales anuales de precipitación es al aumento; 9 de estas muestran tendencias de aumento estadísticamente significativas. En las restantes 13 estaciones, hubo pendientes negativas y solo tres de estas mostraron tendencias a disminución estadísticamente significativa. De acuerdo con las tendencias descritas no ha ocurrido disminución en la precipitación registrada para la gran mayoría de las estaciones pluviométricas examinadas y, presumiblemente, tampoco en la mayoría de las estaciones operadas en la isla por el Servicio Meteorológico Nacional de los Estados Unidos. Discuto brevemente las implicaciones a las proyecciones de disminución en precipitación para Puerto Rico frecuentemente evocadas por agencias gubernamentales ante los escenarios propuestos de cambio climático.

Palabras clave disminución, escala, estable, lluvia, precipitación anual, tendencia.

ABSTRACT

The precipitation in Puerto Rico is complex and influenced by factors that include the dynamics of trade winds from the east-northeast, ocean currents, and local orographic effects; microclimatic conditions in response to microtopography throughout mountain ranges; seasonality of cold fronts from the northwest, and tropical climatic phenomena like storms and hurricanes of greater magnitude and intensity at regional scales, among others. In this study, I examined long-term trends in precipitation (rainfall) in Puerto Rico to determine trends indicative of declining or increasing precipitation in response to projected climatic change. To address this goal, I used daily precipitation data from 41 weather stations (existing and historical) operated by the U.S. National Weather Service with data from 1920 to 2020 and available from the National Oceanic and Atmospheric Administration (NOAA) archives. The stations were selected to represent the various climatic zones and regions in Puerto Rico and to include a minimum of 50 years of daily rainfall data. The data values were converted to monthly and annual totals utilizing the pivot functions of ©Microsoft Excel. The analytical non-parametric statistical procedures described by Mann (1945), Kendall (1975), and Sen (1968) were used to determine the long-term statistical trends of the annual rainfall at each of the 41 stations. The analyzes show that in 28 of the 41 stations, the trend in the annual rainfall total is increasing; 9 of these have a statistically significant trend. The remaining 13 stations show a decreasing trend in total annual rainfall, and only 3 showed a statistically significant trend. Based on these results, there is no evidence of a generalized decrease in annual rainfall totals from 1920 to present in the vast majority of the stations examined and, presumably, neither in most of the weather stations operated on the island by the U.S. National Weather Service. I discuss the implications of these results for effective management and corresponding decision-making process by local governmental agencies to projected climatic-change scenarios.

Keywords annual precipitation, decrease, rainfall, scale, stable, tendency.

INTRODUCCIÓN Y PROPÓSITO

Puerto Rico (PR) y sus islas adyacentes disfrutan de precipitación abundante la mayor parte de los años. El Servicio Nacional de Meteorología (NWS, por sus siglas en inglés; datos accesibles en https://www.ncdc.noaa.gov/cdo-web/datatools/selectlocation) genera datos de precipitación histórica e ilustra que el promedio normal de lluvia en PR (promedio de las décadas de 1990 a 2010; Figura 1) es de ~69 pulgadas anuales (1,752.6 mm). Igualmente, en las islas de Vieques y Culebra e Isla de Mona, estos promedios anuales normales son de 52 (1,320.8 mm), 37 (939.8 mm) y 40 pulgadas (1,016.0 mm) respectivamente (áreas que no se incluyen en el presente estudio). A consecuencia de los efectos del cambio climático a nivel mundial, se ha postulado en varios foros en PR que la cantidad de precipitación en la isla ha mermado, y se proyectan reducciones significativas en el promedio anual de lluvia con efectos adversos severos sobre la flora y fauna y el medioambiente general en la isla (Puerto Rico Climate Change Council [PRCCC] 2013; Walsh-Russo 2018; Khalyani et al. 2016; Runkle et al. 2018; Murry et al. 2019; Gould et al. 2020). No obstante, las conclusiones y predicciones de mermas en la lluvia en Puerto Rico no han sido sustentadas con datos fehacientes del historial de las precipitaciones en la isla y su vecindad.

Análisis preliminares anteriores a este escrito documentan que el promedio de precipitación anual promedio en todo PR no ha disminuido desde 1900 hasta el 2020 (Figura 1, derivada de los datos de la Administración Nacional Oceánica y Atmosférica [NOAA] y del NWS). La figura ilustra la precipitación promedio anual en la isla entre el 1900 al 2020 e incluye una curva de tendencia de 35 años consecutivos, la cual establece que el promedio de precipitación para toda la isla en el 2020 es de 69 pulgadas (1,752.6 mm). Además, los datos en esta la figura son indicativos de sequías moderadas y severas periódicas (representadas en barras rojas con valores menores de 60 pulgadas [1,524 mm] en el año). A pesar de estas sequías periódicas, el promedio anual de lluvia a largo plazo no ha mermado para el período de análisis. Aunque estos datos anuales promedios para todo PR son fehacientes, existe el potencial de que, debido a microclimas en sectores de la isla, en algunas zonas ocurren mermas o aumentos en la precipitación-promedio anual durante el periodo examinado.

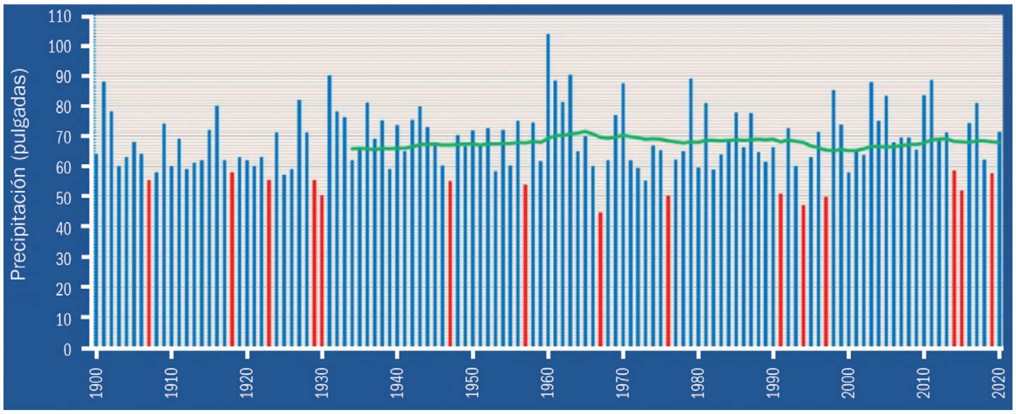


Figura 1. Precipitación promedio anual en Puerto Rico desde el 1900 al 2020 (datos del National Weather Service). Las columnas en azul representan años con precipitación dentro del rango esperado; las columnas en rojo representan años cuya precipitación es menor a la esperada; la línea verde al tope de las columnas representa el Promedio Móvil a intervalo de 35 años.

Afortunadamente, se dispone de suficiente cantidad de datos de precipitación diaria histórica en PR que permiten evaluar con certeza estadística las tendencias en estaciones individuales que reflejan los patrones climáticos en su vecindad y en toda la isla. Por ejemplo, el NWS ha operado redes de pluviómetros a través de toda la isla desde el 1898 con los primeros pluviómetros instalados y en operación en las estaciones experimentales de Lajas, Isabela, Aguirre y Río Piedras. Luego de 1915, se expandió la red de pluviómetros a través de la isla, incluyendo estaciones en Isla de Mona, Vieques y Culebra (en la Figura 2 se ilustra la ubicación general de todas las estaciones operadas por el NWS históricamente y para las cuales existen archivos de precipitación diaria).

Los archivos de NOAA incluyen datos de 216 estaciones, aunque muchos para un periodo corto. En muchas de estas estaciones también se mide o medía la temperatura máxima y mínima, la evaporación (*pan evaporation*) y la velocidad del viento. No obstante, en el presente estudio solamente enfoco en el análisis de la precipitación diaria en cada estación evaluada, y sumada para producir el total de lluvia en pulgadas (seguido en milímetros entre paréntesis) observadas durante cada año de datos.

MÉTODOS Y PROCEDIMIENTOS

Documentación de datos

Los datos de precipitación diaria utilizados en los análisis fueron obtenidos del portal de NOAA (https://www.ncdc.noaa.gov/cdo-web/datatools/selectlocation). Los archivos en este portal contienen datos diarios de la cantidad de precipitación documentada en las estaciones operadas por el NWS en Puerto Rico desde el 1898 hasta el presente. Inicialmente, y hasta mediados de los 70, la cantidad de precipitación diaria era documentada manualmente en el colector de cada pluviómetro. Por ejemplo, en las estaciones ubicadas en instalaciones federales o del gobierno de PR, empleados de las entidades pertinentes medían

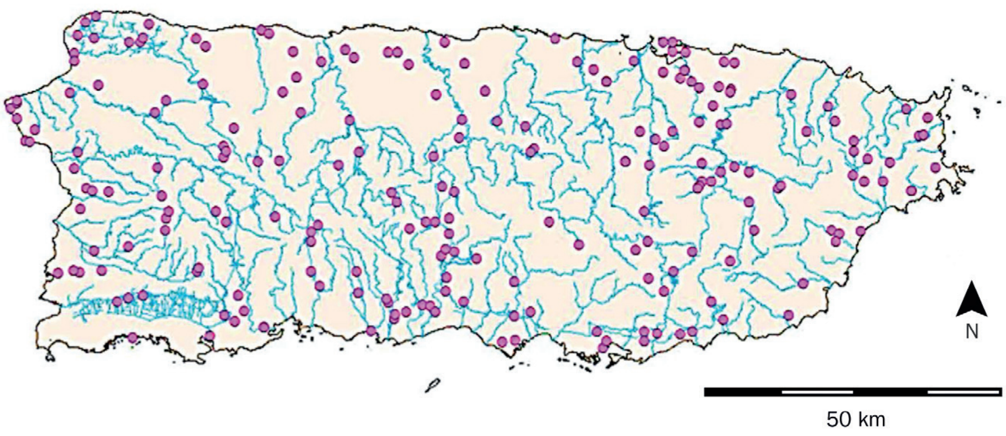


Figura 2. Red de estaciones pluviométricas en Puerto Rico operadas por el Servicio Nacional de Meteorología comenzando en 1898 y parcialmente utilizadas para los análisis de tendencias estadísticas históricas (datos de NOAA).

diariamente la cantidad de precipitación de las 24 horas anteriores. Estos valores se anotaban en libretas que se mantenían en cada instalación o lugar. En el caso de que los pluviómetros ubicaran fuera de las instalaciones federales, un observador voluntario o contratado por el NWS llevaba a cabo las medidas de precipitación y mantenimiento de las estaciones, anotando en libretas del NWS la cantidad de lluvia diaria. Generalmente cada mes, los representantes del NWS visitaban los sitios donde ubicaban los pluviómetros fuera de instalaciones federales y recobraban las libretas con los datos del mes anterior. Los datos eran recopilados por empleados del NWS en archivos manuales, manteniendo la libreta original en sus facilidades.

Eventualmente, en la década de 1970, el NWS comenzó a crear archivos electrónicos de los datos hasta la actualidad y a base de pluviómetros digitales instalados que permiten extraer datos directamente a estos archivos. Luego, NOAA desarrolló un programa para digitalizar los datos originales transferidos de los diarios y libretas de anotaciones, así como datos recolectados electrónicamente desde mediados de los 70, y almacenarlos en un archivo electrónico central (*Climate Data On Line*) disponibles en su portal https://www.ncdc.noaa.gov/cdo-web/.

Manejo inicial de datos para análisis

El siguiente procedimiento fue utilizado en la evaluación y ordenamiento de los datos previo a llevar a cabo los análisis estadísticos utilizando los métodos estadísticos no-paramétricos de Mann (1945) y Kendall (1975) (en adelante Mann-Kendall) y Sen (1968).

1. Los datos disponibles de precipitación diaria en las estaciones seleccionadas para los análisis estadísticos fueron extraídos del portal de NOAA, y descargados en forma de matrices en ©Microsoft Excel (en adelante, Excel).
2. Los datos de precipitación total diaria fueron convertidos a totales mensuales y anuales en matrices, de modo que el producto final fuera una tabla de los promedios anuales de lluvia durante el período de datos de cada estación (*Pivot Table*).
3. Los datos anuales fueron evaluados en acuerdo con los procedimientos descritos por Mann (1945), Kendall (1975) y Sen (1968) (como ejemplo, véase también a Gocic y Trajkovic 2013 y Kamal and Pachauri 2019) para determinar con certeza estadística las tendencias a largo plazo en la cantidad de precipitación anual en cada estación incluida en el análisis.
4. Cada archivo fue inspeccionado detalladamente para identificar la continuidad de los datos y errores potenciales en las transferencias manuales.
5. En aproximadamente el 0.5 % de cada archivo se omitieron anotaciones diarias sin explicaciones que aclararan si las ausencias de datos reflejaban que no había llovido en las 24 horas anteriores. En estos casos se asumió que no había llovido el día pertinente. Por tanto, al asumir que no ocurrió lluvia en los días sin datos y debido al bajo porcentaje de omisión de datos, considero como insignificantes su contribución a los valores de promedios mensuales y anuales en los análisis subsiguientes.
6. Los archivos también incluyen el número de días totales representado por el valor acumulativo anotado. No obstante, algunos de estos archivos reflejan entradas de precipitación acumulativa de varios días, particularmente durante los fines de semanas, pero representando menos del 0.5% de los días totales en el archivo. Dado que el objetivo en el presente estudio es calcular la cantidad de precipitación mensual y luego anual en cada estación analizada, no es necesario realizar correcciones de la precipitación registrada acumulativa. El método de Sen (1968) y Kendall (1975) requiere las tendencias de precipitación anuales y son estas las consideradas en los análisis estadísticos del presente estudio.
7. Finalmente, en las instancias en que los datos de una estación cesan por un período mayor de 30 días (lo cual ocurre en cerca del 10% de los archivos examinados), la evaluación excluyó el año incompleto. Los

Figura 3. Estaciones pluviométricas operadas en Puerto Rico por el Servicio Nacional de Meteorología con datos de lluvia, entre 1920 al 2020, utilizados en los análisis de tendencias a largo plazo (n = 41 estaciones).

análisis que utilizan los métodos de Sen y Kendall permiten excluir períodos relativamente cortos de datos y aunque esto pudiera reducir el número de años de datos, en todas las estaciones seleccionadas para los análisis de tendencias cumplen con el requisito de un mínimo de 40 años de datos, aunque la mayor parte excede los 50 años de datos. En la Figura 3 se ilustra las estaciones pluviométricas utilizadas en los análisis en este estudio.

Red de estaciones pluviométricas utilizada en los análisis y resumen de datos disponibles

En la Tabla 1 se incluye el nombre en los archivos de NOAA y la ubicación de cada estación (coordenadas en unidades decimales), así como un resumen del período de años de datos disponibles para cada una. Con base en estos archivos, escogí 41 estaciones con un mínimo de 40 años consecutivos de datos de precipitación (aunque se evaluaron datos de 60 estaciones, muchas de las estaciones en los archivos de NOAA representan períodos menores de 40 años, así como datos incompletos; ver sección anterior "Manejo inicial de datos para análisis").

Procedimientos analíticos utilizados en el examen de tendencias en la precipitación anual sobre Puerto Rico

Los análisis de tendencias estadísticas permiten detectar cambios, incluyendo aquellos estadísticamente significativos, en el tiempo para un parámetro dado; estos análisis pueden estar fundamentados en métodos o técnicas paramétricas y no-paramétricas (véase además a Hoskin, sin fechar). En estadística, los procedimientos paramétricos requieren el cumplimiento de ciertos supuestos a base de la forma de la distribución del parámetro de interés (ejemplo, distribución normal), así como la forma de la curva de distribución (ejemplo, la media y la desviación estándar) entre otras. En comparación, los métodos no-paramétricos se fundamentan en análisis a partir de una ordenación en rangos de los datos originales y así, requiere el cumplimiento de menos supuestos relativo a la forma de la distribución o de los parámetros en la muestra basado en los datos crudos (ej., sin la conversión en rangos). En ambos procedimientos estadísticos el objetivo es determinar si existe una tendencia significativa en los cambios observados en las muestras o valores a través del tiempo. Existen varios procedimientos para determinar si una tendencia en el tiempo de un parámetro es estadísticamente significativa.

En el caso de datos hidro-climáticos como la precipitación, uno de los métodos utilizados para determinar si existen tendencias en su magnitud (reducciones o aumentos) es el procedimiento de Mann-Kendall en combinación con el método de Sen (ambos no-paramétricos) para examinar la magnitud del cambio en las tendencias resultantes (véase también a Kampata et al. 2008; Modarres y Sarhadi 2009; Xu et al. 2010; Gocic y Trajkovic 2013; Ahmad et al. 2015; Hussain et al.

Tabla 1. Nombre (seguido del municipio donde ubica, cuando aplique; nombres según el Servicio Nacional de Metereología en Puerto Rico) de las 41 estaciones pluviométricas seleccionadas, así como el período de datos de la precipitación anual examinado y localización (latitud y longitud) de la misma.

Nombre	Período	Latitud	Longitud
ADJUNTAS SUBSTATION, US	1970-2019	18.1747	-66.7977
AGUIRRE, US (Salinas)	1970-2019	17.9555	-66.2222
AIBONITO 1 S, US	1931-2020	18.1280	-66.2641
BORINQUEN AIRPORT, US (Aguadilla)	1942-2013	18.4977	-67.1294
CALERO CAMP, US (Aguadilla)	1955-2019	18.4724	-67.1155
CANOVANAS, US	1955-2013	18.3791	-65.8938
CAYEY 1 E, US	1955-2015	18.1188	-66.1658
CERRO MARAVILLA, US (Jayuya)	1969-2012	18.1547	-66.5619
COLOSO, US (Aguada)	1920-2019	18.3808	-67.1569
COROZAL SUBSTATION, US	1931-2012	18.3266	-66.3591
DORADO 2 WNW, US	1931-2019	18.4722	-66.3056
DOS BOCAS, US (Utuado)	1937-2019	18.3361	-66.6666
ENSENADA 1 W, US (Guánica)	1955-2018	17.9754	-66.9113
GUAJATACA DAM, US (Isabela)	1955-2019	18.3963	-66.9244
GUAYAMA 2 E, US	1941-2018	17.9783	-66.0874
GUAYANILLA, US	1955-2012	18.0000	-66.8667
GURABO, US	1956-2019	18.2500	-65.9667
ISABELA SUBSTATION, US	1940-2020	18.4652	-67.0525
JUANA DIAZ CAMP, US	1931-2019	18.0513	-66.4986
JUNCOS 1 SE, US	1935-2019	18.2264	-65.9114
LAJAS SUBSTATION, US	1947-2019	18.0330	-67.0722
MAGUEYES ISLAND, US (Lajas)	1959-2019	17.9722	-67.0461
MANATI 2 E, US	1955-2018	18.4308	-66.4661
MARICAO FISH HATCHERY, US	1955-2019	18.1725	-66.9872
MAUNABO, US	1923-2002	18.0094	-65.8989
MAYAGUEZ CITY, US	1920-2019	18.1875	-67.1377
MOROVIS 1 N, US	1956-2019	18.3344	-66.4078
PARAISO, US (Naguabo)	1956-2019	18.2650	-65.7208
PENUELAS 1 E, US	1972-2020	18.0585	-66.7184
PONCE 4 E, US	1931-2019	18.0258	-66.5252
RINCON, US	1958-2020	18.3375	-67.2497
RÍO BLANCO LOWER, US (Naguabo)	1956-2020	18.2426	-65.7849
RÍO PIEDRAS EXPERIMENTAL STATION, US (San Juan)	1959-2019	18.3905	-66.0541
ROOSEVELT ROADS, US (Ceiba)	1958-2020	18.2552	-65.6411
SABANA GRANDE 2 ENE, US	1978-2019	18.0888	-66.9300
SAN JUAN L M MARIN INTERNATIONAL AIRPORT, US	1956-2019	18.4325	-66.0108
SAN LORENZO 3 S, US	1969-2018	18.1517	-65.9589
TRUJILLO ALTO 2 SSW, US	1968-2019	18.3283	-66.0163
UTUADO, US	1936-2020	18.2617	-66.6864
VILLABA 1 SE, US	1955-2020	18.1094	-66.5055
YAUCO 1 S, US	1955-2016	18.0167	-66.8500

2015). El método de Mann-Kendall permite comparar la hipótesis nula (no cambio) con la hipótesis alterna de aumentos o disminuciones significativas en la tendencia en el tiempo de los datos evaluados. Este método permite evaluar si el parámetro de interés aumenta o disminuye en el tiempo, utilizando una regresión no-paramétrica, y comparando la diferencia matemática entre valores más recientes del parámetro de interés con valores anteriores (por ejemplo, véase a Gao et al. 2020). Cada valor más reciente es comparado con todos los valores anteriores, resultando en una distribución total de "n(n-1)/2" posibles parejas de comparaciones (siendo "n" el número total de observaciones).

En la aplicación del método de Mann-Kendall se computa la diferencia entre el valor más reciente contra todos los valores evaluados anteriormente $(j_{j\text{-}yi})$, dónde j > i. En los cálculos se asignan los valores íntegros de +1, 0 o -1 a las diferencias positivas, no-diferencias, y diferencias negativas, respectivamente. El valor estadístico resultante se define como "S", el cual se calcula como la suma de los íntegros obtenidos utilizando la siguiente fórmula:

$$S = \sum_{i=1}^{n-1} \sum_{i=i+1}^{n} \text{sign}(yj\text{-}yi),$$

donde sign(yj-yi), es igual a +1, 0 o -1 cómo se indicó anteriormente. Cuando el valor de S es un número positivo "grande", los valores medidos posteriormente tienden a ser mayores que los anteriores, resultando en una tendencia ascendente. Si el valor de S es un número negativo "grande", los valores calculados posteriormente tienden a ser de menor magnitud, resultando en una tendencia descendente. Si el valor de S es pequeño –alrededor de 0– sugiere una falta de tendencia.

La estadística T siguiente se computa como parte del proceso de prueba de los cálculos de las tendencias:

$$T = S/((n(n\text{-}1)/2).$$

Este parámetro varía entre -1 a + 1, y es análogo al coeficiente de correlación en análisis comunes de regresiones matemáticas. La hipótesis nula de que no existe una tendencia significativa se rechaza cuando los valores de S y T son significativamente diferentes de cero. Cuando los datos exhiben una tendencia significativa, la tasa de cambio en la tendencia puede ser calculada mediante la siguiente ecuación de Sen (Helsen y Hirsch 1992):

$$B1 = \text{Mediana } S/((y_j\text{-}y_i)/(x_j\text{-}x_i)),$$

para todos los valores de $i < j$ y $i = 1, 2, \ldots, n\text{-}1$, y $j = 2, 3, \ldots, n$. Este cálculo resulta en la pendiente de todos los pares de datos que se utilizaron para computar el valor de S. La mediana de estas pendientes representa la pendiente promedio de Sen (vea también a Gocic y Trajkovic 2013).

El método Mann-Kendall entonces permite que falten valores en la serie analizada sin invalidar su aplicabilidad, y asume que cualquier valor puede ser mayor, menor, o igual que otros valores, que los datos son independientes y que la distribución de los datos es constante en las unidades originales o transformadas (Helsen and Hirch 1992). El procedimiento es aplicable, por tanto, a datos de diversos tipos de parámetros, incluyendo la precipitación.

El procedimiento para aplicar el método de Mann-Kendall consiste en los siguientes pasos:

1. Organizar los datos a ser evaluados en una matriz.
2. Calcular los promedios de precipitación anuales utilizando los datos obtenidos de NOAA. Excel provee un protocolo interno para desarrollar “pivots” (tablas) donde los datos diarios de precipitación (o el parámetro pertinente) son convertidos a totales mensuales, y estos a su vez agregados en una matriz de totales anuales para el período de récord.
3. Activar el protocolo de “Makesens 1.0” (Salmi et al. 2002) para análisis en forma automática y simple. Este protocolo estadístico “Makesens 1.0” es publicado por el Instituto Meteorológico de Finlandia, disponible en el siguiente enlace: https://en.ilmatieteenlaitos.fi/makesens.
4. El protocolo computa la diferencia entre el último valor medido “y_j”, y cada uno de los valores anteriores (“y_j-y_i”), donde “$j > 1$”, desarrollando gráficas simples de la tendencia en los valores para el período de datos evaluados.
5. El protocolo de Makesens también incluye un módulo para calcular en Excel las pendientes de las curvas anuales obtenidas en el proceso, referidas como *Sen's Slope Estimates* (Kamal and Pachauri 2019; Sen 1968). Las tendencias calculadas con el estimado de Senn se basan en la mediana de pares de datos de una pendiente (en este estudio, la pendiente de la curva entre datos de precipitación de dos años consecutivos) y genera intervalos de confianza para examinar la tendencia, a largo plazo, en una serie de datos en tiempo (Sen 1968). Este estimado no es sensitivo a un valor extremo en un año dado (*outliers*) ni a la no-normalidad en la distribución de los datos, lo que hace del estimado uno más robusto comparado con el de una regresión simple de valores exponenciales mínimos (*least squares*) (Senn 1968). Las pendientes de las curvas de datos anuales se utilizan para definir tendencias en series univariadas como es la cantidad de precipitación anual.
6. Finalmente, el método de Mann-Kendall permite evaluar tendencias en una serie de datos en tiempo, como la precipitación anual, de manera más precisa y el resultado de su aplicación incluye la significancia de la pendiente calculada y permite generar una gráfica relativamente simple ilustrando la tendencia en tiempo de los valores analizados.

Resultados

Las tendencias en precipitación de entre 41 estaciones pluviométricas examinadas muestran que en la mayoría de las estaciones, la precipitación aumentó a través de PR. Específicamente, hubo tendencias a aumento en precipitación en 28 de las 41 estaciones pluviométricas analizadas mediante el protocolo de Mann-Kendall (Figura 4 y Tabla 2; Apéndice 1). En nueve (9) de estas estaciones la tendencia fue estadísticamente significativa (Tabla 2). Por el contrario, hubo tendencias a disminución en precipita-

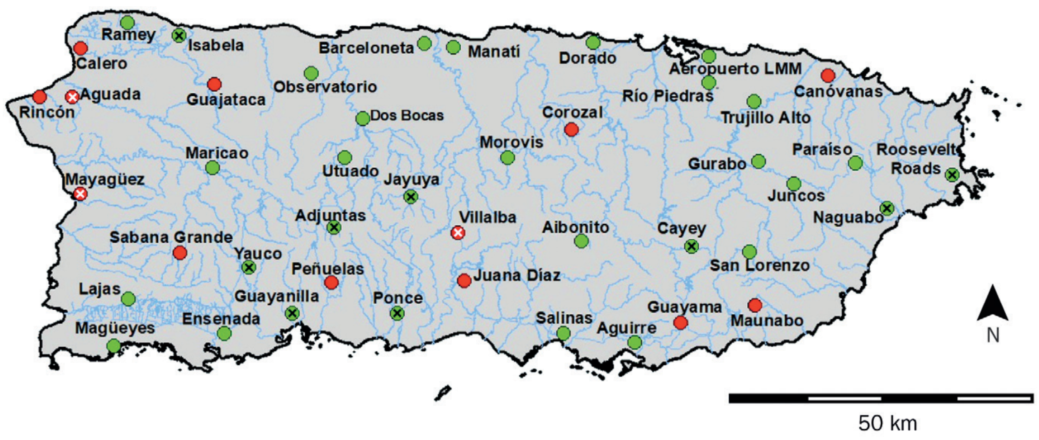


Figura 4. Estaciones pluviales (círculos) en Puerto Rico donde se detectó tendencias a aumento en lluvia total annual (círculos de color verde; n = 28) o disminución (círculos de color rojo; n = 13). Las cruces “×” dentro de los círculos indican tendencias significativas a aumentos (cruces de color negro dentro de círculos verdes; n = 9) o a disminución (cruces de color blanco dentro de círculos rojos; n = 3) detalladas en la Tabla 2.

ción en 13 estaciones, de las cuales solo 3 resultaron con tendencias estadísticamente significativas. No se observó un patrón claro en la distribución de las tendencias obtenidas entre zonas costeras y montañosas, ni en puntos cardinales en Puerto Rico (Figura 4 y Tabla 2).

DISCUSIÓN

Los resultados de los análisis estadísticos de datos de lluvia desde el 1920 hasta el 2020 reflejan tendencias de aumento en la lluvia promedio anual en el 68.3% (28/41) de las estaciones pluviométricas en PR operadas históricamente por el NWS. Esto contrasta con proyecciones de lluvia generadas con los modelos regionales a nivel del Caribe (por ejemplo, Intergovernmental Panel on Climate Change [IPCC] 2007:11), lo que tiene implicaciones para acciones de manejo del recurso agua en PR ante futuros escenarios de desertificación o disminuciones en precipitación a nivel isla. Aunque existen estudios que sugieren que la precipitación disminuye en PR (mayormente en zonas costeras), opino que las interpretaciones a base de proyecciones (extrapolaciones) de modelos climáticos globales para ser utilizados para la toma de decisiones a nivel local, no es adecuado. Lo anterior, debido a que estos modelos globales no representan la realidad física a escalas espaciales más pequeñas como en el caso de Puerto Rico, y no consideran una serie de factores climáticos y físicos que afectan la cantidad de precipitación según cambia la escala de observación. Por ejemplo, la precipitación en Puerto Rico está influenciada por la dinámicas de los vientos alisios del este-noreste, corrientes oceánicas y efectos orográficos a nivel local; microclimas generados en respuesta a la microtopografía en zonas montañosas; la estacionalidad en los frentes de frío provenientes del noroeste; fenómenos climáticos tropicales como tormentas y huracanes de mayor magnitud e intensidad a nivel regional, entre otros. Por tanto, el caso de PR es un ejemplo típico donde no es posible predecir el clima de islas relativamente de menor tamaño cuando utilizamos modelos globales o regionales para predecir dinámicas climáticas. La aplicabilidad de estos modelos regionales a islas pequeñas como PR depende de la interacción de múltiples factores que varían según la escala de observación, factores que la resolución de los modelos climáticos no suele incluir.

No existen dudas de que el cambio climático está ocurriendo a nivel global y que en PR y su vecindad una manifestación de éste durante el pasado siglo es el aumento en nivel del mar en zonas costeras y la temperatura del aire en la superficie de la isla. No obstante, aclaro que del presente análisis y descripción de las tendencias de precipitación anuales históricas en PR se refleja, sin muchas dudas, que la precipitación anual no ha disminuido desde el 1920 hasta el 2020 en la mayor parte de las zonas de la isla. Por tanto, las agencias concernidas y responsables de ejecutar acciones proactivas ante las proyecciones de cambio climático frecuentemente referidas para PR (por ejemplo Kalnay and Cai 2003; Runkle et al. 2018) tienen que considerar la aplicabilidad de los modelos y sus supuestos globales/regionales en los procesos internos de toma de decisiones para su aplicabilidad a nivel local.

Tabla 2. Tendencia en la cantidad de lluvia promedio anual detectada en las estaciones pluviométricas seleccionadas. Período analizado seguido por la cantidad de años con datos para análisis (n, en paréntesis). Senn = pendiente estimada; M-K stat. = estadística Mann-Kendall; Valor-Z de M-K stat.; P = significancia del Valor-Z; nivel de significancia (α) 0.10 y 0.05, donde * = significativo (tendencia en función de Senn; parámetros en negrilla), – = no significativo (hipótesis nula).

Nombre de la estación (municipalidad)	Período (n)	Senn	M-K stat.	Valor-Z	P	α	
						0.10	0.05
Tendencia: Aumento							
CAYEY 1 E, US	1955-2015 (61)	0.391	496	3.080	0.0021	*	*
CERRO MARAVILLA, US (Jayuya)	1969-2012 (44)	0.488	196	1.972	0.0486	*	*
GUAYANILLA, US	1955-2012 (58)	0.181	301	2.012	0.0442	*	*
PONCE 4 E, US	1931-2019 (83)	0.116	536	2.104	0.0354	*	*
ROOSEVELT ROADS, US (Ceiba)	1958-2020 (62)	0.296	360	2.181	0.0292	*	*
ADJUNTAS SUBSTATION, US	1970-2019 (50)	0.240	213	1.773	0.0762	*	–
ISABELA SUBSTATION, US	1940-2020 (81)	0.103	460	1.872	0.0612	*	–
RÍO BLANCO LOWER, US (Naguabo)	1956-2020 (65)	0.284	310	1.749	0.0802	*	–
YAUCO 1 S, US	1955-2016 (57)	0.187	282	1.934	0.0531	*	–
Tendencia: Disminución							
MAYAGUEZ CITY, US	1920-2019 (100)	-0.108	-867	-2.579	0.0099	*	*
VILLABA 1 SE, US	1955-2020 (66)	-0.253	-392	-2.164	0.0305	*	*
COLOSO, US (Aguada)	1920-2019 (100)	-0.065	-618	-1.837	0.0661	*	–
No tendencia							
AGUIRRE, US (Salinas)	1970-2019 (50)	0.066	91	0.753	0.4515	–	–
AIBONITO 1 S, US	1931-2020 (69)	0.143	278	1.435	0.1514	–	–
BORINQUEN AIRPORT, US (Aguadilla)	1942-2013 (67)	0.085	215	1.158	0.2468	–	–
DORADO 2 WNW, US	1931-2019 (89)	0.117	133	0.985	0.3247	–	–
DOS BOCAS, US (Utuado)	1937-2019 (83)	0.033	129	0.503	0.6147	–	–
ENSENADA 1 W, US (Guánica)	1955-2018 (64)	0.105	259	1.495	0.1350	–	–
GURABO, US	1956-2019 (64)	0.002	4	0.017	0.9861	–	–
JUNCOS 1 SE, US	1935-2019 (82)	0.082	305	1.217	0.2235	–	–
LAJAS SUBSTATION, US	1947-2019 (72)	0.056	195	0.943	0.3456	–	–
MAGUEYES ISLAND, US (Lajas)	1959-2019 (61)	0.074	157	0.971	0.3317	–	–
MANATI 2 E, US	1955-2018 (64)	0.103	136	0.782	0.4341	–	–
MARICAO FISH HATCHERY, US	1955-2019 (61)	0.090	152	0.940	0.3474	–	–
MOROVIS 1 N, US	1956-2019 (64)	0.162	188	1.083	0.2786	–	–
PARAISO, US (Naguabo)	1956-2019 (64)	0.243	280	1.616	0.1060	–	–
RIO PIEDRAS EXPERIMENTAL STATION, US (San Juan)	1959-2019 (60)	0.122	208	1.320	0.1868	–	–
SAN JUAN L M MARIN INTERNATIONAL AIRPORT, US	1956-2019 (64)	0.110	216	1.246	0.2129	–	–
SAN LORENZO 3 S, US	1969-2018 (50)	0.151	111	0.920	0.3575	–	–
TRUJILLO ALTO 2 SSW, US	1968-2019 (52)	0.162	102	0.797	0.4254	–	–
UTUADO, US	1936-2020 (77)	0.072	241	1.056	0.2911	–	–
CALERO CAMP, US (Aguadilla)	1955-2019 (65)	-0.018	-52	-0.289	0.7728	–	–
CANOVANAS, US	1955-2013 (59)	-0.001	-7	-0.039	0.9687	–	–
COROZAL SUBSTATION, US	1931-2012 (79)	-0.027	-95	-0.398	0.6907	–	–
GUAJATACA DAM, US (Isabela)	1955-2019 (65)	-0.028	-51	-0.283	0.7771	–	–
GUAYAMA 2 E, US	1941-2018 (70)	-0.022	-41	-0.203	0.8393	–	–
JUANA DIAZ CAMP, US	1931-2019 (86)	-0.072	-399	-1.484	0.1377	–	–
MAUNABO, US	1923-2002 (72)	-0.124	-216	-1.045	0.2959	–	–
PENUELAS 1 E, US	1972-2020 (48)	-0.006	-3	-0.018	0.9858	–	–
RINCON, US	1958-2020 (58)	-0.117	-213	-1.422	0.1549	–	–
SABANA GRANDE 2 ENE, US	1978-2019 (42)	-0.127	-69	-0.737	0.4611	–	–
Total de estaciones: 41							

CONCLUSIONES

Las proyecciones usando los modelos globales climáticos generales y/o regionales aparentan no simular con precisión la cantidad de lluvia futura en islas pequeñas como PR. No obstante, existen datos adecuados (particularmente en Puerto Rico) para desarrollar modelos climáticos enfocados en islas y áreas pequeñas que tomen en cuenta la multiplicidad de interacciones de sus factores físicos y microclimáticos, y que estudios futuros y las agencias gubernamentales locales encargadas de la toma de decisiones y acciones proactivas efectivas de cara al cambio climático pudieran examinar y considerar en mayor detalle a lo presentado en el presente estudio. Sin embargo, y según los datos de lluvia histórica en Puerto Rico, concluyo, sin muchas dudas, que el promedio de lluvia anual en la isla no ha disminuido al menos desde el 1920 hasta el 2020, lo que contrasta con resultados frecuentemente reseñados en la literatura científica y destacados en agencias gubernamentales en general.

AGRADECIMIENTOS

El autor agradece a tres revisores anónimos por sus sugerencias y recomendaciones que mejoraron este manuscrito.

REFERENCIAS

Ahmad, I., D. Tang, T-F Wang, M. Wang, and B. Wagan. 2015. Precipitation trends over time using Mann-Kendall and Spearman's rho tests in Swat River Basin, Pakistan. Advances in Meteorology 2015:Article ID 431860 (15 pages). http://dx.doi.org/10.1155/2015/431860.

Gao, F., Y. Wang, X. Chen, and W. Yang. 2020. Trend analysis of rainfall time series in Shanxi Province, Northern China (1957–2019). Water 12:1–22.

Gocic, M., and S. Trajkovic. 2013. Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global and Planetary Change 100:172–182.

Gould, W. A., J. Castro-Prieto, and N. L. Álvarez-Berríos. 2020. Climate change and biodiversity conservation in the Caribbean islands. Encyclopedia of the World's Biomes 1:114–125.

Helsel, D. R., and R. M. Hirsch. 2002. Statistical methods in water resources. Chapter A3, Book 4, Hydrologic Analysis and Interpretation. Techniques of Water-Resources Investigations of the United States Geological Survey. U.S. Geological Survey, U.S. Department of the Interior. 510 pp. Available at http://water.usgs.gov/pubs/twri/twri4a3/.

Hoskin, T. Sin fechar. Parametric and Nonparametric: Demystifying the Terms. https://www.mayo.edu/research/documents/parametric-and-nonparametric-demystifying-the-terms/doc-20408960.

Hussain, F., G. Nabi, and M. Waseem Boota. 2015. Rainfall Trend Analysis by Using the Mann-Kendall Test and Sen's Slope Estimates in the Barani Area, Punjab Province, Pakistan. Science International 27:3159–3165.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Working group II Contribution to the Intergovernmental Panel on Climate Change, Fourth Assessment Report. Summary for Policymakers. 22 pp.

Kalnay, E., and M. Cai. 2003. Impact of urbanization and land use changes on climate. Nature 423:528–531.

Kamal, N., and S. Pachauri. 2019. Mann-Kendall, and Sen's slope estimators for precipitation trend analysis in North-Eastern states of India. International Journal of Computer Applications 177:7–16.

Kampata, J. M., B. P., Parida, and D. B. Moalafhi. 2008. Trend analysis of rainfall in the headstreams of the Zambezi River Basin in Zambia. Physics and Chemistry of Earth 33:621–625.

Khalyani, A. H., W. A. Gould, E. Harmsen, A. Terrando, M. Quinones, and J. A. Collazo. 2016. Climate change implications for tropical islands: interpolating and interpreting statistically downscaled GCM projects for management and planning. Journal of Applied Meteorology and Climatology 55:265–282.

Kendall, M. G. 1975. Rank Correlation Methods, 4th edition. Charles Griffin, London, UK.

Mann, H. B. 1945. Non-parametric test against trend. Econometrica 13:245–259.

Modarres, R., and A. Sarhadi. 2009. Rainfall trends analysis of Iran in the last half of the twentieth century. Journal of Geophysical Research 114:D03101.

Murry, B., J. Bowden, B. Branoff, M. García-Bermúdez, B. A. Middleton, J. R. Ortiz-Zayaz, C. Restrepo, and A. Terando. 2019. Perspective: Developing Flow Policies to Balance the Water Needs of Humans and Wetlands Requires a Landscape Scale Approach Inclusive of Future Scenarios and Multiple Timescales. Wetlands 39:1329–1341.

Puerto Rico Climate Change Council (PRCCC). 2013. State of Puerto Rico's Climate 2010-2013 Executive Summary. Assessing Puerto Rico's Social-Ecological Vulnerabilities in a Changing Climate. ELECTRONIC VERSION. Puerto Rico Coastal Zone Management Program, Departament of Natural and Environmental Resources, Office of Ocean and Coastal Resource Management (NOAA-OCRM). San Juan, PR.

Runkle, J., K. Kunkel, and L. Stevens. 2018. Puerto Rico and the U.S. Virgin Islands State Climate Summary. NOAA Technical Report NESDIS 149-PR. 4 pp.

Salmi, T., A. Määttä, P. Anttila, T. Ruoho-Airola, and T. Amnell. 2002. Detecting trends of annual values of atmospheric pollutants by the Mann-Kendal test and Sen's slope estimates – the Excel template application MAKESENS. User manual, Publication on air quality, Finish Meteorological Institute. p.35.

Sen, P. K. 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63:1379–1389.

Walsh-Russo, C. 2018. Planning for the Unimaginable: Puerto Rico and Strategies for Climate Change Adaptation. Metropolitics (1 May 2018). Disponible en http://www.metropolitiques.eu/Planningfor-the-Unimaginable-Puerto-Rico-and-Strategies-for-Climate-Change.html.

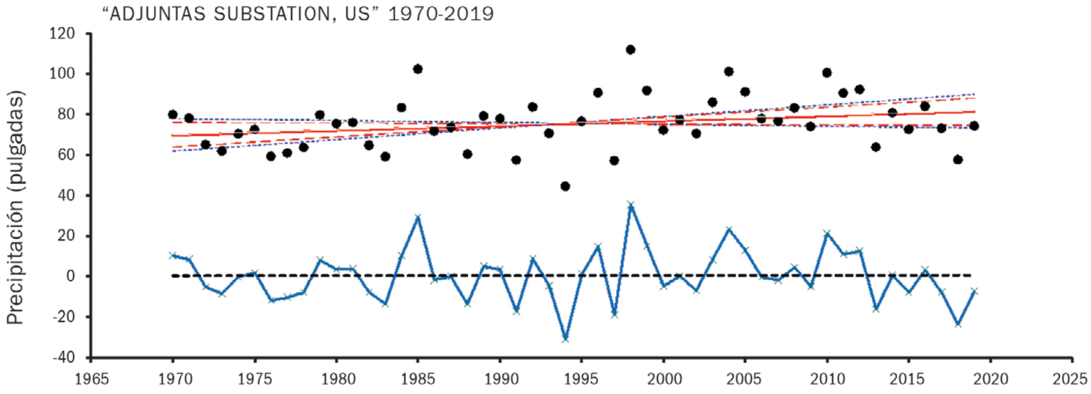
Xu, K., J. D. Milliman, and H. Xu. 2010. Temporal trend of precipitation and runoff in major Chinese Rivers since 1951. Global and Planetary Change 73:219–232.

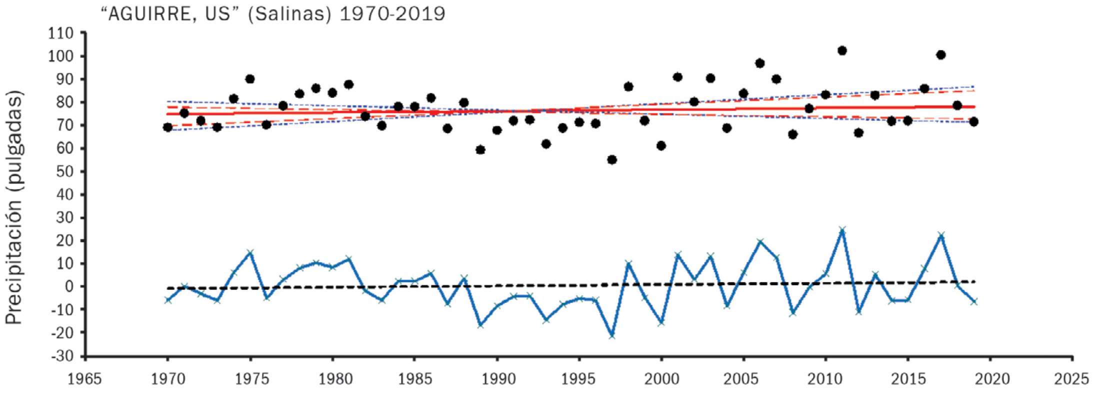
APÉNDICE I

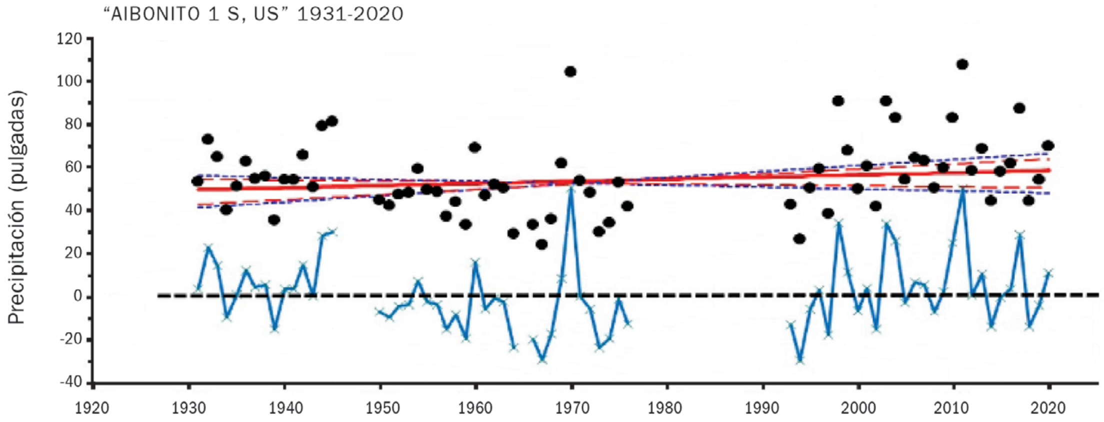
Gráficas individuales de los análisis Mans-Kendal y Sen para cada una de las estaciones pluviométricas seleccionadas para cómputo de tendencias estadísticas de la precipitación anual en Puerto Rico. Para cada estación, los círculos negros representan el total de lluvia anual; la línea negra entrecortada representa la tendencia en los residuales; otros elementos de la leyenda a continuación:

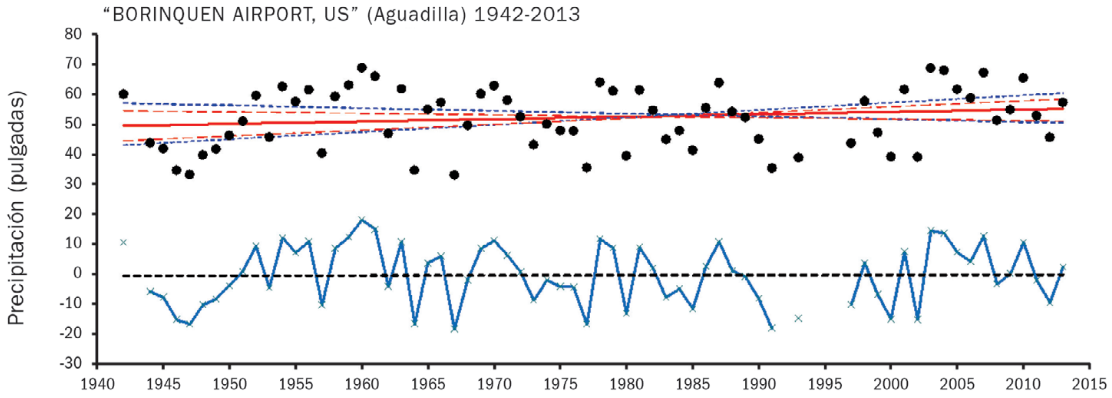
Leyenda general

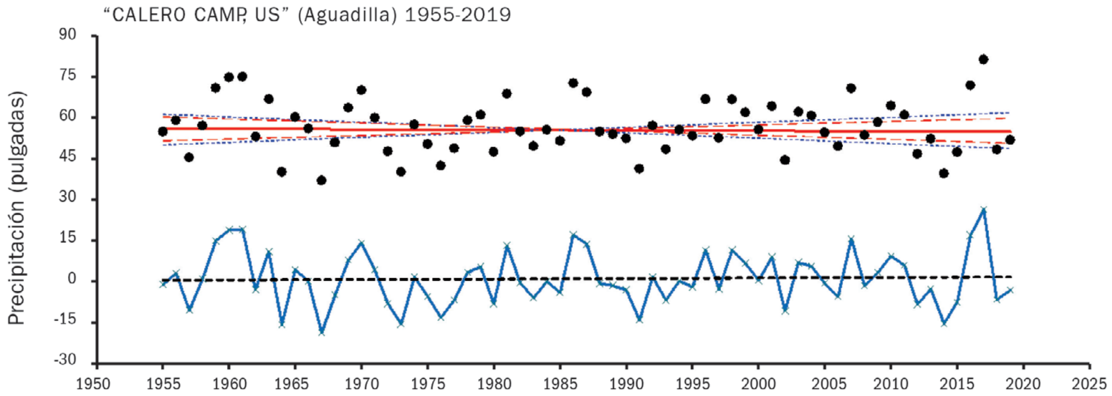
━ Regresión de Sen
┈ 99 % conf. min
┈ 99 % conf. max
‐ ‐ ‐ 95 % conf. min
‐ ‐ ‐ 95 % conf. max
━✕━ Residual

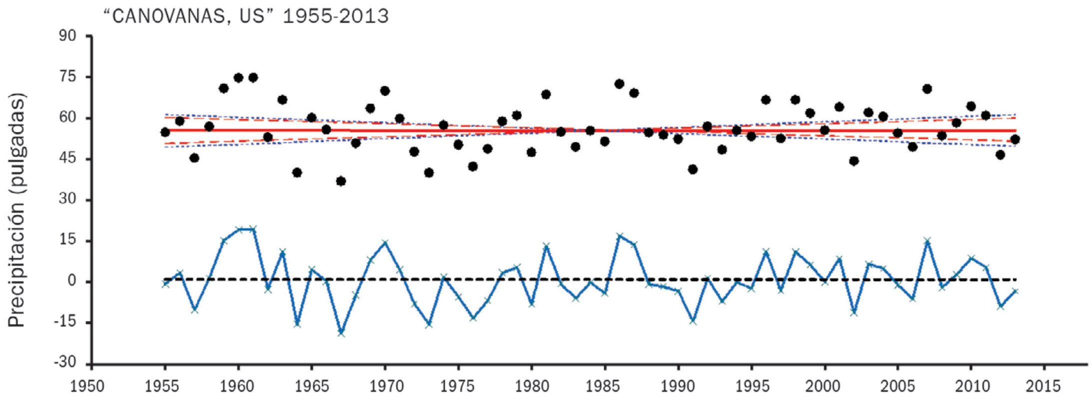

“ADJUNTAS SUBSTATION, US” 1970-2019

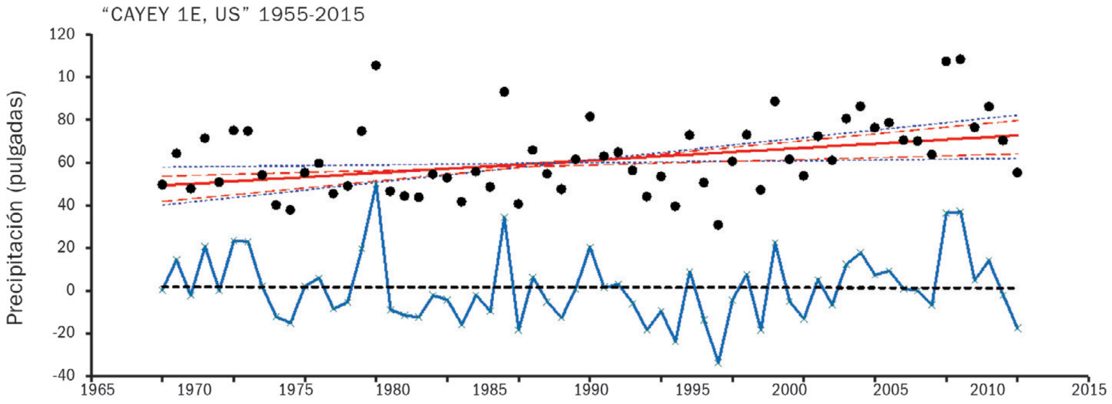

“AGUIRRE, US” (Salinas) 1970-2019

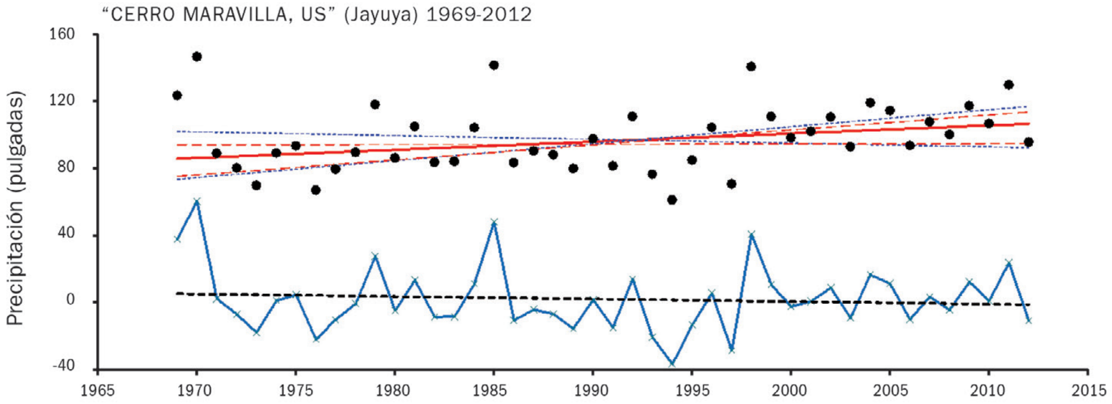

"AIBONITO 1 S, US" 1931-2020
Precipitación (pulgadas)
120
100
80
60
40
20
0
-20
-40
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

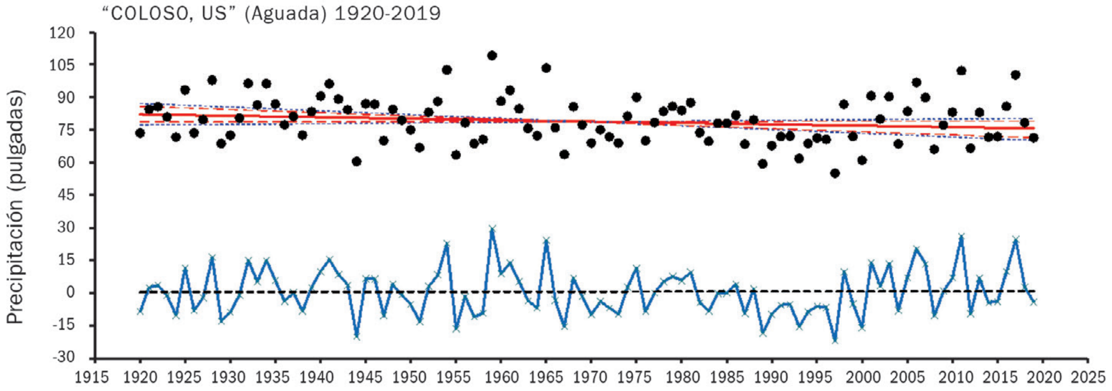

"BORINQUEN AIRPORT, US" (Aguadilla) 1942-2013
Precipitación (pulgadas)
80
70
60
50
40
30
20
10
0
-10
-20
-30
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

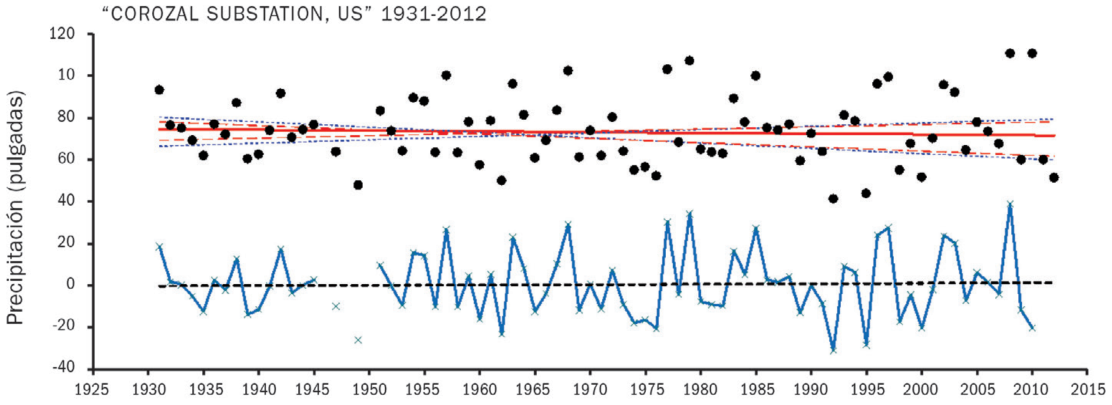

"CALERO CAMP, US" (Aguadilla) 1955-2019
Precipitación (pulgadas)
90
75
60
45
30
15
0
-15
-30
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025


"CANOVANAS, US" 1955-2013
Precipitación (pulgadas)
90
75
60
45
30
15
0
-15
-30
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

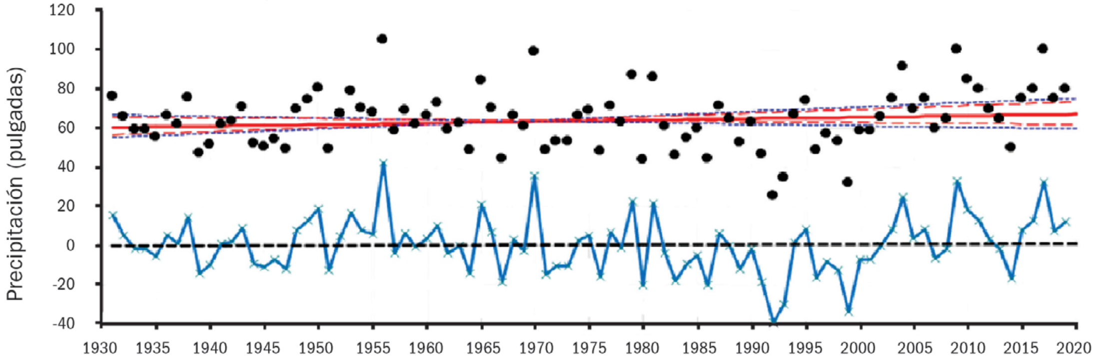

"CAYEY 1E, US" 1955-2015
Precipitación (pulgadas)
120
10
80
60
40
20
0
-20
-40
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015


"CERRO MARAVILLA, US" (Jayuya) 1969-2012
Precipitación (pulgadas)
160
120
80
40
0
-40
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

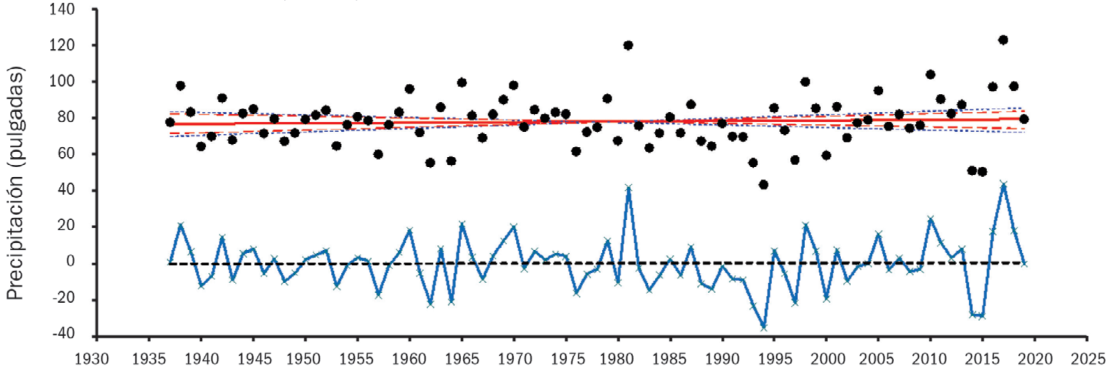

"COLOSO, US" (Aguada) 1920-2019
Precipitación (pulgadas)
120
105
90
75
60
45
30
15
0
-15
-30
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025


"COROZAL SUBSTATION, US" 1931-2012
Precipitación (pulgadas)
120
10
80
60
40
20
0
-20
-40
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

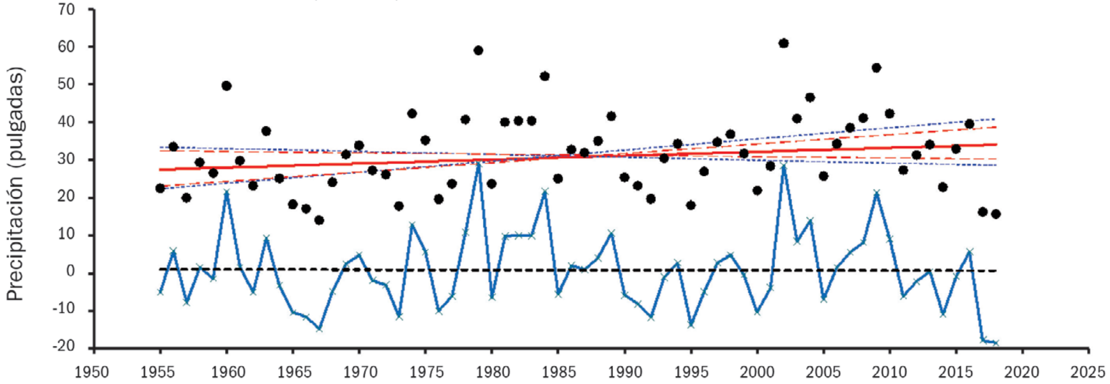
“DORADO 2 WNW, US” 1931-2019



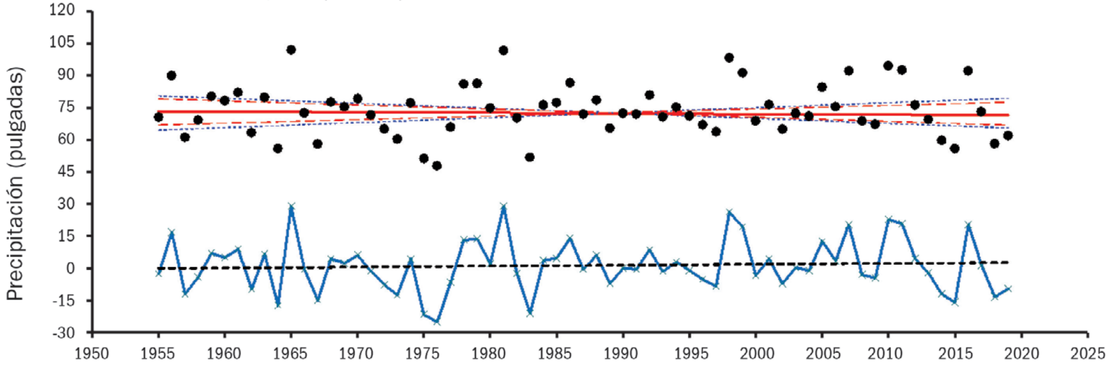
“DOS BOCAS, US” (Utuado) 1937-2019

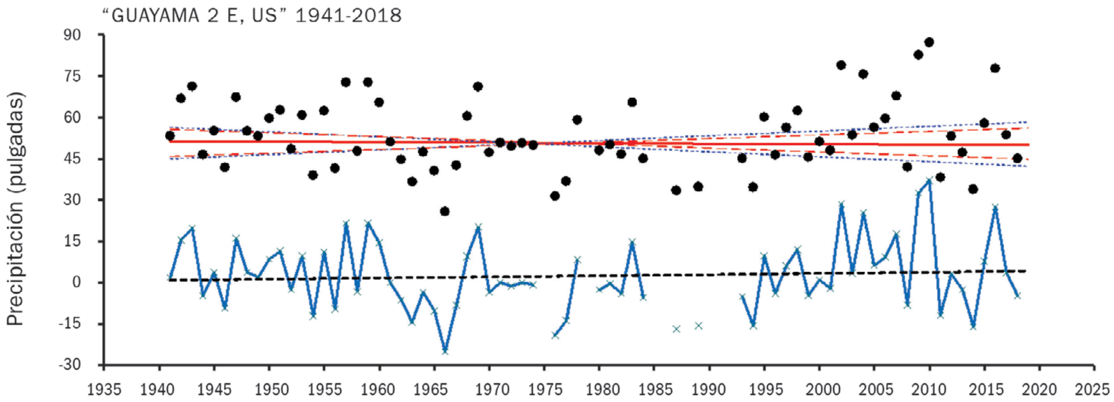


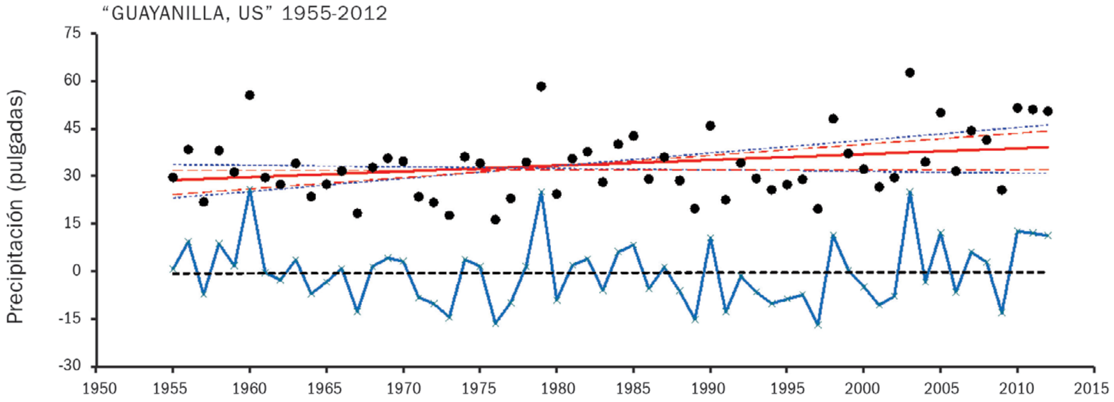
“ENSENADA 1 W, US” (Guánica) 1955-2018

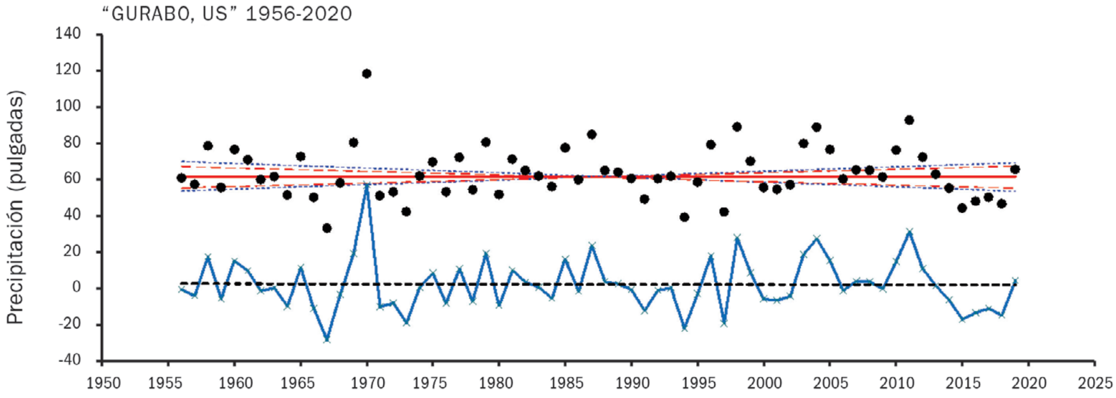


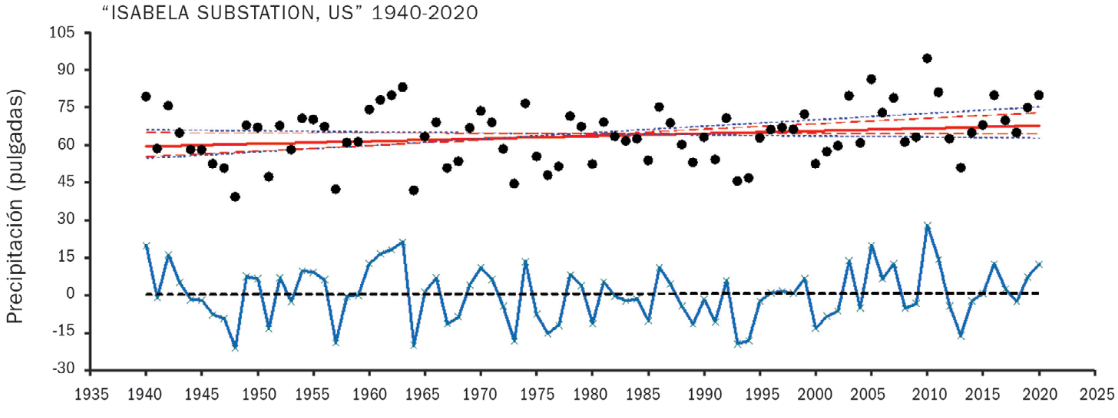
“GUAJATACA DAM, US” (Isabela) 1955-2019

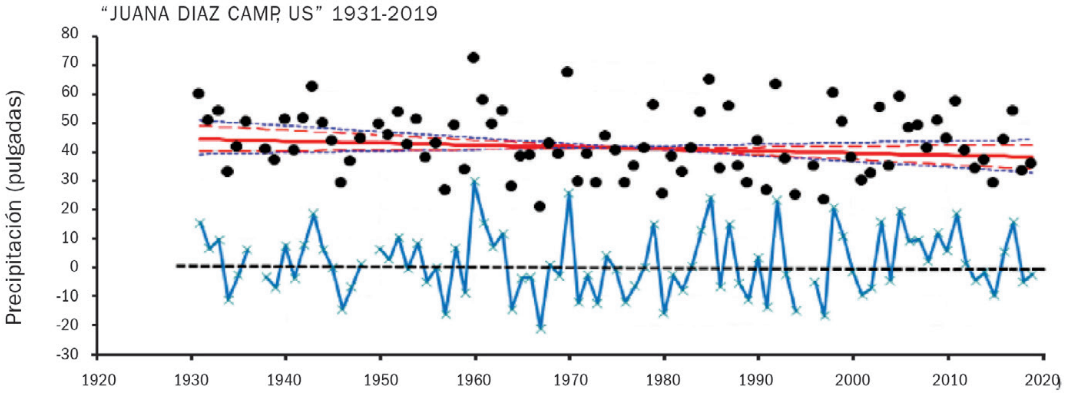



"GUAYAMA 2 E, US" 1941-2018
Precipitación (pulgadas)
90
75
60
45
30
15
0
-15
-30
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

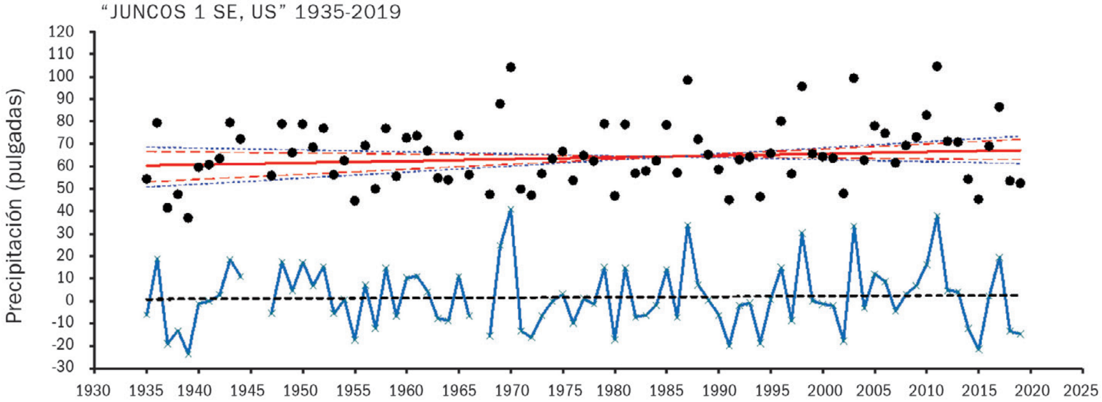

"GUAYANILLA, US" 1955-2012
Precipitación (pulgadas)
75
60
45
30
15
0
-15
-30
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015


"GURABO, US" 1956-2020
Precipitación (pulgadas)
140
120
100
80
60
40
20
0
-20
-40
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

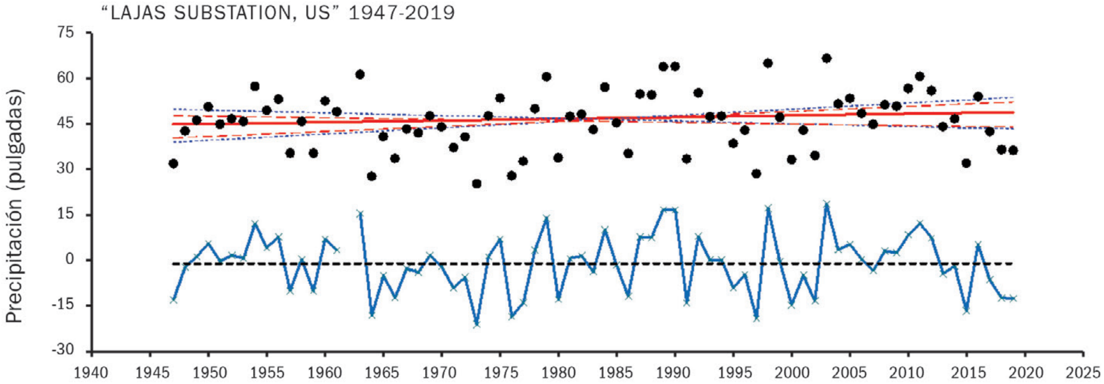

"ISABELA SUBSTATION, US" 1940-2020
Precipitación (pulgadas)
105
90
75
60
45
30
15
0
-15
-30
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025



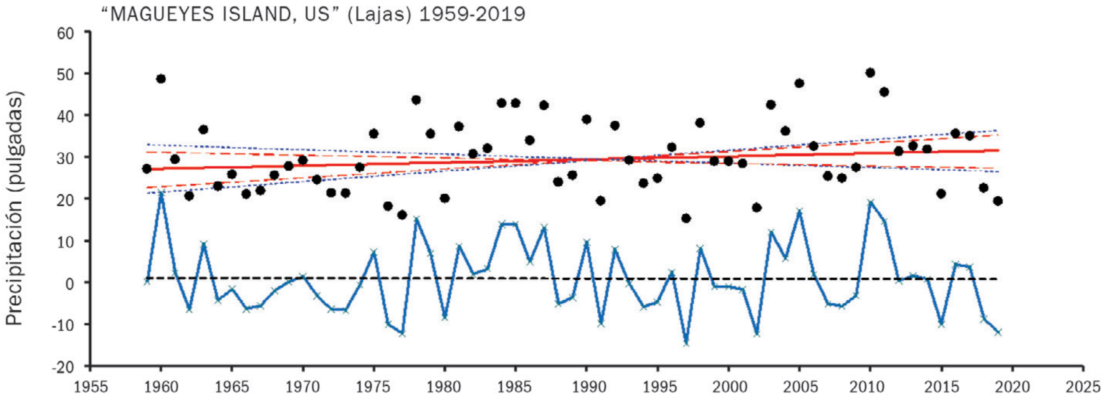
"JUANA DIAZ CAMP, US" 1931-2019



"JUNCOS 1 SE, US" 1935-2019

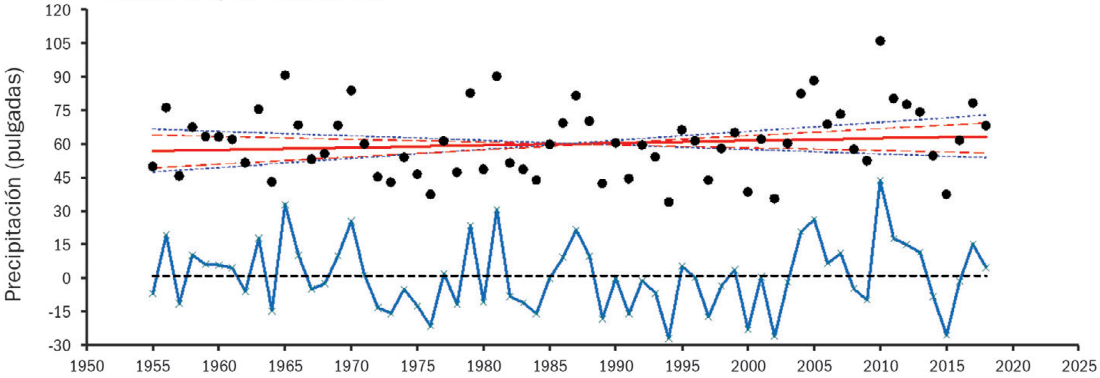


"LAJAS SUBSTATION, US" 1947-2019

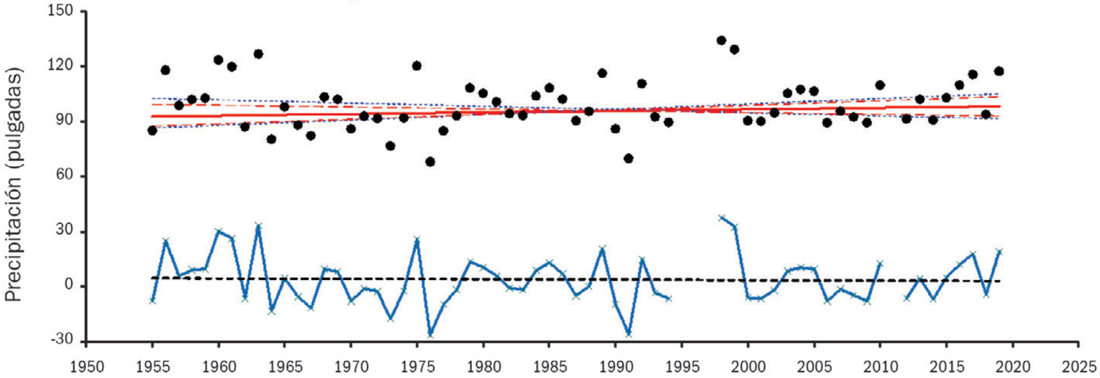


"MAGUEYES ISLAND, US" (Lajas) 1959-2019

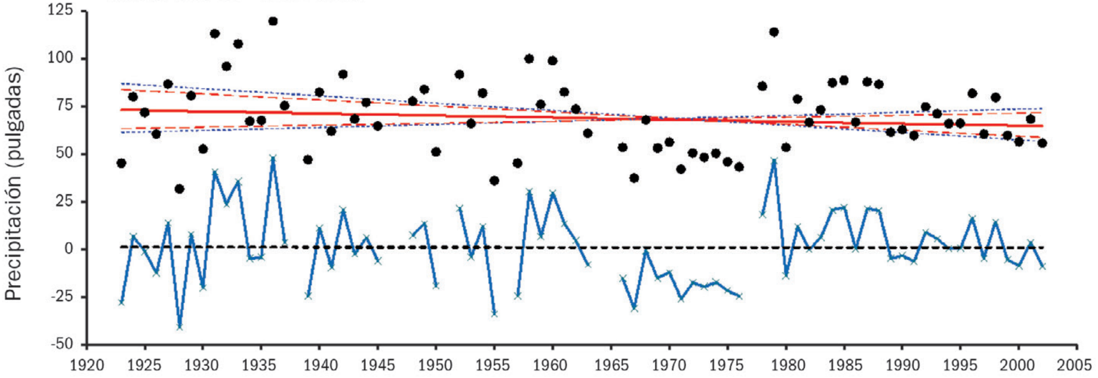
“MANATI 2 E, US” 1955-2018



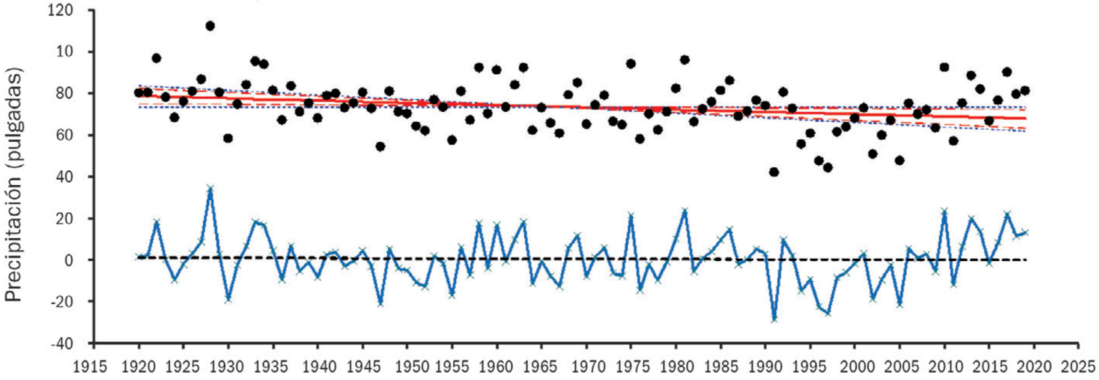
“MARICAO FISH HATCHERY, US” 1955-2019

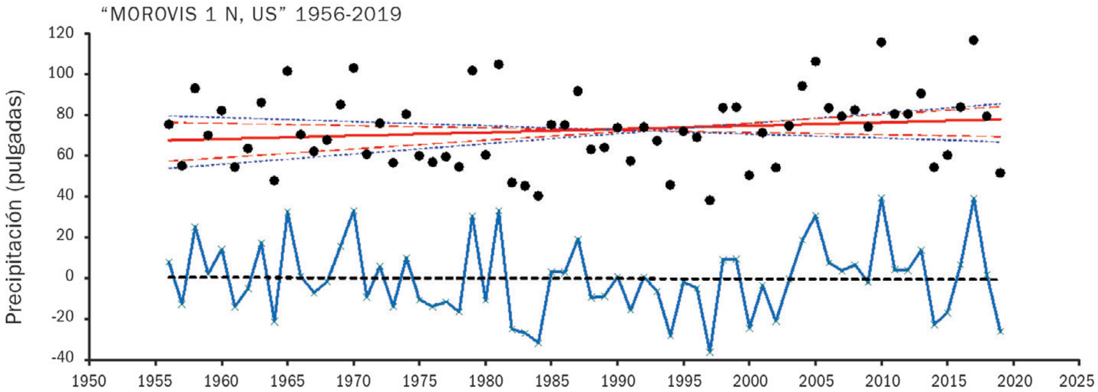


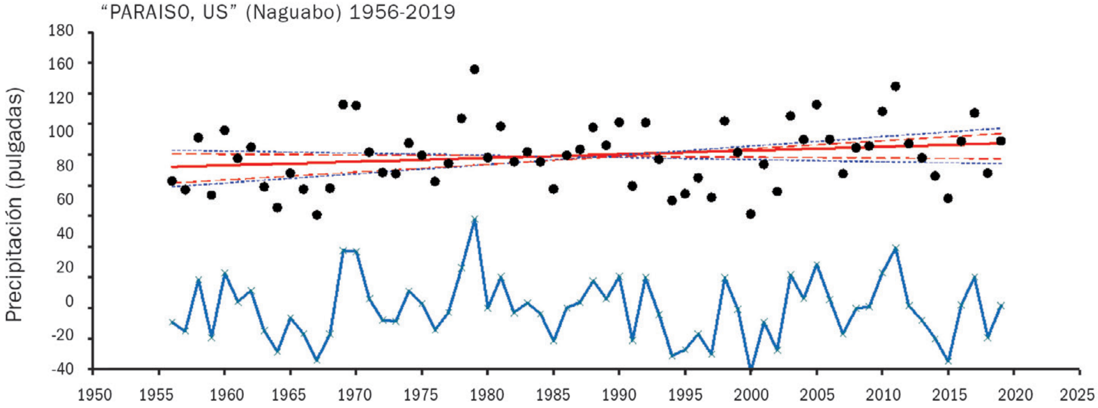
“MAUNABO, US” 1923-2002

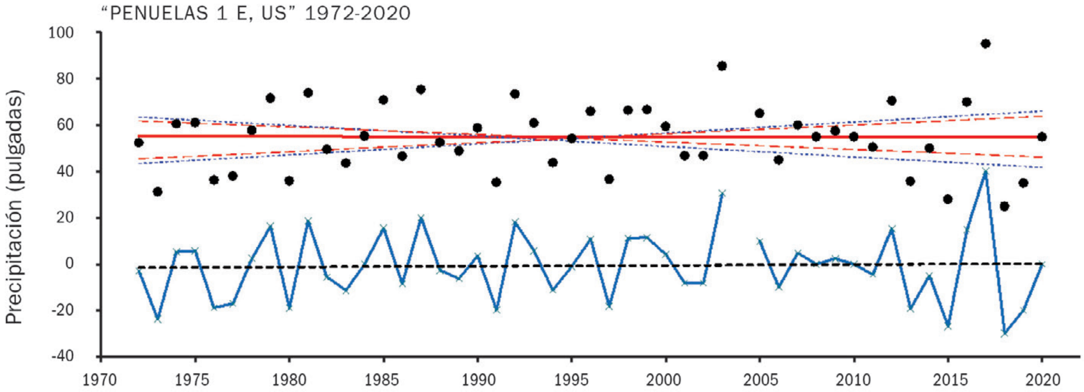


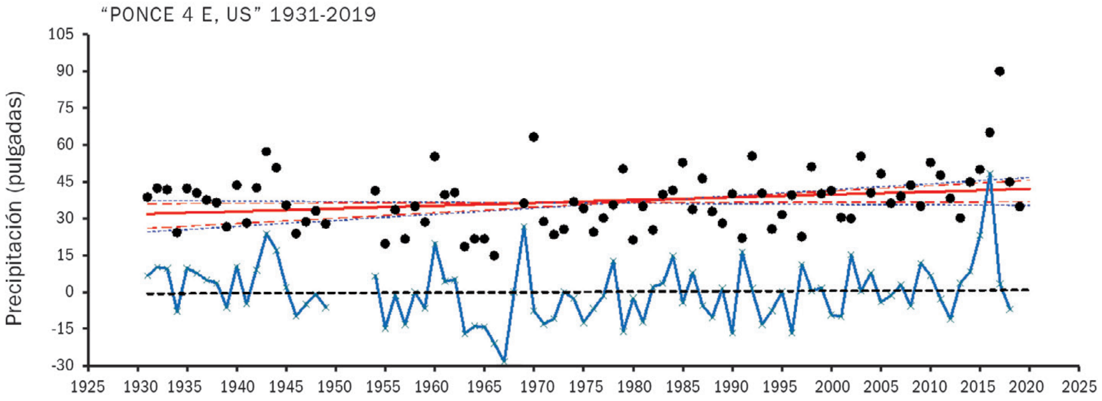
“MAYAGUEZ CITY, US” 1920-2019

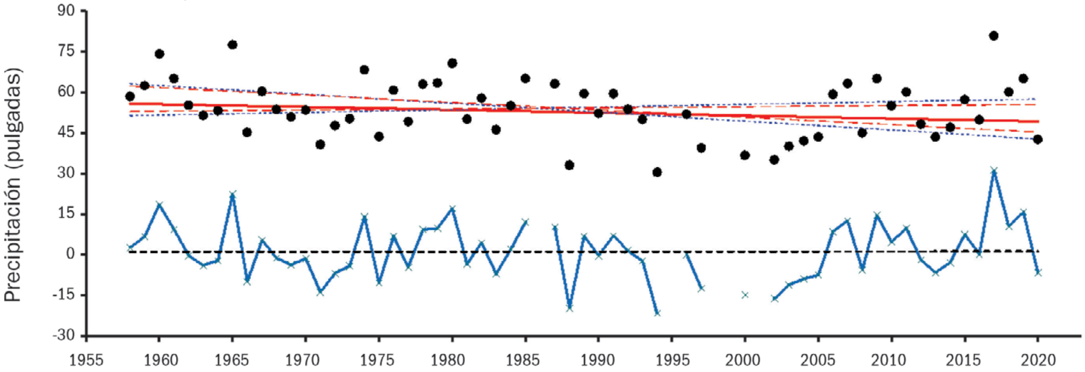



"MOROVIS 1 N, US" 1956-2019
Precipitación (pulgadas)
120
100
80
60
40
20
0
-20
-40
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

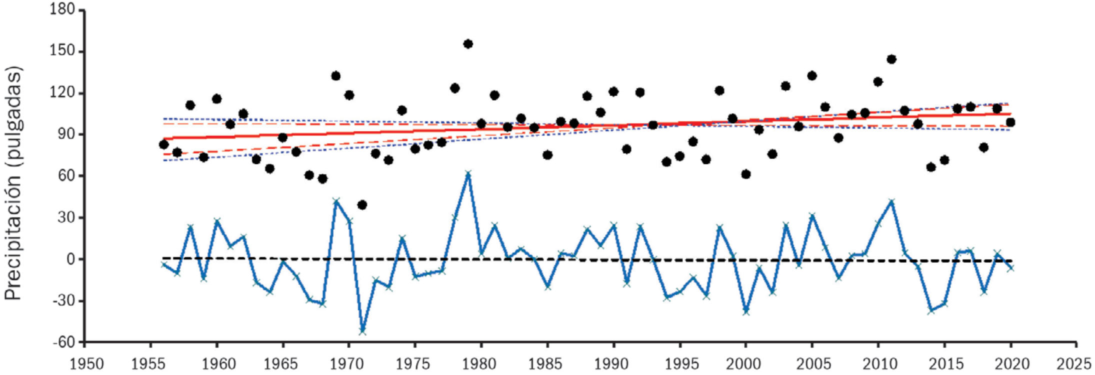

"PARAISO, US" (Naguabo) 1956-2019
Precipitación (pulgadas)
180
160
140
120
100
80
60
40
20
0
-20
-40
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025


"PENUELAS 1 E, US" 1972-2020
Precipitación (pulgadas)
100
80
60
40
20
0
-20
-40
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

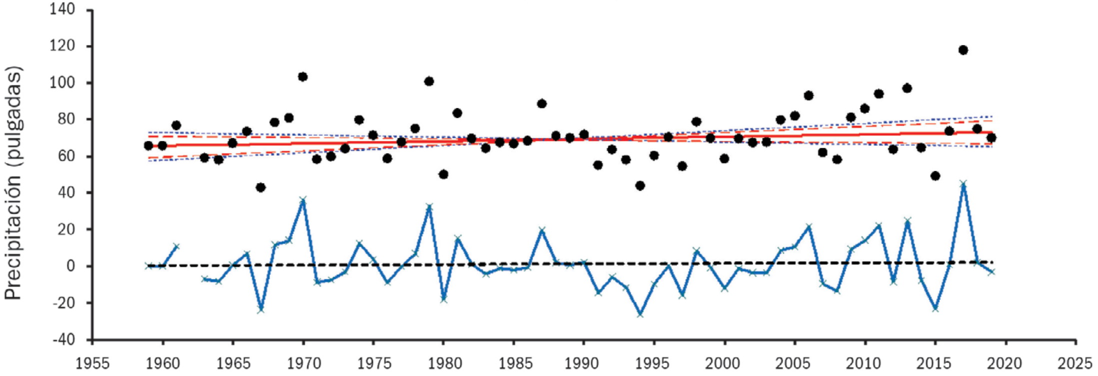

"PONCE 4 E, US" 1931-2019
Precipitación (pulgadas)
105
90
75
60
45
30
15
0
-15
-30
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025



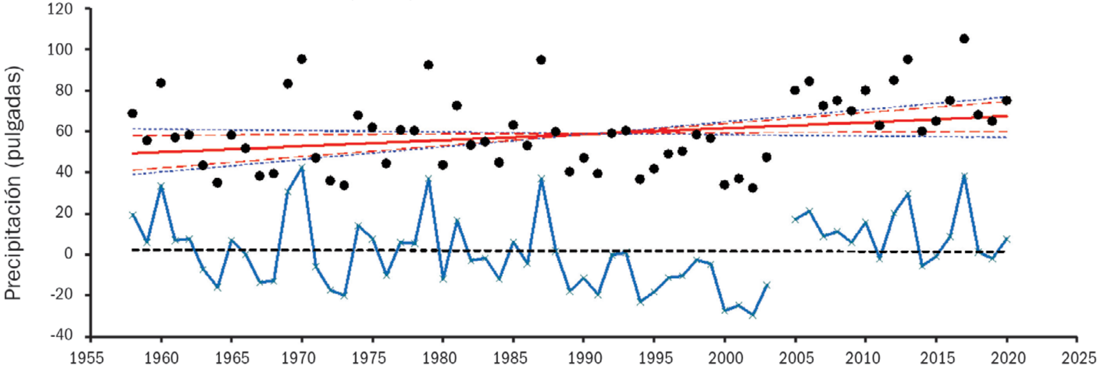
“RINCON, US” 1958-2020



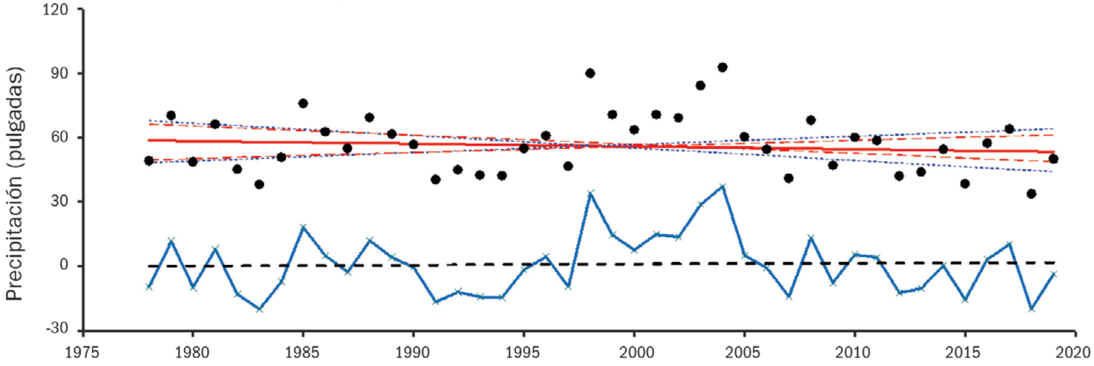
“RIO BLANCO LOWER, US” (Naguabo) 1956-2020

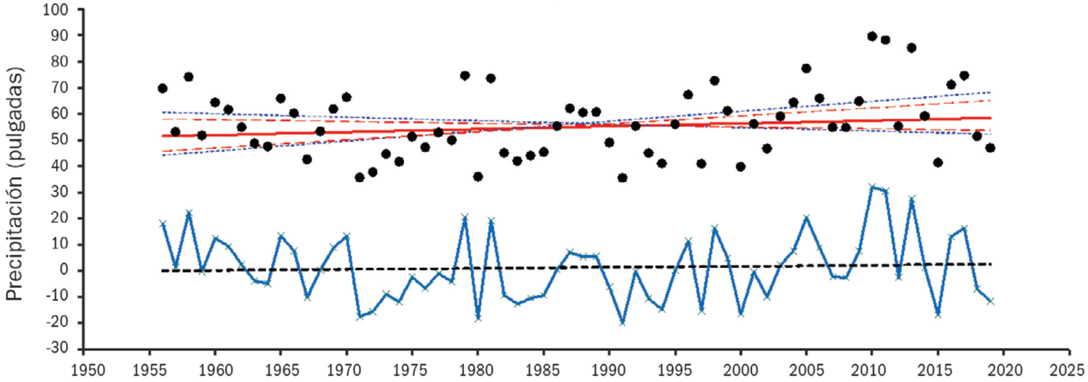


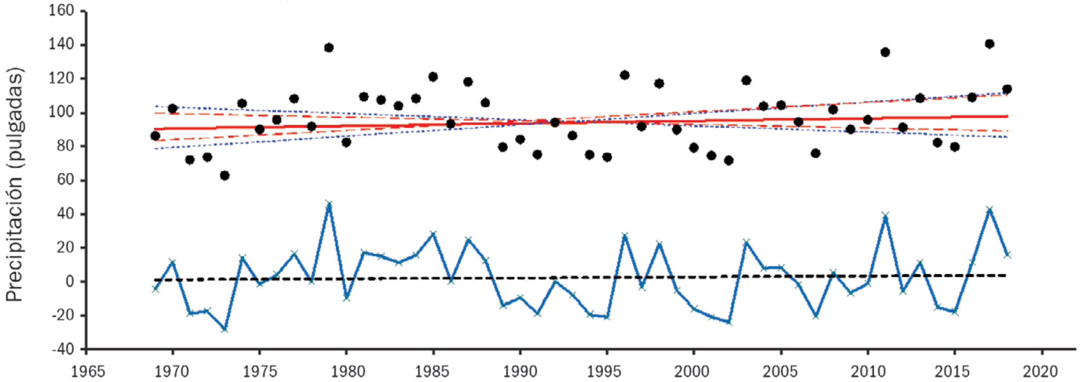
“RIO PIEDRAS EXPERIMENTAL STATION, US” (San Juan) 1959-2019

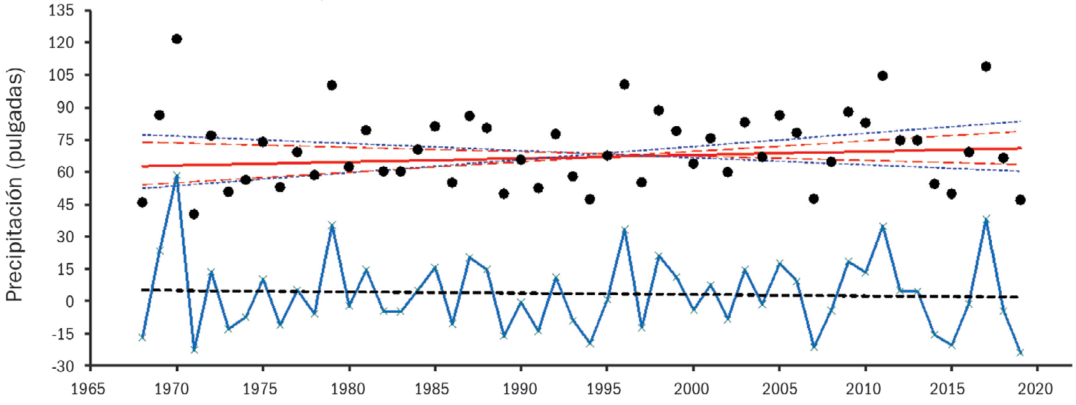


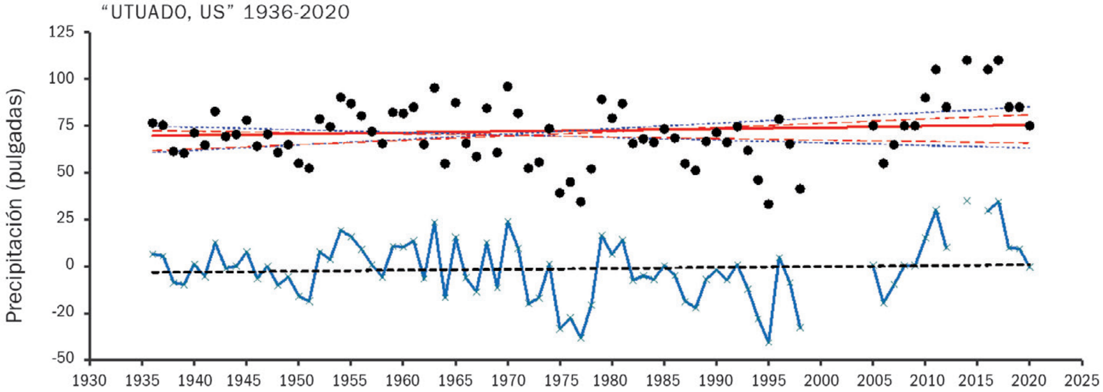
“ROOSEVELT ROADS, US” (Ceiba) 1958-2020

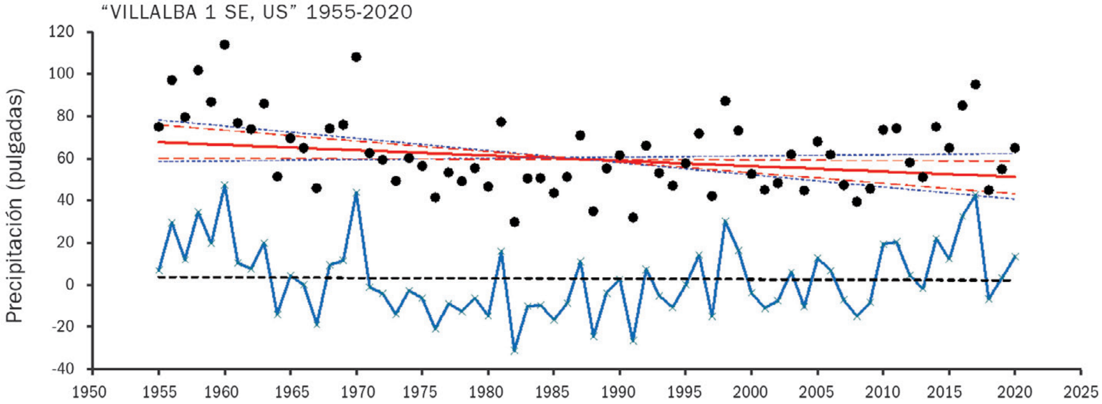

“SABANA GRANDE 2 ENE, US” 1978-2019

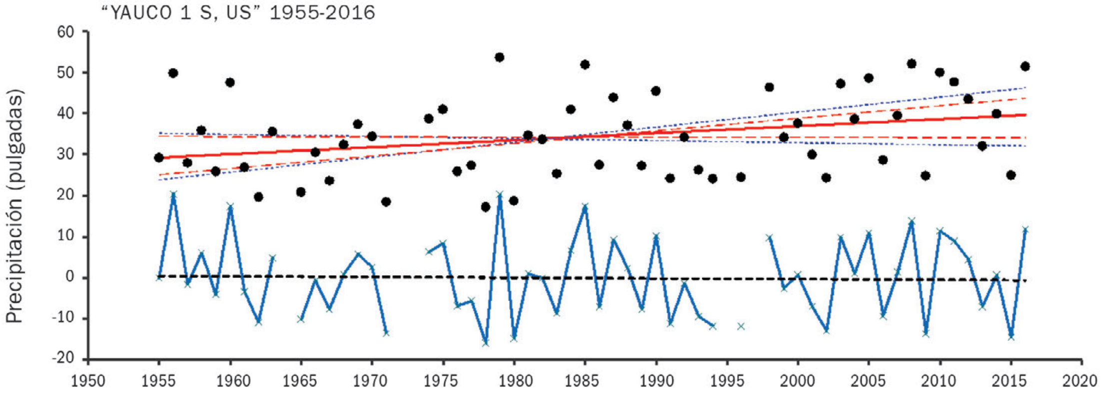

“SAN JUAN L M MARIN INTERNATIONAL AIRPORT, US” 1956-2019


“SAN LORENZO 3 S, US” 1969-2018


“TRUJILLO ALTO 2 SSW, US” 1968-2019


"UTUADO, US" 1936-2020
Precipitación (pulgadas)
125
100
75
50
25
0
-20
-50
1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025


"VILLALBA 1 SE, US" 1955-2020
Precipitación (pulgadas)
120
100
80
60
40
20
0
-20
-40
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025


"YAUCO 1 S, US" 1955-2016
Precipitación (pulgadas)
60
50
40
30
20
10
0
-10
-20
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020

IS THE INTRODUCED AMERICAN BULLFROG COMPETING FOR FOOD RESOURCES WITH THE CUBAN WESTERN GIANT TOAD?

L. Yusnaviel García-Padrón[1,*], Juan C. Cordero Acosta[2], and Rider Baños Utria[2]

[1] Museo de Historia Natural "Tranquilino Sandalio de Noda", Pinar del Río, Cuba. Martí 202, Pinar del Río. CP: 20100.
[2] Estación Biológica, Reserva de la Biosfera Sierra del Rosario. Comunidad Las Terrazas, Candelaria, Artemisa.
* Author for correspondence: yusnaviel@gmail.com

ABSTRACT

Bullfrogs (*Lithobates catesbeianus*) is considered one of the most harmful amphibian species of the world for native amphibians. Its voracity can displace other species that live in sympatry because of competition for food or direct predation. *Peltophryne fustiger* (Western giant toad) is a regional endemic toad species that lives associated with water bodies were it reproduces, and can share the same space and time with bullfrogs in western Cuba. No studies have been made to understand the interactions and impact of bullfrogs on native amphibians in Cuba. Herein we studied the possible feeding competition between the western giant toad (one population) and the introduced bullfrog. We visited one locality where these two species co-occur, in Western Cuba. *Peltophryne fustiger* had a higher proportion of prey/stomach than bullfrogs, but the latter consumed larger preys. The most abundant prey items in *P. fustiger* stomach were diplopods and roaches, meanwhile in bullfrogs were freshwater crabs. No overlap was detected between these two species in the study area. We consider that bullfrogs' major threat is on the native invertebrate fauna rather than competition for food resources with *P. fustiger.*

Keywords Cuba, diet, invasive species, *Lithobates catesbeianus*, native fauna, *Peltophryne fustiger*, West Indies.

Resumen

La rana toro (*Lithobates catesbeianus*) es considerada uno de las especies de anfibios más dañinos del mundo para la fauna nativa. Su voracidad puede desplazar a especies nativas que viven en simpatría con esta, debido a la competencia por alimento o depredación directa. *Peltophryne fustiger* es un sapo endémico regional del occidente cubano, que habita en cuerpos de agua donde se reproduce, y comparte el mismo espacio y tiempo con la rana toro. No se ha realizado ningún estudio en Cuba hasta ahora para conocer la interacción e impacto de esta rana sobre los anfibios nativos. Aquí estudiamos la posible competencia por el recurso alimenticio entre el sapo de occidente y la rana toro, en una población del occidente cubano. Se encontró que *P. fustiger* tiene más presas por estómago, pero la rana toro consume presas de mayor tamaño. La presa más abundante en el estómago de este sapo son los diplópodos y las cucarachas, mientras que la rana toro prefiere cangrejos de agua dulce. No se detectó solapamiento trófico entre estas dos especies en el área de estudio. Consideramos que la mayor amenaza de esta especie de rana introducida es sobre la fauna invertebrada nativa, más que la competencia por el recurso trófico de *P. fustiger.*

Palabras clave Caribe, Cuba, Dieta, especie invasora, fauna nativa, *Lithobates catesbeianus*, *Peltophryne fustiger.*

ISSN: 1940-1148

INTRODUCTION

Introduced species are one of the leading causes of loss of biodiversity globally (Escoriza and Boix 2012), and a large number of studies have focused on documenting and proposing strategies for eliminating or reducing these species' negative impacts at large. The American Bullfrog (*Lithobates catesbeianus* Shaw, 1802, hereafter "bullfrogs") is considered one of the most harmful species of the world (Lowe et al. 2000) and can harm native amphibian populations (Fiscerola et al. 2007). This species also is probably one of the vectors for the expansion of *Batrachochytrium dendrobatidis* (Garner et al. 2006). Another impact of bullfrogs can be competition with native amphibians for trophic resources. The bullfrog is a voracious, generalist, and opportunistic species (Korschgen and Moyle 1955; Sampedro Marín et al. 2003; Cross and Gerstenberger 2002; Ficerola et al. 2007; Snow and Witmer 2010). Sampedro Marín et al. (1985) conducted the first study focused on the diet of bullfrogs in Cuba and documented that this species consumed many types of prey, including beetles, crickets, roaches, and freshwater fishes. Although these authors found a high fish consumption in one locality (Pinar del Río), they did not discuss the impact of bullfrogs upon native fauna. This type of predation could be damaging the economy in that region (Sampedro Marín et al. 1985).

In the West Indies, species in the genus *Peltophryne* are endemic of their respective territories, and the major radiation occurs in Cuba (Alonso et al. 2012; Alonso and García 2017). The Western Giant Toad (*Peltophryne fustiger*) is an endemic species from Western Cuba (Díaz and Cádiz 2008; Henderson and Powell 2009; Alonso and García 2017). This species occurs in undisturbed bodies of water, mostly streams and rivers (Henderson and Powell 2009). This is the largest toad of the genus *Peltophryne* (Alonso et al. 2014) and has been categorized as Least Concern by the International Union for Conservation of Nature (IUCN), although it has not been included in Cuban assessments (Alonso and García 2017). The only known record of the diet of this species was given by Ruiz García (1987) when he exposed that this toad feeds on insects, slugs, scorpions, and plant material, and the stomach had a capacity of 40 cm^3.

These two species shared four main traits of concern for conservationist because of their possible competitive interactions: 1) both share the same microhabitat (Díaz and Cádiz 2008); 2) tadpoles share the same space in the rivers (LYGP, personal observation), and bullfrog tadpoles are recognized as competitors and predators of native tadpoles (Blaustein and Kiesecker 2002; Kats and Ferrer 2003); 3) both vocalize at the shore or in shallow parts of the rivers (Alonso and Rodriguez 2003; Díaz and Cádiz 2008); and 4) both have a similar body size (i.e., snout-vent length [SVL]; Henderson and Powell 2009). Werner et al. (1995) suggested that species of similar body size may feed on similar prey types (dietary overlap). However, no studies have been made to understand the possible competition in habitat use, space, acoustics, and diet between these two species. Herein, we examine interspecific interactions for food resources to test the hypothesis of competition interference for food resources between *Peltophryne fustiger* and the introduced *Lithobates catesbeianus* in Western Cuba. Due to the similarities in body size and habitat use between these two species, we predict they will show high overlap between their diets.

METHODS

Study area and data collection

We visited "Manantiales" river, Candelaria Municipality, Artemisa Province (83º0'31.442"W, 22º47'39.424"N; WGS 84) (Figure 1A) in June 2018, and July 2019, at 21:30h to 23:30h. We captured all *Peltophryne fustiger* (Figure 1B) and *L. catesbeianus* (Figure 1C) along a 300-m transect, walking across

Figure 1. A, panoramic view of Manantiales river; B, *Peltophryne fustiger*; C, *Lithobates catesbeianus*; D, to the left, a freshwater crab (*Epilobocera gilmani*), and, to the right, two crayfish (*Procambarus* sp.). Photos: LYGP.

the middle of the river (maximum depth: 0.8 m); individuals of *P. fustiger* were captured by hand, and bullfrogs were captured by gigging. The snout-vent length (SVL) of each individual was measured to the nearest 0.05 mm. For *P. fustiger*, we used the stomach-flushing method (Solé et al. 2005) to obtain the stomach content, and all individuals were released at the site of capture. For euthanasia of bullfrogs we cooling down the specimens in a freezer (~ -10ºC) (Lillywhite et al. 2020) for 20 to 35 minutes, and later the stomachs were extracted. All stomach contents were kept in 0.1-L containers with 75% ethanol and analyzed in the Museo de Historia Natural "Tranquilino Sandalio de Noda" laboratory, in Pinar del Río, Cuba. We identify all prey items to the lowest possible taxonomic level, and the prey's maximum length and maximum width were documented to the nearest 0.01 mm.

Data analyses

The data was not normally distributed, and we used the Mann-Whitney U-test to determine if differences exist in SVL between species and differences in the length of prey items consumed that can be attributed to the size of species of anurans and volume of prey between these two species. All results are shown as mean ± standard deviation (SD). For all tests, we adopted a significance level $\alpha \leq 0.05$.

Table 1. Diet of *Peltophryne fustiger* and *Lithobates catesbeianus*.

Prey categories	*P. fustiger* (n = 6)				*L. catesbeianus* (n = 15)			
	F (%)	N (%)	V (%)	IRI	F (%)	N (%)	V (%)	IRI
(C) Chilopoda (t)	1 (5.26)	1 (1.89)	234.66 (9.07)	5.41	0	0	0	0
(C) Diplopoda (t)	7 (36.84)	37 (69.81)	144.02 (5.55)	37.4	1 (3.03)	1 (1.52)	21.41 (0.14)	1.56
(C) Gastropoda (t)	1 (5.26)	2 (3.77)	117.07 (4.52)	4.52	1 (3.03)	1 (1.52)	294.20 (1.94)	2.16
(C) Pisces (a)	0	0	0	0	1 (3.03)	1 (1.52)	576.70 (3.81)	2.79
(O) Araneae (t)	0	0	0	0	1 (3.03)	1 (1.52)	154.62 (1.02)	1.86
(O) Blattodea (t)	4 (21.05)	4 (7.55)	2011.07 (77.71)	35.44	0	0	0	0
(O) Decapoda (sa)	0	0	0	0	16 (48.48)	45 (68.18)	14103.64 (93.09)	69.92
(O) Dermaptera (t)	1 (5.26)	4 (7.55)	43.83 (1.69)	4.83	0	0	0	0
(O) Hymenoptera (t)	2 (10.53)	2 (3.77)	37.27 (1.44)	5.25	0	0	0	0
Plan material	3 (15.8)	3 (5.66)	0	0	9 (27.27)	9 (13.64)	0	0
“dirt”/rocks	0	0	0	0	4 (12.12)	8 (12.12)	0	0

F = frequency of occurrence and its percent (%); N = number of items and its percent (%); V = volume and its percent (%); IRI = Index of Relative Importance. (C) = Class; (O) = Order. In lower case: (t) = terrestrial; (a) = aquatic; (sa) = semi-aquatic.

We used the ellipsoid formula ($V = 4/3\pi\ [L/2][W/2]^2$; Magnusson et al. 2003) to calculated the volume (mm^3) of each prey item. We calculated the number of consumed items (N) and its percent (N%); the frequency of occurrence (F, number of stomachs in which a given prey category was found), and its percent (F%), and the volume percent (V%) for each prey category. Prey items were nested into categories, and the Index of Relative Importance (IRI) was obtained for every prey category using the formula: $IRI = N\% + V\% + F\% / 3$ (Pianka 1973). In addition, we compared species trophic niche overlap and trophic niche breadth. Specifically, we calculated niche overlap using Pianka’s overlap index (POI), which varies from 0 (no overlap in resource use) to 1 (complete overlap) (Pianka 1973, 1974). Likewise, we used the Levins’ index (B) (Krebs 1999) to calculate the trophic niche breadth: $B = 1/(\Sigma Pi^2)$, where Pi = fraction of items in the food category i, range = 1 to N, and values of B vary from 1 (no diversity, exclusive use of a single prey type, specialist) to N (highest diversity, prey items of all categories, generalist).

RESULTS

We captured six *P. fustiger* (mean ± SD: SVL 140.55 mm ± 2.83 mm) (Figure 1B), and 18 *L. catesbeianus* (SVL 156.33 mm ± 14.03 mm, mean ± SD) (Figure 1C). Individuals of *L. catesbeianus* were larger than *P. fustiger* (U-test = 6.000; p = 0.002). Differences were observed in prey length consumed by *L. catesbeianus* (38.57 mm ± 0.94 mm; range = 12.35–61.8 mm; n = 38) and *P. fustiger* (26.77 mm ± 10.75 mm; range = 10.43–42.19 mm; n = 13) (U-test = 19.000; p = 0.025).

Ninety-nine prey items of nine prey categories were consumed by these two species, plus plant material, rocks, and undetermined sediments/particles. No differences were detected in the number of prey items consumed (U-test, p = 0.290) by *L. catesbeianus* and *P. fustiger*. When comparing the total prey consumed by both species, *Peltophryne fustiger* consumed 50.5% of total prey (mean 2.83 prey/stomach ± 0.71 SD, n = 6 toads), and *L. catesbeianus* consumed 49.5% of total prey (mean 2.33 prey/stomach ± 1.41 SD, n = 18 frogs). The mean volume per individual was 431.32 mm^3 (± 19.06 SD) for *Peltophryne fustiger*, while *L. catesbeianus* had 1,010.04 mm^3 (± 392.65 SD). No difference was observed in the volume of food consumed between these two species (U-test = 10.000; p = 0.361).

The most abundant and important prey category for *L. catesbeianus* were decapods (Table 1): the freshwater crab (*Epilobocera gilmani*), were observed in 86.7% of the samples, and crayfish (*Procambarus* sp.) in 13.3% of the samples (Figure 1D). Collectively, freshwater crabs and crayfish (Figure 1D) represented 59.2% (53.1% and 6.1% respectively) of the total prey consumed by *L.*

catesbeianus. The total volume of decapods founded in this species was higher than the total volume of prey items found in *P. fustiger*. In addition, we detected the endemic fish *Rivulus cylindraceus* in one stomach of *L. catesbeianus*. In contrast, *P. fustiger* ate mostly diplopods (IRI = 37.4, $F_{\%}$ = 36.84, $V_{\%}$ = 5.55) and roaches (Blattodea; IRI = 35.44, $F_{\%}$ = 21.05, $V_{\%}$ = 77.71), although the latter represented the largest percent volume among samples (Table 1). The only mollusk observed was the land slug *Leidyula* sp. (Gastropoda), consumed by both species. In this study, *L. catesbeianus* preyed mostly on aquatic or semi-aquatic species while *P. fustiger* consumed more terrestrial species (Table 1). Nonetheless, on average, *L. catesbeianus* consumed approximately two-thirds the number of prey items found in *P. fustiger* (mean 2.2 items per stomach in *L. catesbeianus* and 3.2 items per stomach in *P. fustiger*) (Table 1).

No overlap was detected between these two species in the frequency of occurrence (F) (POI = 0.06) and number of prey (N) (POI = 0.02). The niche breadth was slightly wider in *L. catesbeianus* (Levins' index = 2.15) than in *P. fustiger* (Levins' index = 1.7).

DISCUSSION

The difference in prey items between species of anurans – *Lithobates catesbeianus* predates more aquatic organisms than did the *Peltophryne fustiger*, which preferred terrestrial ones – revealed no overlap in diet resources between these sympatric species. We suggest that this difference points at various foraging grounds that may potentially result in little interaction related to the feeding ecology between these anurans in the study area (see next).

Previous studies showed that *Lithobates catesbeianus* consumed mainly aquatic prey (Stewart and Sandison 1972; Werner et al. 1995), while *Peltophryne fustiger* preferred terrestrial prey (this study). Prey items from the Class Decapoda represented the most important food source for *L. catesbeianus* at our study site, and a large amount of the freshwater crab, *Epilobocera gilmani*, in bullfrogs suggests that this freshwater crab is an important food resource for this species in the study area. These results, along with the generalized aquatic feeding ecology of the bullfrog, supported previous findings: Korschgen and Moyle (1955) found that the second most consumed prey by bullfrogs was crayfish; Clarkson and DeVos (1986) and Hirai (2004) stated that crayfish is one of the most important components in the diet of bullfrogs worldwide; bullfrogs consumed mostly aquatic prey, especially crayfish (Korschgen and Moyle 1955; Wu et al. 2005; Vrcibradic et al. 2017). In Cuba, predators of freshwater crabs include mammals (*Solenodon cubanus*; Abreu and de la Cruz 1988), the invasive African catfish (*Clarias gariepinus*; Perez-Osoria and Figueredo 2013), and birds (*Nyctanassa violacea*; Rodríguez-Cabrera et al. 2018). Our study adds *L. catesbeianus* as another predator of crustaceans in Cuba.

We found that *P. fustiger*, on average, consumed at least 31% more prey items than *L. catesbeianus*. This difference may be originated from differences in their feeding ecology and anatomy: while the stomach of this toad had a large-volume capacity (Ruiz García 1987), the prey consumed occupied a small volume, which required more amount of items to fulfill its feeding requirements. In contrast, bullfrogs frequently feed on larger but fewer prey items, which occupied a larger volume in their stomach (Frost 1924, 1935). Nonetheless, in our study, no difference in volume was observed between these two species (despite the higher mean volume of *L. catesbeianus*, biased by several larger preys [e.g., decapods] that represented extreme values in size).

We recognize several limitations of our study: different sampling procedures for collecting stomach content between species and relatively small sample sizes. However, we kept our sampling to the same season (summer) and time (of most activity of each species). In addition, stomach flushing in *P. fustiger* could only underestimate the abundance and volume of prey, particularly for very small-sized items, which may increase the interspecific differences examine in our study. Considering the limitations of our study, we may suggest that limited or no dietary overlap occurs between *P. fustiger* and *L. catesbeianus* in our study area.

Werner et al. (1995) observed that similar body-sized species could overlap in diet, especially if they share the same microhabitat. The body size between species may influence the nature and strength of interactions (Werner et al. 1995). The bullfrog and the Western Giant Toad had similar body sizes (Henderson and Powell 2009; Alonso et al. 2014). In addition, Werner et al. (1995) suggested that the potential strength of competitive interactions among species is likely mitigated (or reduced) by differences associated with habitat-related resource use (diets). Bullfrogs prefer to feed underwater (Frost 1935), which we also found at our study site, while the diet of *P. fustiger* consisted mostly of terrestrial prey. While bullfrogs may come out to the land to feed at night (Sampedro Marín et al. 2003), we provided data supporting minimal, interspecific interaction for food, which could result from differences in microhabitat use between species.

For humans, bullfrogs are used as food and research (Culley 1981; Bury and Whelan 1984; Sampedro Marín et al. 1985). Nonetheless, the limited knowledge about the influence of the bullfrog on the native fauna in the insular Caribbean (contrary to continental areas) makes it challenging to develop effective management and conservation strategies as "evidence" is frequently circumstantial or anecdotal (e.g., Adams and Pearl 2007; Snow and Witmer 2010; Ríos-López et al., in press). We consider that the major threat in the study area regarding bullfrogs is the consumption of many endemic species, including the freshwater crab *E. gilmani* (most frequent prey item) or the freshwater fish *R. cylindraceus* (less frequent prey item). Studies addressing the feeding ecology of the bullfrog (from various ecological situations and seasons) are needed in Cuba.

The research agenda about introduced species and their influence on native species is of paramount importance in conservation biology. For most introduced species of anurans in the Caribbean, we still need empirical data from field studies about their ecological requirements, interspecific interactions, and the factors that most likely facilitate their establishment beyond their origins (Ficerola et al. 2007; Ríos-López et al., in press). We provided the first approximation of such a study in Cuba, which may allow for future, more-detailed studies about the ecology of this introduced species of anuran in Cuba and elsewhere in the insular Caribbean.

ACKNOWLEDGEMENTS

This research was undertaken by the "Proyecto Técnico para la investigación, estudio y monitoreo de la flora y fauna silvestre, FONADEF" of the Estación Biológica Sierra del Rosario. We are very grateful to the direction and staff of the Botanical Garden "Orquidiario de Soroa" for logistical support. To Yeniseys Cabrales Caballero for assistance during the fieldwork. To Tomás M. Rodríguez-Cabrera and the anonymous reviewers for the comments on the manuscript.

LITERATURE CITED

Abreu, R. N., and J. de la Cruz. 1988. Algunos datos sobre la alimentación del almiquí (*Solenodon cubanus*) (Insectivora: Solenodontidae) en vida libre. Miscelánea Zoológica 10:2–3.

Adams, M. J., and C. A. Pearl. 2007. Problems and opportunities managing invasive bullfrogs: Is there any hope? Pages 679–693 in F. Gherardi, editor. *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats.* Springer, Dordrecht, The Netherlands.

Alonso, R., and L. Y. García Padrón. 2017. Anfibios. Pages 348–375 in C. A. Mancina and D. D. Cruz, editors. *Diversidad biológica de Cuba: métodos de inventario, monitoreo y colecciones biológicas.* Editorial AMA, La Habana, Cuba.

Alonso, R., and A. Rodríguez. 2003. Advertisement calls of Cuban toads of the genus *Bufo* (Anura, Bufonidae). Phyllomedusa 2(2):75–82.

Alonso, R., A. J. Crawford, and E. Bermingham. 2012. Molecular phylogeny of an endemic radiation of Cuban toads (Bufonidae: *Peltophryne*) based on mitochondrial and nuclear genes. Journal of Biogeography 39:434–451.

Alonso, R., S. del Castillo Domínguez, E. L. Torres Martínez, and L. Y. García Padrón. 2014. El anfibio endémico cubano de mayor talla: conciliando récords, literatura y colecciones. Revista Cubana de Ciencias Biológicas 3(3):60–64.

Blaustein, A. R., and J. M. Kiesecker. 2002. Complexity in conservation: lessons from the global decline of amphibian populations. Ecology Letters 5:597–608.

Bury, B. R., and J. A. Whelan. 1984. Ecology and management of the bullfrog. Resource Publication 155. U.S. Fish and Wildlife Service, Washington, DC.

Clarkson, R. W., and J. C. De Vos. 1986. The Bullfrog, *Rana catesbeiana* Shaw, in the lower Colorado river, Arizona-California. Journal of Herpetology 20:42–49.

Cross, C. L., and S. L. Gerstenberger. 2002. *Rana catesbeiana* (American Bullfrog). Diet. Herpetological Review 33(2):129–130.

Culley, D. D., Jr. 1981. Have we turned the corner on bullfrog culture? Aquaculture Magazine 7:20–24.

Díaz, L. M., and A. Cádiz. 2008. Guía taxonómica de los anfibios de Cuba. AbcTaxa 4:1–294.

Escoriza, D., and D. Boix. 2012. Assesing the potential of an invasive species on a Mediterranean amphibian assemblage: a morphological and ecological approach. Hydrobiologia 680:233–245.

Ficerola, G. F., T. Thuiller, and C. Miaud. 2007. Prediction and validation of the potential global distribution of a problematic alien invasive species - the American bullfrog. Diversity and Distribution 13:476–485.

Frost, S. W. 1924. Frogs as insect collectors. Journal of the New York Entomological Society 32(4):174–185.

Frost, S. W. 1935. The Food of *Rana catesbeiana* Shaw. Copeia 1935(1):15–18.

Garner, T.W. J., M. Perkins, P. Govindarajulu, D. Seglie, S. J. Walker, A. A. Cunningham, and M. C. Fisher. 2006. The emerging amphibian pathogen *Batrachochytrium dendrobatidis* globally infects introduced populations of the North American bullfrog, *Rana catesbeiana*. Biology Letters 2:455–459.

Henderson, R. W., and R. Powell. 2009. Natural history of West Indian reptiles and amphibians: University Press of Florida, Gainesville, FL.

Hirai, T. 2004. Diet composition of introduced bullfrog *Rana catesbeiana*, in the Mizorogaike Pond of Kyoto, Japan. Ecological Research 19:375–380.

Kats, L. B., and R. P. Ferrer. 2003. Alien predators and amphibian declines: Review of two decades of science and the transition to conservation. Diversity and Distribution 9:99–110.

Korschgen, L. J., and D. L. Moyle. 1955. Food habits of the bullfrog in central Missouri farm ponds. The American Midland Naturalist 54 (2):332–341.

Krebs, C. J. 1999. Ecological Methodology. 2nd Edition. Addison-Wesley Educational Publishers, Inc. Menlo Park, CA.

Lillywhite, H. B., Shine R., Jacobson E., Denardo D. F., Gordon M. S., Navas C. A., Wang T., Seymour R. S., Storey K. B., Heatwole H., Heard D., Brattstrom B., and G. M. Burghardt. 2020. Anesthesia and euthanasia of amphibians and reptiles used in scientific research: should hypothermia and freezing be prohibited? BioScience 67:53–61.

Lowe, S., Browne, M., Boudjelas, S., and M. De Poorter. 2000. 100 of the world's worst invasive alien species. A selection from the global invasive species database. ISSG, SSC and IUCN. Available at www.issg.org/booklet.pdf.

Magnusson, W. E., A. P. Lima, W. A. Silva, and M. C. Araújo. 2003. Use of geometric forms to estimate volume of invertebrates in ecological studies of dietary overlap. Copeia 2003:13–19.

Pérez-Osoria, J. E., and L. M. Figueredo Cardona. 2013. Hábitos alimentarios de la especie invasora *Clarias gariepinus* (Burchell, 1822) (Siluriformes: Clariidae) en la laguna Leonero, Granma, Cuba. Brenesia 79:58–63.

Pianka, E. R. 1973. The structure of lizard communities. Annual Review of Ecology and Systematics 4:53–74.

Pianka, E. R., 1974. Niche overlap and diffuse competition. Proceedings of the National Academy of Sciences 71: 2141–2145.

Ríos-López, N., Puente-Rolón, A. R., Angeli, N. F., Vega-Castillo, S., and Dávila-Casanova, D. Amphibians and their history, distribution, and conservation in Puerto Rico and the Virgin Islands. Chapter 21 in Part 5. The Conservation, Demise, and Biogeography of Amphibians in the Caribbean, in Volume 9 of *Status and Decline of Amphibians: Western Hemisphere*, edited by Neftalí Ríos-López and Harold Heatwole. Series: Amphibian Biology. Pelagic Press, Exeter, UK. *In press.*

Rodríguez-Cabrera, T. M., A. del Río Leal, and S. Rodríguez-Machado. 2018. First record of predation on the Cuban endemic freshwater crab *Epilobocera capolongoi* (Brachyura: Pseudothelphusidae). Poeyana 507:84–86.

Ruiz García, F. N. 1987. Anfibios de Cuba. Editorial Gente Nueva, La Habana, Cuba.

Sampedro Marín, A., L. Montañéz Huguez, and O. Suárez Boado. 1985. Alimentación de *Rana catesbeiana* en dos zonas de captura de Cuba. Ciencias Biológicas 13:59–66.

Sampedro Marín, A., V. Rivalta González, and L. M. Díaz Beltrán. 2003. Ranas acuáticas y rivereñas. Pages 38–43 in L. Rodríguez Schettino, editor. *Anfibios y Reptiles de Cuba*. Instituto de Ecología y Sistematica, Academia de Ciencias de Cuba. Ciudad de La Habana, Cuba.

Snow, N. P., and G. Witmer. 2010. American Bullfrogs as invasive species: A review of the introduction, subsequent problems, management options, and future directions. Proceedings of the Vertebrate Pest Conference 24(24):86–89.

Solé, M., O. Beckmann, B. Pelz, A. Kwet, and W. Engels. 2005. Stomach-flushing for diet analysis in anurans: an improved protocol evaluated in a case study in Araucaria forests, southern Brazil. Studies on Neotropical Fauna and Environment 40(1):23–28.

Stewart, M. M., and P. Sandison. 1972. Comparative food habits of sympatric mink frogs, bullfrogs, and green frogs. Journal of Herpetology 6:241–244.

Vrcibradic, D., A. Diaz, B. N. Cosendey, B. B. Nascimento, and V. N. T. Borges-Júnior. 2017. *Trichodactylus dentatus* (Crustacea, Decapoda, Trichodactylidae) and other prey of a large adult of the exotic American bullfrog, *Lithobates catesbeianus* (Ranidae), caught in a disturbed habitat in southeastern Brazil. Herpetology Notes 10:375–378.

Werner, E. E., G. A. Wellborn, and M. A. McPeek. 1995. Diet composition in postmetamorphic bullfrogs and green frogs: Implications for interspecific predation and competition. Journal of Herpetology 29(4):600–607.

Wu, Z., Y. Li, Y. Wang, and M. J. Adams. 2005. Diet of introduced bullfrogs (*Rana catesbeiana*): Predation on and diet overlap with native frogs on Daishan Island, China. Journal of Herpetology 39(4):668–674.

THE CUBAN TREEFROG (AMPHIBIA: ANURA: HYLIDAE: *Osteopilus septentrionalis*), AN EXOTIC ANUROPHAGOUS ON THE LOOSE: A CASE STUDY AND REVIEW

Neftalí Ríos-López[1,*]

[1]Department of Biology, University of Puerto Rico at Humacao, Call Box 860, Humacao, P.R. 00792.
* Author for correspondence: neftali.rios@upr.edu

ABSTRACT

The Cuban Treefrog, *Osteopilus septentrionalis*, has been introduced throughout the Caribbean and southern continental areas in the U.S.A. Scientists frequently refer to it as an invasive that preys upon native anurans voraciously, thus threatening their populations elsewhere. I document the diet of the Cuban Treefrog and compare it with that of two anurans, *Eleutherodactylus coqui* (Common Coqui, endemic) and *Leptodactylus albilabris* (Caribbean White-lipped Frog, native) in an urban area in Puerto Rico and review and re-analyze the available data on its predator-prey dynamics by use of two measures – Number of Frequently-Used Prey Items and frequency of anurans among stomachs. I use these measures to examine published results from the island and continental contexts relative to the Cuban Treefrog's anurophagous reputation. I found that native anurans (and vertebrates at large) represent a negligible fraction of this species' diet in all but one continental location. I suggest that generalized claims about the species' influence on native anurans, specifically those about predation, are equivocal and most likely based on fortuitous accounts available in the scientific literature and non-scientific outlets. Consequently, these findings have profound implications for prioritizing and justifying conservation needs throughout the species' non-native distribution, particularly when ecological, evolutionary, biogeographical, and anthropogenic considerations, other than predator-prey interaction, are frequently overlooked.

Keywords Anurophagy, Caribbean White-Lipped Frog, Common Coqui, Cuban treefrog, feeding ecology, niche breadth, niche overlap.

RESUMEN

La Rana Cubana, *Osteopilus septentrionalis*, ha sido introducida en áreas del Caribe y sureste continental de los EEUU. Frecuentemente, los científicos se han referido a esta especie como una invasiva que depreda vorazmente anuros nativos, amenazando así a sus poblaciones independientemente el lugar de introducción. En este trabajo, documento la dieta de la Rana Cubana y comparo los datos de alimentación con los de dos ranas en Puerto Rico, el Coquí Común (*Eleutherodactylus coqui*) y la Ranita de Labio Blanco (*Leptodactylus albilabris*), en un área urbana, y reviso y reanalizo los datos de alimentación de esta rana que están disponibles en la literatura científica en el tema de la dinámica de presa-depredador que involucra a esta especie. Para este análisis utilicé dos parámetros – el Número de Presas Frecuentemente Utilizadas y la frecuencia de anuros en los estómagos examinados – para examinar resultados publicados, desde los contextos de islas y continente, que se refieren a la reputación de la Rana Cubana como anurófago. Encontré que los anuros nativos (y verte-

ISSN: 1940-1148

brados en general) constituyen un fracción muy pequeña en la dieta de esta especie en todas las áreas y localidades para los que estos datos están disponibles, excepto en una localidad continental. Ante esto, sugiero que los reclamos frecuentemente esbozados en diversos medios informativos y literatura herpetológica sobre la extraordinaria influencia por depredación de anuros de parte de esta especie en su extención geográfica donde ha sido introducida son equívocos y fundamentados mayormente por eventos fortuitos diseminados en la literatura científica y de interés al público no-especializado por igual. Por lo tanto, argumento que estos hallazgos tienen implicaciones profundas para la priorización y justificación de necesidades para la conservación de la fauna nativa ante la Rana Cubana en las áreas donde ha sido introducida, principalmente cuando pudiera pasarse por alto consideraciones ecológicas, biogeográficas, evolutivas y antrópicas aparte de las interacciones presa-depredador.

Palabras clave **Anurofagia, Coquí Común, ecología de alimentación, Rana Cubana, Ranita de Labio Blanco del Caribe, solape y amplitud de nicho.**

INTRODUCTION

The Cuban Treefrog *Osteopilus septentrionalis* is frequently referred to as a successful invasive species with established populations in Florida (U.S.A.), Hawaiian Islands, Costa Rica, Puerto Rico, and in few islands in the Lesser Antilles (Meshaka 1994, 2001; Breuil 2002; Lever 2003; Censki and Kaiser 1999; Henderson and Powell 2009; Meshaka et al. 2020). In continental U.S.A., the species is known to prey upon arboreal and terrestrial anurans from five families (Meshaka 1994, 2001) and is preyed upon by invertebrates, conspecifics, lizards, snakes, turtles, and birds (Lowe 1995; Mitchell and Johnston 2013; Meshaka et al. 2020; Ríos-López et al., unpublished data). Nonetheless, the herpetological literature frequently refers to the "demonstrably negative predatory impacts on native" frogs (Meshaka 2011), that it "will eat anything it can shove into its mouth" (Platenberg 2007), and "can suppress native treefrog populations" (Meshaka et al. 2020). In other words, wherever introduced, it is asserted that *O. septentrionalis* has a negative influence on the local herpetofauna through predator-prey interactions that lead to anuran population-level effects of conservation concern (Breuil 2002; Owen 2005; Burrowes and Joglar 2005; Platenberg 2007; Meshaka 2001, 2011; Meshaka et al. 2020; Rice et al. 2011; Glorioso et al. 2012).

In Puerto Rico, *O. septentrionalis* was collected in Aguadilla to the northwest in 1959 (Rivero 1998; Ríos-López et al., in press), and during the following decades, the species has been documented throughout the coastal lowlands (Joglar and Ríos-López 1995; Joglar et al. 1998), uplands up to urban areas in the Cordillera Central (e.g., Jayuya; personal observation), and Vieques island (Herrera-Giraldo 2010). Some authors have suggested that the increased geographic distribution, presumable few predators, and the voracity of *O. septentrionalis* should have adverse effects on the Puerto Rican frogs as well, particularly to those with threatened and endangered population status (Joglar 1998; Burrowes and Joglar 2005; see Powell and Henderson, in press). However, although predation of native Puertorican frogs by *O. septentrionalis* may seem of conservation concern, its feeding ecology has not been documented in Puerto Rico; it is barely assessed in the Caribbean islands in general.

In this study, I examined the diet of *O. septentrionalis* in a lowland urban secondary-forest in Puerto Rico and compared its diet with that of two endemic/native frogs (*Eleutherodactylus coqui* and *Leptodactylus albilabris*) to examine if *O. septentrionalis* shows dietary overlap with sympatric species of frogs and whether it includes anurans – or other vertebrates – in its diet. Based on the herpetological literature, I assumed that the three species of frogs herein examined are generalists in their feeding requirements and considered this forest site a depauperate ecological situation compared to a mature forest. Therefore, I expected that the diet of the Cuban Treefrog would overlap that of sympatric anurans and that it will significantly prey upon them (and other herpetofauna, including those with nocturnal habits), as suggested elsewhere (e.g., Burrowes and Joglar 2005; Owen et al. 2005; Platenberg and Boulon 2006; Platenberg 2007; Rice et al. 2011; Beard et al. 2018; Meshaka 1994, 2011; Meshaka et al. 2020). Also, I analyzed and contrasted my results of stomach content with published data about the diet of the Cuban Treefrog, both from islands (Meshaka 1996a; Owen 2005) and continental areas (Meshaka 1994; Glorioso et al. 2012). My intention was to find generalities about the influence of this introduced predator, mostly on sympatric anurans, that also apply to Puerto Rico (and elsewhere).

METHODS

Study site and species

The urban secondary-forest is classified in the Subtropical Moist Forest life zone (Ewel and Whitmore 1973). Specifically, this forest lies in the vicinity of a housing project in the municipality of Trujillo Alto (WGS 84: 18° 22’ 39.38” N, 66° 1’ 50.19” W; 100–125 masl), northern Puerto Rico (Figure 1). At the time (and since at least the 1980s), this area was frequently deforested for failed urban projects and used to extract rock slabs for the gardening business. The forest has few plant species, numerous

Figure 1. Study area in urban, northern Puerto Rico (top and second pane). Bottom two panes: study site in June 2002 (deforested), and in January 2020 (reforested; bottom pane).

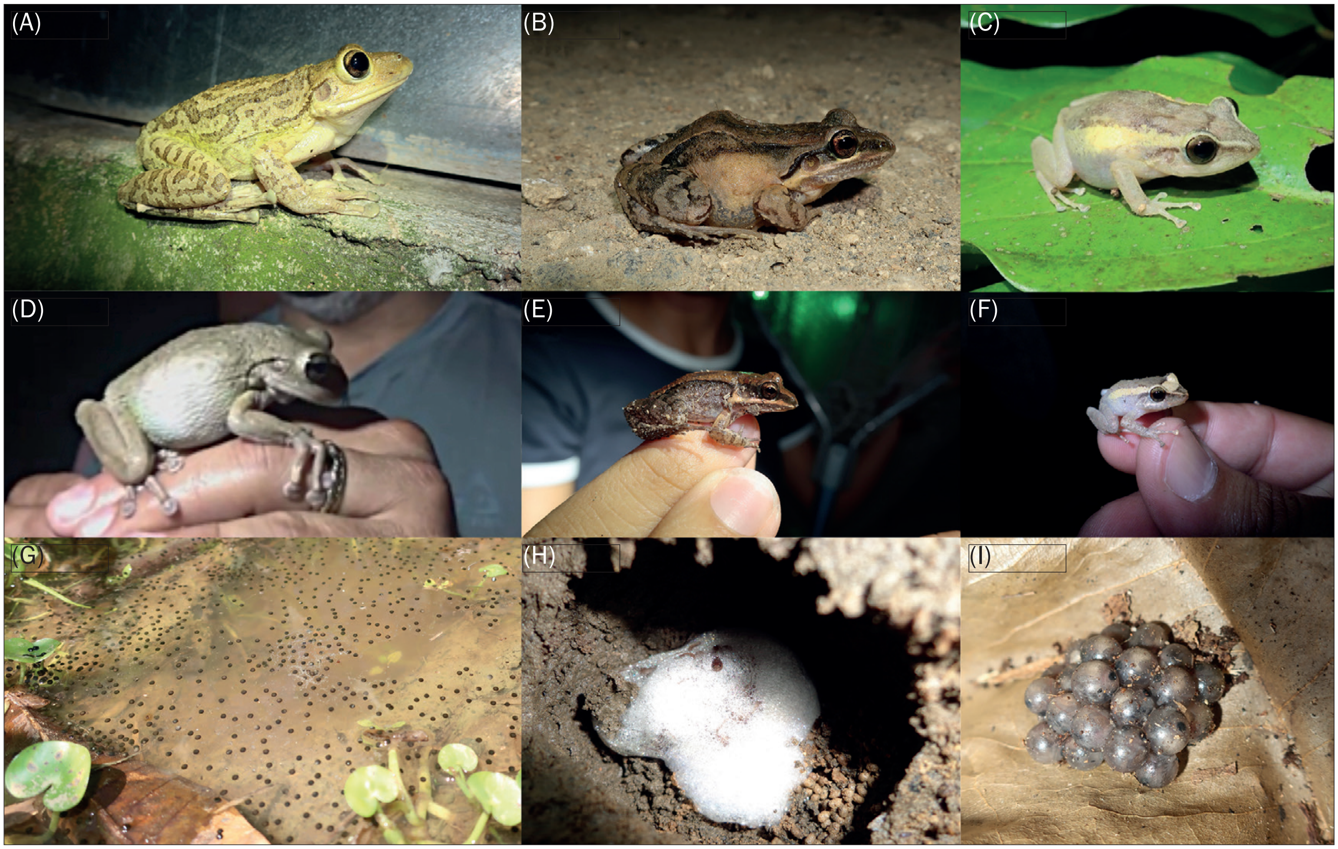


Figure 2. Adult of *Ostepilus septentrionalis* (A), *Leptodactylus albilabris* (B), and *Eleutherodactylus coqui* (C); D–F individuals of the same species as a reference of body size. G–I nest of each species for comparative purposes: *O. septentrionalis*, egg mass floating on standing water (G), eggs of *L. albilabris* in typical foam-nest deposited in a terrestrial burrow (embryos develop into free-swimming larvae until metamorphosis once in water after heavy rains) (H), and terrestrial eggs of *E. coqui* (embryos with direct development and hatch into miniature replicas of adults, no free-swimming stages) (I).

pools throughout the shallow layer of bedrock, and soil that mainly consisted of gravel and a shallow bed of leaf litter from pioneer woody-plant species. The dominant woody vegetation consisted of *Leucaena leucochephala* (Lam.) DeWit (Wild Tamarind, Leguminosae-Mimosoideae). *Leucaena* is a shrub or small tree that grows to 10-m tall and is found in disturbed areas (hillsides, woodlands, and thickets) at low and middle elevations (Liogier 1988). At my collection site (see next), the ground cover consisted mainly of rocks with sparsely-distributed grasses. Adults of *O. septentrionalis* and *E. coqui* (Figure 2) were found throughout the vertical extent of the vegetation and along the edges of trails, while adults of *L. albilabris* were frequently found under rocks and vegetation debris around the edges of ephemeral ponds. Since my collection, the vegetation has recovered, formerly open areas now covered with woody vegetation albeit of pioneer species, and has remained relatively undisturbed for more than a decade and a half.

Sample collection

On 30 September 2002, I collected *E. coqui* (n = 19; snout-vent length [SVL; mean ± SD] in mm = 30.4 ± 1.7 [9 adult males] and 38.4 ± 3.5 [10 adult females]; one female with an empty stomach [Zoological Museum of the University of Puerto Rico-Río Piédras Campus, UPRRP-5793]) and *L. albilabris* (n = 27; SVL = 34.4 ± 1.4 [8 adult males], 20.9 ± 2.5 [3 juvenile males, UPRRP-5845–47], and 40.6 ± 2.2 [16 females]; two males [UPRRP-5810, 5812] and five females [UPRRP-5804–05, 5828, 5833, 5841] with an empty stomach). A week later, on 7 October 2002, I collected

O. septentrionalis (n = 34; SVL = 54.0 ± 2.5 [22 adult males] and 74.9 ± 6.8 [n = 12 adult females]; four males [UPRRP-5820–21, 5822, 5824] and three females [UPRRP-5773, 5775, 5778] with an empty stomach). On both dates, I collected frogs between 1930 hr and 2200 hr.

An anesthetic overdose euthanized frogs by the following day after capture as follows (American Veterinary Medical Association [AVMA] 2001: 685; AVMA 2007: 18): each frog was immersed in commercial benzocaine solution until gular movement, withdrawal reflex when pinching, and visible heartbeats (at the upper third of ventral midline) ceased, usually between ~15 min. for small individuals like *E. coqui* to ~40 min. for larger ones like *O. septentrionalis*. Once these signs ceased, each frog was injected with 10% formalin in its inguinal area, abdominal cavity, and thoracic upper-lateral area and fixed for 24 hrs; afterwards, they were stored in 70% ETOH. Each frog was processed for stomach content and was deposited in the Zoological Museum of the University of Puerto Rico-Río Piedras Campus (UPRRP).

Prey identification, measures of dietary niche, statistical analyses, and comparison of similar data from islands and continental areas

Preyed items in each stomach were classified either to Class, Subclass, Order, Family (in a few cases to Genus and Species), with the vast majority classified to numbered morphospecies. The degree of taxonomic subdivision herein adopted – morphospecies – allowed me to determine measures of ecological parameters (following Krebs 2014): 1) dietary niche breadth (Hurlbert's standardized niche breadth of Levin; *BA*, varies from 0 [maximum discrimination in diet] to 1 [no discrimination in diet]), Shannon-Wiener diversity index (*H'*, as a proxy of breadth for comparative purposes; the larger the index value the broadest its dietary niche), and "Number of Frequently Used Prey Items" (for descriptive purposes); 2) Pianka's index of niche overlap (mean and per species pair [O_{jk}], where *j* and *k* are a pair of frog species; varies from 0 [no overlap] to 1 [complete overlap] for each pair of frog species); 3) and Jaccard's similarity index (S*j*; varies from 0 [completely dissimilar in the proportion of shared morphospecies] to 1 [completely similar] for each pair of frog species). Also, I calculated the number of frequently-used prey items, which is the reciprocal of total taxa (in this study, morphospecies) used per species of frog. More specifically, following Krebs' (2014: 610) recommendations: "If resources are subdivided in great detail, the minimum cutoff for the calculation of the number of frequently-used resources will have to be reduced. As a rule of thumb, the cutoff should be approximately equal to the reciprocal of the number of resources, but never above 10%." Consequently, this number sets the minimum cutoff of frequently-used prey items for descriptive purposes for each species of frog.

I calculated Pianka's niche overlap (and satistical significance) using EcoSim v7.71 (Gotelli and Edntsminger 2015) based on the following design and parameters: a matrix of 3 species of frogs (rows) and 74 morphospecies (columns); 1,000 randomized iterations (random seed = 7); and Randomized Algorithm 3 (RA3; as recommended by Gotelli and Graver [1996: 85], as the "best algorithm to use in resource overlap null models") to retain the amount of discrimination for each species of frog, but allow it to use potentially other morphospecies detected among species of frogs. I adopted $\alpha \leq 0.05$ for statistical significance.

Finally, I reanalyzed dietary data from various publications and sources. These include: 1) Meshaka (1996a) from Havana (Cuba), Nassau (New Providence Islands, Bahamas), and Grand Cayman Islands (Cayman Islands, United Kingdom); 2) Owen (2005) from the British Virgin Islands (United Kingdom); 3) Meshaka (1994) and Glorioso et al. (2012) from South Florida, continental U.S.A.; 4) Vega-Castillo et al. (unpublished data from Cabo Rojo, Puerto Rico). I then contrasted my data for the number of frequently-used

Table 1. Stomach contents by taxonomy and morphospecies number (n = 74 morphospecies total) in decreasing order of occurrence of *Eleutherodactylus coqui* (Ecq), and extended to *Osteopilus septentrionalis* (Os) and *Leptodactylus albilabris* (La). For each species of frog, columns represent the number of Prey Items Detected (PI-D), Frequency of Occurrence (FO; percentage of stomachs with the morphospecies), and Relative Frequency of Occurrence (RFO; percentage of individuals of a morphospecies counted from the total prey items in stomachs with the morphospecies). PI-D includes the absolute quantity of prey followed in parenthesis by % quantity of prey from the total quantity of prey among all stomachs of each species of frog, with the Number of Frequently-Used Prey Items – those used in excess of a minimum cutoff – highlighted in bold. For *E. coqui*, this minimum cutoff was 3.0%, for *O. septentrionalis* was 3.3%, and for *L. albilabris* was 2.9%. FO includes the number of stomachs that contains a given prey (in %). RFO includes the number of times a specific prey was found as a percentage of all prey found in stomachs with the given specific prey. The total quantity of prey items, total morphospecies, and unique morphospecies per frog species are shown at the end of the table. In parenthesis, C = Class, SC = Subclass, or O = Order precedes morphospecies, while Family in parenthesis (or Order within SC) follows morphospecies; otherwise, after morphospecies identification number, notes or Genus (or Species) follows hyphens.

Class-Subclass/Order/Family/ morpho-species – notes	PI-D			FO (%)			RFO (%)		
	Ecq	Os	La	Ecq	Os	La	Ecq	Os	La
(SC) Acari 2 (Order Oribatida)	80 (**44.94**)	455 (**84.10**)	1 (1.35)	38.89	29.63	5.00	62.02	97.64	50.00
(O) Hymenoptera 2 (Formicidae)	31 (**17.42**)	6 (1.11)	8 (**10.81**)	27.78	3.70	10.00	35.63	66.67	25.81
(O) Hymenoptera 1 (Formicidae)	10 (**5.62**)	0	0	22.22	–	–	13.51	–	–
(SC) Acari 1	6 (**3.37**)	1 (0.18)	0	11.11	3.70	–	50.00	2.78	–
(SC) Collembola 1	5 (2.81)	0	0	5.56	–	–	9.62	–	–
(SC) Acari 4	4 (2.25)	5 (0.92)	0	22.22	3.70	–	5.33	83.33	–
(C) Diplopoda 1	4 (2.25)	0	1 (1.35)	16.67	–	5.00	5.97	–	4.35
(SC) Acari 6	3 (1.69)	2 (0.37)	1 (1.35)	11.11	7.41	5.00	17.65	100.00	50.00
(O) Hymenoptera 5 (Formicidae)	3 (1.69)	0	0	11.11	–	–	23.08	–	–
(O) Lepidoptera 1 - *Spodoptera* sp.	3 (1.69)	5 (0.92)	5 (**6.76**)	16.67	18.52	15.00	27.27	1.67	33.33
(SC) Acari 3	2 (1.12)	32 (**5.91**)	1 (1.35)	11.11	3.70	5.00	28.57	88.89	33.33
(O) Blattodea 3	2 (1.12)	0	2 (2.70)	5.56	–	10.00	33.33	–	15.38
(O) Blattodea 4	2 (1.12)	4 (0.74)	0	11.11	7.41	–	9.52	1.48	–
(SC) Collembola 2	2 (1.12)	0	0	5.56	–	–	28.57	–	–
(O) Lepidoptera 2	2 (1.12)	6 (1.11)	0	11.11	14.81	–	18.18	54.55	–
(O) Psocoptera 1	2 (1.12)	0	0	5.56	–	–	40.00	–	–
(SC) Coleoptera 2	1 (0.56)	1 (0.18)	0	5.56	3.70	–	25.00	50.00	–
(SC) Coleoptera 4 (Cerambycidae)	1 (0.56)	1 (0.18)	0	5.56	3.70	–	50.00	100.00	–
(O) Hymenoptera 3 (Formicidae)	1 (0.56)	0	3 (**4.05**)	5.56	–	10.00	1.92	–	27.27
(O) Dermaptera 1	1 (0.56)	0	1 (1.35)	5.56	–	5.00	20.00	–	50.00
(O) Araneae 1	1 (0.56)	0	0	5.56	–	–	7.14	–	–
(O) Araneae 2	1 (0.56)	0	0	5.56	–	–	16.67	–	–
(O) Blattodea 1 (Blattidae)	1 (0.56)	0	0	5.56	–	–	50.00	–	–
(O) Blattodea 2	1 (0.56)	0	0	5.56	–	–	25.00	–	–
(SC) Coleoptera 5	1 (0.56)	0	0	5.56	–	–	20.00	–	–
(O) Diptera 2	1 (0.56)	0	0	5.56	–	–	20.00	–	–
(O) Diptera 3	1 (0.56)	0	0	5.56	–	–	16.67	–	–
(O) Hymenoptera 4 (Formicidae)	1 (0.56)	0	0	5.56	–	–	1.92	–	–
(O) Orthoptera 3 - immature	1 (0.56)	0	0	5.56	–	–	1.92	–	–
(O) Orthoptera 4	1 (0.56)	0	0	5.56	–	–	33.33	–	–
(O) Psocoptera 2	1 (0.56)	0	0	5.56	–	–	25.00	–	–
(O) Psocoptera 3	1 (0.56)	0	0	5.56	–	–	14.29	–	–
(O) Thysanoptera 1	1 (0.56)	0	0	5.56	–	–	1.92	–	–
(SC) Collembola 3	0	3 (0.55)	0	–	3.70	–	–	60.00	–
(O) Diptera 5	0	2 (0.37)	0	–	3.70	–	–	22.22	–
(O) Hymenoptera 6 (Formicidae)	0	2 (0.37)	1 (1.35)	–	3.70	5.00	–	5.41	100.00
(C) Gastropoda 1 - snail	0	1 (0.18)	5 (**6.76**)	–	3.70	20.00	–	3.85	35.71
(O) Diptera 8	0	1 (0.18)	2 (2.70)	–	3.70	10.00	–	0.40	8.33
(O) Lepidoptera 3	0	1 (0.18)	2 (2.70)	–	3.70	10.00	–	7.69	40.00
(O) Anura - *Eleutherodactylus coqui*	0	1 (0.18)	0	–	3.70	–	–	100.00	–
(O) Araneae 7	0	1 (0.18)	0	–	3.70	–	–	100.00	–
(O) Araneae 8	0	1 (0.18)	0	–	3.70	–	–	50.00	–
(O) Coleoptera 1	0	1 (0.18)	0	–	3.70	–	–	3.85	–
(O) Coleoptera 3	0	1 (0.18)	0	–	3.70	–	–	100.00	–
(O) Coleoptera 6	0	1 (0.18)	0	–	3.70	–	–	20.00	–
(O) Diptera 4	0	1 (0.18)	0	–	3.70	–	–	2.78	–
(O) Diptera 6	0	1 (0.18)	0	–	3.70	–	–	100.00	–

(C) Gastropoda 2 - snail	0	1 (0.18)	0	–	3.70	–	–	7.69	–
(O) Hymenoptera 7 (Formicidae)	0	1 (0.18)	0	–	3.70	–	–	3.85	–
(O) Hymenoptera 11	0	1 (0.18)	0	–	3.70	–	–	50.00	–
(O) Lepidoptera - adult	0	1 (0.18)	0	–	3.70	–	–	7.69	–
(O) Orthoptera 2	0	1 (0.18)	0	–	3.70	–	–	100.00	–
(O) Diptera 11	0	0	7 (**9.46**)	–	–	10.00	–	–	22.58
(O) Araneae 4	0	0	5 (**6.76**)	–	–	10.00	–	–	31.25
(O) Diptera 12	0	0	4 (**5.41**)	–	–	5.00	–	–	17.39
(O) Diptera 10	0	0	3 (**4.05**)	–	–	5.00	–	–	60.00
(O) Hymenoptera 10 (Formicidae)	0	0	3 (**4.05**)	–	–	5.00	–	–	37.50
(O) Diptera 1	0	0	2 (2.70)	–	–	5.00	–	–	40.00
(O) Orthoptera 1	0	0	2 (2.70)	–	–	10.00	–	–	66.67
(SC) Acari 5	0	0	1 (1.35)	–	–	5.00	–	–	50.00
(O) Araneae 3	0	0	1 (1.35)	–	–	5.00	–	–	100.00
(O) Araneae 5	0	0	1 (1.35)	–	–	5.00	–	–	12.50
(O) Araneae 6	0	0	1 (1.35)	–	–	5.00	–	–	4.35
(O) Coleoptera 7	0	0	1 (1.35)	–	–	5.00	–	–	4.35
(SC) Collembola 4	0	0	1 (1.35)	–	–	5.00	–	–	50.00
(O) Dermaptera 2	0	0	1 (1.35)	–	–	5.00	–	–	50.00
(C) Diplopoda 2	0	0	1 (1.35)	–	–	5.00	–	–	25.00
(O) Diptera 7	0	0	1 (1.35)	–	–	5.00	–	–	25.00
(O) Diptera 9	0	0	1 (1.35)	–	–	5.00	–	–	20.00
(O) Diptera 13	0	0	1 (1.35)	–	–	5.00	–	–	4.35
(O) Diptera 14 (Psychodidae)	0	0	1 (1.35)	–	–	5.00	–	–	4.35
(O) Hymenoptera 8 (Formicidae)	0	0	1 (1.35)	–	–	5.00	–	–	20.00
(O) Hymenoptera 9 (Formicidae)	0	0	1 (1.35)	–	–	5.00	–	–	50.00
(O) Scolopendromorpha 1	0	0	1 (1.35)	–	–	5.00	–	–	20.00
Total prey items	178 (100.00)	541 (100.00)	74 (100.00)	–	–	–	–	–	–
Total morphospecies	33	30	35	–	–	–	–	–	–
Unique morphospecies	18	15	22	–	–	–	–	–	–
Frequently-Used Items	4	2	9	–	–	–	–	–	–

prey items and the frequency of vertebrates among stomachs of *O. septentrionalis* with the reanalyzed available data. I also provided a review of relevant studies with *O. septentrionalis*.

RESULTS

Part I. Trujillo Alto, Puerto Rico

Stomach content among the three species of frog included 74 morphospecies, and multiple prey items were found in 15/18 stomachs in *E. coqui*, 10/27 in *O. septentrionalis*, and 12/20 in *L. albilabris* (Table 1). In general, all three species of frogs generated a relatively similar amount of morphospecies (from 30 to 35) but differed in the number of prey items: *O. septentrionalis* had the highest number of prey items (541), followed by *E. coqui* (178), and *L. albilabris* (74) (Table 1). Also, all three species of frogs differed in the number of frequently-used prey items, and the minimum cutoff of frequently-used prey items for *E. coqui* was 3.0% (1/33 morphospecies); for *O. septentrionalis* and *L. albilabris* was 3.3% (1/30 morphospecies) and 2.9% (1/35 morphospecies), respectively. For example, Acari (mostly oribatid mites) and Hymenoptera (ants) comprised 71.4% of the prey items in the diet in *E. coqui*, while Acari comprised 90.0% in the diet of *O. septentrionalis* (Table 1); these prey were used more frequently than expected from the minimum cutoff for each species of frog. Both species of frogs shared most prey items (highest Jaccard's S_j among species pairs) and showed significant niche overlap (Pianka's $O_{jk} = 0.922$; $p < 0.0001$) (Table 2). Also, a non-gravid female *O. septentrionalis* (SVL 73.4 mm, UPRRP-5774) had ingested a male *E. coqui* (SVL 26.1 mm), but I can not determine if

Table 2. Pairwise comparison of dietary niche overlap (Pianka's index) and Jaccard's similarity index of species of frogs; Shannon-Wiener Index of Diversity. * = significant at $p < 0.0001$. NS = non significant.

Estimator	*Eleutherodactylus coqui*	*Osteopilus septentrionalis*	*Leptodactylus albilabris*
(a) Pianka's Index (O_{jk})			
E. coqui	–	0.922*	0.250 NS
O. septentrionalis	–	–	0.076 NS
(b) Jaccard's Index (S_j)			
E. coqui	–	0.212	0.153
O. septentrionalis	–	–	0.161
(c) Standardized Levin's Niche Breadth (*BA*)	0.043	0.006	0.262
(d) Shannon-Wiener Index (*H'*)	2.215	0.848	3.267

Table 3. Summary of the percentage of anurans utilized as food resources by *Osteopilus septentrionalis* and minimum cutoff based on dietary data (abundance of prey) from various geographical contexts and sources in herpetological literature. Values of minimum cutoff are followed in parenthesis by the number of categories of prey taxa identified. ENP = Everglades National Park.

Geographical context and study	% anurans	Minimum cutoff in %	Locality
Islands			
This study	0.18	3.3 (74)	Puerto Rico (Trujillo Alto)
Vega-Castillo et al. (unpub. data)	3.9	6.25 (16)	Puerto Rico (Cabo Rojo)
Meshaka 1996[a]	2.0 0.0 6.1	6.25 (16) 10.0 (10) 8.3 (12)	Cuba (Havana) The Bahamas (Nassau) Grand Cayman Is. (Georgetown)
Owen (2005) – data from stomachs	0.28	4.0 (25)	British Virgin Islands
Owen (2005) – data from intestines	0.12	4.2 (24)	British Virgin Islands
Continent			
Meshaka (1994) – all individuals – data for males – data for females – data for females	2.6 2.0 3.7 14.9	3.0 (33) 4.2 (24) 4.2 (24) 5.0 (20)	Florida (ENP; building areas) “ “ Florida (ENP; natural areas)
Glorioso et al. (2012)	5.0	5.6 (18)	Florida (several areas)

this predatory event was due to opportunistic or active foraging behavior. Nonetheless, I found a low frequency of anurans in its diet: one anuran among the 27 stomachs (specimens) examined or 3.7% anurans (one *E. coqui*; no reptiles) among stomachs; the percentage use of anurans by *O. septentrionalis* as a food resource was below its minimum cutoff and represented 0.18%. On the other hand, Lepidoptera, Hymenoptera, gastropods, Diptera, and Araneae comprised 58.1% of the diet of *L. albilabris* (Table 1). Its diet was the most diverse (*H'* = 3.267), had the highest number of unique morphospecies (n = 22), showed the widest breadth (*BA* = 0.262), and the lowest dietary similarity (lowest Jaccard's S_j) and the lowest niche overlap (lowest Pianka's O_{jk}, but non-significant, with either species: Pianka's O_{jk} with *E. coqui* = 0.250; p > 0.134; Pianka's O_{jk} with *O. septentrionalis* = 0.076; p > 0.229) (Table 2). The second most diverse diet came from *E. coqui*, being the lowest that of *O. septentrionalis*, which also had the lowest niche breadth (*BA* = 0.006) (Table 2).

Part II. An island context

In the municipality of Cabo Rojo, southwestern Puerto Rico, Vega-Castillo et al. (unpublished data) collected, from a coastal lagoon, 139 *O. septentrionalis* (77 females and 32 males) from which 66 stomachs had prey items. They found five individuals of *Leptodactylus albilabris*, one per stomach, which represented 7.8% of native anurans among 66 stomachs. The minimum cutoff of the number of frequently-used prey items in their sample was 6.25% (1/16 prey categories; category "others", unidentified, was not used in this analysis) (Table 3). Based on 127 prey items and 16 prey categories, the percentage of anurans used as food resources was lower than the minimum cutoff (Table 3). These authors also found six *Anolis* lizards; the percentage of squamates used as food resources was 4.7%, which was lower than the minimum cutoff.

Meshaka (1996a) conducted studies of the diet of *O. septentrionalis* from other islands and documented: (1) 2.0% anurans among stomachs (a nonspecific metamorphic hylid in a stomach: n = 49 stomachs) and 2.0% reptiles (one *Anolis sagrei* in one, but different stomach; n = 49 stomachs) from Havana, Cuba; (2) 0.0% species of herpetofauna (n = 12 stomachs) in Nassau, New Providence Island, The Bahamas (which harbors 26 species of herpetofauna; see www.caribherp.org); (3) 6.1% anurans (one Eleutherodactylidae [*Eleutherodactylus planirostris*, formerly Leptodactylidae; Meshaka {1994}] and one Microhylidae [*Gastrophryne carolinensis*; Meshaka {1994}], each on different stomachs; n

= 33 stomachs) in Georgetown, Grand Cayman Island, U.K. (Table 3). Based on 83 prey items and 16 prey categories from Cuba, 49 prey items and 10 prey categories from The Bahamas, and 38 prey items and 12 prey categories from Grand Cayman Island, the percentage of anurans utilized as food resources by *O. septentrionalis* was under the minimum cutoff of the number of frequently-used prey items from each of the three islands (Table 3).

Similarly, in the British Virgin Islands (BVI), Owen (2005: 21; her Table 3.1) collected 428 *O. septentrionalis* from which 241 stomachs had prey items; I examined her data based on these 241 individuals for conservative considerations. She generated 25 prey categories (one category, "bones", from three stomachs was not considered in my analysis) and found 725 prey items among stomachs. Also, she found anurans (two individuals) in two stomachs (2/241 = 0.83%) and squamates (four individuals) in four stomachs (4/241 = 1.66%), although she did not specify if from the same or different stomachs. Based on 725 prey items and 25 prey categories, the percentage of anurans utilized as food resources was negligible (Table 3); similarly, the percentage of squamates used as food resources was negligible and represented 0.55% of prey items.

Also, Owen (2005; her Table 3.1) included data for prey items in the intestines among her sample of 428 individuals of *O. septentrionalis*, and found items in 393 intestines and generated 24 prey categories (Arachnida: Sulfugidae, not found in intestines; category "bones", with remains in 10 intestines, not considered in my analysis). Anurans (two individuals) were represented in 0.51% of intestines (2/393), and squamates (four individuals) were represented in 1.02% of intestines (4/393); as before, the author did not specify if these items came from the same or different intestines. Compared with data from stomachs (see above paragraph), the minimum cutoff number of frequently-used prey items from intestines increased slightly to 4.2%. Based on 1,663 prey items and 24 prey categories, the percentage of anurans utilized as food resources also was very negligible (Table 3); similarly, the percentage of squamates used as food resources was very negligible and represented 0.24% of prey items.

Part III. A continental context

Meshaka (1994) examined the diet of *Osteopilus septentrionalis* in Florida's Everglades National Park and compared its diet composition between areas classified "buildings" and "natural", and Butterfield et al. (1997: p. 134) mentioned that "The Cuban tree frog, *Osteopilus septentrionalis*, preys on *Bufo terrestris*, *Gastrophryne carolinensis*, *Rana sphenocephala*, *Hyla cinerea*, *H. squirella*, and conspecifics (Meshaka 1994)." However, Meshaka et al. (2000) documented 16 species of amphibians (4 species of Caudata; 12 species of Anura – frogs and toads) and 47 species of reptiles from the Everglades National Park in Florida (U.S.A.). Except for the direct-developer *Eleutherodactylus planirostris* (introduced), all amphibians documented by Meshaka et al. (2000) depend on water for reproduction and development of larvae (or pre-metamorphic efts of *Notophthalmus viridescens*), which overlaps *O. septentrionalis*' ecological requirements for reproduction and development. From this context, I will show results from these studies separately for "building" and "natural" areas (Table 3).

From "building" areas, Meshaka (1994: 55) examined 47 stomachs of males and 60 stomachs of females of *O. septentrionalis* with prey items, generated 33 prey categories with representatives among stomachs (his Table 5, pages 101–102), and 417 prey items among stomachs. He found anurans in 11 stomachs (one anuran in each stomach; 11/107 stomachs) for a 10.3% native anurans represented among stomachs of *O. septentrionalis*. These anurans were six individuals of *Gastrophryne carolinensis* (Microhylidae; terrestrial) and five of *Dryophytes* spp. (*D. squirella* and *D. cinereus*; arboreal). He also found two conspecifics, which increases the representation of anurans in stomachs to 12.1% (two stomachs with one conspecific each). Also, he found 0.9% reptiles represented among stomachs of

O. septentrionalis (one gekkonid in one stomach; species undetermined). Based on 417 prey items and 33 prey categories, the percentage of native anurans used as food resources by *O. septentrionalis* was lower than the minimum cutoff number of frequently-used prey items (Table 3); similarly, the percentage of squamates used as food resources was negligible and represented 0.24% of prey items from "building" areas.

If diet's data from Meshaka (1994) are divided between males and females from "building" areas, the representation of anurans among stomachs in males of *O. septentrionalis* (n = 47 stomachs) reaches 6.4% (three stomachs with one anuran each). Based on 150 prey items and 24 prey categories, the percentage of anurans utilized as food resources by males was lower than the minimum cutoff in "building" areas (Table 3). Likewise, the representation of anurans among stomachs in females (n = 60 stomachs) reaches 15.0% (nine stomachs with one anuran each). This representation increases to 18.3% when including conspecifics (two stomachs with one conspecific each); also, squamates were found in one stomach (one gekkonid in one stomach; species undetermined: 1/60 = 1.7%), but it was not specified if it was found in one of the stomachs with a conspecifics or a third stomach. However, based on 267 prey items and also 24 prey categories (categories different than those identified for males), the percentage of anurans utilized as food resources by females also was lower than the minimum cutoff (Table 3).

From "natural" areas, Meshaka (1994: 56–57) provided data only for females of *O. septentrionalis*. He examined 62 stomachs of female *O. septentrionalis* with prey items, generated 20 prey categories with representatives among stomachs (his Table 5, pages 101–102), and 87 prey items among stomachs. He found anurans in 13 stomachs (one anuran in each stomach; 13/62 stomachs) for a 21.0% representation of native anurans in stomachs (there were no conspecifics). These anurans were 11 individuals of *Dryophites* spp., 1 *Lithobates sphenocephalus* (Ranidae; terrestrial), and 1 *Anaxyrus* (*Bufo*) *terrestris* (Bufonidae; terrestrial). Also, he found squamates in one stomach (one iguanid in one stomach; species not identified: 1/62 = 1.6% squamates among stomachs). Based on 87 prey items and 20 prey categories identified for these females, the percentage of anurans utilized as food resources was higher than the minimum cutoff in "natural" areas (Table 3).

Finally, Glorioso et al. (2012) examined the diet of *O. septentrionalis* in several areas in South Florida, U.S.A., including two "natural" microhabitats sampled by Meshaka (1994), pine rockland and mangrove sites. These authors (their Table 1, page 351) found 585 stomachs (from a sample of 767 frogs) with prey items, and 18 categories adequate for comparative purposes (they included categories "Skin" [unidentified], "Unidentified Invert." [52 individuals?], "Insect Matter" [unidentified], "Unidentified Vert." [two individuals?], and "Unidentified" that limits comparison of data herein included). There were 581 prey items among these categories, excluding "Unidentified Invert." and "Unidentified Vert.". They found anurans in 29 stomachs (29/585 = 4.96% representation among stomachs), a squamate in one stomach (= 0.17%), and a mammal in one stomach (= 0.17%). Based on 581 prey items and 18 prey categories, the percentage of anurans utilized as food resources was lower than the minimum cutoff (Table 3). Suppose I use Glorioso's et al. (2012) data from two additional categories, "Unidentified Invert." (assuming 52 individuals found among 49 stomachs) and "Unidentified Vert." (assuming 2 individuals among two stomachs), the percentage of anurans utilized as food resources decreases to 4.6%. In that case, however, it remains lower than the minimum cutoff number of frequently-used prey items of 5.0% (1/20 prey categories).

DISCUSSION

Part I. Trujillo Alto, Puerto Rico

Eleutherodactylus coqui and *O. septentrionalis* are mainly arboreal, and as expected, they had similar diets, as revealed by their significant dietary overlap.

However, this overlap may not be indicative of competition necessarily. For example, their dietary overlap might result from feeding on the same resources that are themselves abundant, and, as such, I can only say that both species of frogs shared a significant proportion of the available prey items at my study site (see Colwell and Futuyma 1971). Nonetheless, these arboreal species of frog also showed the smallest niche breadth, and a large fraction of their diet was characterized by relatively small items like Acari (mostly oribatid mites) and Hymenoptera (all ants found). In contrast, *L. albilabris* had the most different diet composition, which may relate to its different foraging regime as a ground-dwelling species. The most frequent prey items in the diet of *L. albilabris* included morphospecies in orders Dermaptera, Scolopendromorpha, Diplopoda, Orthoptera, Araneae, Diptera, Hymenoptera, Lepidoptera (*Spodoptera* sp. or armyworm moths, one of eight documented species in Puerto Rico [most formerly under various genera in Wolcott {1948b: 537–748}; also see http://mothphotographersgroup.msstate.edu/AC-PR/ACchecklist.shtml]). Also frequently consumed were gastropods, barely shared, if at all, with the other species of frogs; its diet also included prey items frequently found in the ground at my study site and rarely among samples of the other two species of frogs (e.g., Scolopendromorpha, Dermaptera, Diplopoda, gastropods). However, that oribatid mites (Suborder Oribatidae; e.g., Acari 2) were exceedingly represented in the diet of *E. coqui* and *O. septentrionalis* was, at first, unexpected (considering the large body size of *O. septentrionalis*), but may reflect the relatively simple microhabitat (leaflitter and landscape at large) at this site and may relate to the microhabitat and feeding mode of oribatids (see next paragraph).

As non-parasitic and decomposers (e.g., saprophagous, although many are microphytophagous), mites in the Suborder Oribatidae are most conspicuous in the leaflitter and soils (Subías 2004; Abreu-Rodríguez 2017). For example, in Puerto Rico, Abreu-Rodríguez (2017) listed 45 species in 24 families in the Suborder Oribatida (non-parasitic species): 51.1% (23 species) documented only from the leaflitter, 15.6% (7 species) only from bat's guano, 17.8% (8 species) only from plants, and 2.2% (1 species) from debris and excrements of the sugarcane-borer moth *Diatraea saccharalis*. Also, 8.9% (4 species) documented by Abreu-Rodríguez (2017) consists of mites known from both the leaflitter and bat's guano, which increases the percentage of mites represented in the leaflitter to 60. These mites also may congregate in excrements and dead organisms and, because of their numbers and mobility, may attract the attention of frogs foraging on the ground. Wolcott (1948a: 27) mentioned that "*Mites are an important item of food for the 'zapitos' or minute toads of Bufo marinus*", and documented three species of mites from the diet of *Rhinella marina*, all oribatids (see also Abreu-Rodríguez 2017). On the other hand, Meshaka (1994) mentioned that in the Everglades National Park in Florida, U.S.A., the predatory behavior of *O. septentrionalis* changes with the availability of prey in disturbed habitats compared with natural areas. Therefore, I may think of two scenarios that may explain the high frequency of oribatid mites in the diet of *O. septentrionalis* (and, to a lesser extent, of *E. coqui*) in my study site (discussed next).

Although *O. septentrionalis* is a sit-and-wait predator, it is plausible that aggregations of mites in the leaflitter (e.g., on top of decaying organic matter) at my study site may elicit its predatory response. Alternatively, a few species of oribatid mites are capable of phoretic dispersal, "usually on beetles" (Coons and Rothschild 2008), and may have been ingested in considerable quantity while on any of the six morphospecies of Coleoptera found in the diet of *O. septentrionalis* (five morphospecies) and *E. coqui* (three morphospecies) (see Table 1). However, one *E. coqui* (UPRRP-5794, female) had both a Coleoptera (morphospecies 2, one individual) and the oribatid mite "Acari 2" (two individuals), while one *O. septentriona-*

lis (UPRRP-5818, male) had both a Coleoptera (morphospecies 1, one individual) and the oribatid mite "Acari 2" (23 individuals). The number of the oribatid mite "Acari 2" found along with morphospecies of Coleoptera in *E. coqui* and *O. septentrionalis* fell extremely short of what would have been expected if these mites were using beetles for dispersal: the number of "Acari 2" found among other stomachs without Coleoptera in *E. coqui* was 8, and *O. septentrionalis* was 432 (from Table 1). Consequently, although little is known about the ecology of mites in general, I suggest the former scenario as a plausible explanation for the high representativeness of mites in both frog's diets: mites aggregated on organic matter on the ground may have elicited a predatory response leading to ingest clumps of oribatid mites by *E. coqui* and *O. septentrionalis*. If so, this scenario supports that oribatid mites also are important arthropods for ecosystem processes related to carbon, nutrients, and energy flows through accelerating decomposition (OConnor 2003; Abreu-Rodríguez 2017) and by way of predator-prey interactions (Wolcott 1948a; this study).

Mites also were consumed by *L. albilabris*, but one possible explanation for their low frequency in its diet may relate to a more diverse dietary base at ground level in this study site. Thus, investing energy in foraging and preying smaller items like these mites, compared to, for example, ground-dwelling snails (gastropods) at this site, may not be favored from a cost-benefit foraging perspective. However, *L. albilabris* also frequently consumed ants (as well as did *E. coqui*), which reveals the difficulty of interpreting these patterns, more so considering the limited information about the feeding ecology of *L. albilabris*, and why, if it is a generality, this species may feed on Hymenopterans more frequently than Acari.

To my knowledge, the information about the diet of *L. albilabris* in Puerto Rico and the Virgin Islands (either from the systematic collection or fortuitous observations) exists from three sources: 1) Schmidt (1920: 169), which mentioned the stomach content found among 17 individuals out of 25 collected throughout Puerto Rico, but unfortunately, all items were lumped into very coarse generalized categories (i.e., land snails, spiders, ants, beetles, bugs, flies [Muscidae], small moth, large caterpillar, cockroach remains of an unidentified insect); 2) Lavigne and Drewry (1970: 66), which mentioned the stomach content found among three females and only used Order or Class of items (i.e., Araneida, Diplopoda, Hemiptera, and Hymenoptera); 3) and Joglar (2005: 74), which mentioned having observed an adult frog preying upon an earthworm. Notably, *L. albilabris* deserves special attention because it is widely distributed throughout Puerto Rico and the Virgin Islands (U.S. and British), and classified Least Concern by the International Union of Conservation of Nature (IUCN) (IUCN SSC Amphibian Specialist Group 2021). Yet, few studies exist about its population and community dynamics and feeding ecology. As a result, we know very little about most of its ecological requirements in Puerto Rico and the Virgin Islands (see review in Henderson and Powell 2009), which justifies additional studies of its natural history and ecology throughout its distribution.

Finally, I found a similarity in diet composition between *Eleutherodactylus coqui* and *Osteopilus septentrionalis* (and to a lesser degree, predation of *E. coqui*), which could be expected due to similar habitat use, compared to the diet of *L. albilabris*. Also, I found that species of herpetofauna (only Anura) represented 3.7% of stomachs of *O. septentrionalis* (n = 27 stomachs; one *E. coqui* in one stomach), but this represents 0.18% of its Number of Frequently-Used Prey Item (Table 1), which, compared with the minimum cutoff of 3.3%, is negligible. Notably, the percentage of occurrence of anurans in stomachs of *O. septentrionalis* seems very low, bearing in mind that: 1) *E. coqui* is the most abundant frog on the island, and 2) considering that the diversity of the Puertorican herpetofauna (as is of islands in general; see Rodda and Dean-Bradley 2002) also is characterized by density-compensation: relatively few species, but of high density, compared to continental areas (e.g., Ríos-López et al. 2015). For instance, Stewart and Woolbright (1996: 284) estimated the population density of *E. coqui* to be 20,570 individuals at El Verde, Luquillo Experimental Forest, northeastern Puerto Rico, which, according to Rodda et al. (2001: 334) is "…the highest published density of non-aggregated frogs".

How do my results compare to results from other studies of the diet of *O. septentrionalis* indicative of a predator of anurans elsewhere? I use two indices that allow for direct comparisons among data from this and other studies that document the diet of *O. septentrionalis* in islands and continental areas: the percentage of anurans among stomachs and the Number of Frequently-Used Prey Items (calculated from published data).

Dietary data among similar studies with the Cuban Treefrog: an island and continental contexts

Part II. An island context

Data from Vega-Castillo et al. (unpublished data) revealed that predation of anurans by *Osteopilus septentrionalis* is negligible in Puerto Rico, and their data on diet composition is similar to the one documented herein from Trujillo Alto. Likewise, the evidence from (1) Havana (Cuba), (2) Nassau, New Providence Island (The Bahamas), and (3) Georgetown, Grand Cayman Island (U.K.) by Meshaka (1996a), and (4) British Virgin Islands (U.K.) by Owen (2005) revealed that predation of anurans (and herpetofauna at large) also is negligible in the species' diet (Table 3). Consequently, I suggest that the evidence favors an opportunistic but very infrequent predator of anurans (and reptiles) in these islands. Most likely, the influence of *O. septentrionalis* may not be different from that of sympatric species of native anurans in Caribbean island ecosystems. However, the latter statement could be hard to test – other than fortuitous observations on anurophagy or saurophagy – without studies of feeding ecology in multispecies assemblages.

Part III. A continental context

The evidence is equivocal based on data from various studies in the Everglades National Park in Florida, U.S.A., by Meshaka (1994), and South Florida, U.S.A., by Glorioso et al. (2012) and Rice et al. (2011). For instance, anurophagy in *O. septentrionalis* occurred more frequently than expected in "natural" areas in the Everglades National Park, not so in "building" areas (see Results; Table 3). A detailed analysis of the species' diet revealed two trends in predation. First, a sex-related bias in anurophagy, between male and female *O. septentrionalis*, with females feeding on anurans at a higher frequency compared to males, regardless of microhabitat (i.e., "buildings", "natural"); nonetheless, saurophagy (and cannibalism) was negligible. Second, anurophagy was higher for the ground-dwelling *Gastrophryne carolinensis* in "buildings" microhabitat and the arboreal-dwelling *Dryophites* spp. in "natural" microhabitat, compared to other sympatric species of frogs. Whether the evidence relates (1) to different foraging behavior (ground or arboreal) by *O. septentrionalis* depending on environmental context (2) or the relative abundance of prey under each environmental context (see Heflick 2001) remains undetermined as far as I know.

Glorioso et al. (2012), however, sampled *O. septentrionalis* for dietary analyses and included two of the "natural" microhabitats sampled by Meshaka (1994), pine rockland and mangrove sites. Also, Glorioso et al. (2012) more than tripled the number of individuals of *O. septentrionalis* sampled by Meshaka (1994) (i.e., 585 versus 169) and concluded that "Corroborating previous research…" anurans played "…only a minor role in the overall diet [of *O. septentrionalis*]". This latter statement contrasts with evidence from Meshaka (1994) and statements elsewhere (e.g., "The effect of Cuban Treefrog predation on native hylid treefrogs can be profound" Meshaka [2011: 12]; "…it can suppress native treefrog populations" Meshaka et al. [2020: 1]).

Notably, Rice et al. (2011) examined responses of native hylid frogs to the removal of *O. septentrionalis* in the Everglades National Park, Florida, U.S.A. These authors, however:

1. "found only limited evidence of an increase in survival of native species" (page 114) with the removal of *O. septentrionalis*;
2. "no support…that Cuban Treefrogs were excluding native treefrogs behaviorally" (page 114; and as also found by Hoffman 2007 from laboratory experiments);
3. "have no means to evaluate whether resource competition is a factor…but know that there is a degree of overlap in the prey of the treefrog species…and that there may be competition taking place among larvae" (page 114; even though they did found no larvae at their sites during their study);
4. speculated about the possible role of predation in the decline of native populations of treefrogs based on data from Glorioso et al. (at the time, in press; published in 2012; see above).

Nonetheless, Rice et al. (2011: 105) asserted that their study "demonstrates that an introduced predator [*O. septentrionalis*] can have population-level effects on similar native species" of frogs.

Lessons and Implications for Conservation

Since the early 1990s, a peculiar interest in studying the influence of *O. septentrionalis* elsewhere arose notably and highlighted the "negative impacts" of this species on native herpetofauna throughout its non-native distribution. Other studies found it rather difficult to explicitly mention the lack of evidence favoring such claims, even though their results pointed in that direction (e.g., Rice et al. 2011; Glorioso et al. 2012). Others are less explicit: Hoffman (2007) and Hoffman et al. (2018) did not find evidence that *O. septentrionalis* influenced native anuran behaviorally nor chemically (under captive conditions). Unfortunately, Hoffman et al. (2018) mentioned that native treefrogs could be "unable to detect and avoid pipes used by predatory Cuban treefrogs" because of their experimental design. These authors added that "if large Cuban treefrogs residing in a PVC refuge regularly consume other treefrogs attracted to that refuge, smaller individuals might be underrepresented in PVC refuge samples and the refuges themselves could act as sinks for native treefrogs. We suggest that future research should address this important topic." These authors cited Wyatt and Forys (2004) as the source for their speculation (see next paragraph).

Wyatt and Forys (2004) and Burrowes and Joglar (2005: 65) mostly examined predation of native anurans by *O. septentrionalis* under captive conditions. In both studies, *O. septentrionalis* ate anurans: *Dryophytes cinereus* and conspecifics of various body sizes (Wyatt and Forys 2004), and adult and hatchlings of *Eleutherodactylus coqui* (Burrowes and Joglar 2005). Both studies concluded that (1) "the feeding trials did show that predation does occur on Green Treefrogs [*D. cinereus*] and that the feeding strategy of Cuban Treefrogs [*O. septentrionalis*] is to consume whatever prey is abundant and easily consumed" (Wyatt and Forys 2004: 699) and (2) that *O. septentrionalis* "competes with the Common Coqui [*E. coqui*] for daytime retreats, calling sites, and food, and that its introduction in Puerto Rico could cause the population decline of the native species and other ecologically similar species" (translated freely from Burrowes and Joglar 2005: 65). Notably, neither study described the housing conditions/terraria used to run the feeding trials and keep frogs in captivity, and the sample size was small (5 individuals of *O. septentrionalis* in Wyatt and Forys 2004) or not mentioned in Burrowes and Joglar (2005). Both issues are not trivial because a small housing and a few or lack of retreat sites, along with limited feeding regimes, and if that were the case in these studies, would inevitably lead to a predation event, and using a small sample size could generate a wide variety of outputs that would be misleading in search of generalities and confirmation purposes.

Other studies missed citations that are nonetheless relevant to their studies, which may generate questions about the accuracy of major conclusions or arguments about the influence of this species elsewhere. As a simple example, Meshaka (1996b) documented and described the occurrence of the nematode *Skrjabinoptera scelopori* in *O. septentrionalis* from the Everglades National Park, and presented data about the potential implication of *O. septentrionalis* as a vector of parasites throughout its distribution (both, introduced and native; e.g., the U.S.A., Cayman Islands, Bahamas, and Cuba). However, in a publication examining this topic in Tampa, Florida, U.S.A., Ortega et al. (2015: 380) mentioned that although *O. septentrionalis* "have inhabited Florida for nearly 100 years, we are unaware of any published surveys of its parasites in this introduced range."

This literature review, though not exhaustive, revealed mostly anecdotal-like assertions about the influence of *O. septentrionalis* on native anurans wherever introduced. A foremost influence being its voracious behavior as a predator of native and introduced herpetofauna (e.g., Breuil 2002; Wyatt and Forys 2004; Owen 2005; Burrowes and Joglar 2005; Platenberg 2007; Meshaka 1996a, 2001, 2011; Meshaka et al. 2020; Rice et al. 2011; Glorioso et al. 2012; Portal Ríos et al. 2020; see Introduction) (Figure 3).

Noticias · Puerto Rico

Rana depredadora del coquí campea por su respeto en Puerto Rico

Se trata de la rana cubana, la cual ha sido avistada tan reciente como este fin de semana en un patio residencial de Cupey

El nombre científico de la rana cubana es Osteopilus septentrionalis. (Flickr: Thomas Brown)

Nota de archivo: esta historia fue publicada hace más de *7 años.*

Por Rosita Marrero
18 de noviembre de 2014 · 10:20am

Se cree que llegó a la Isla de forma clandestina para los años 70 y hoy, al igual que otras especies exóticas, constituye una amenaza para nuestra fauna, particularmente para nuestro coquí, al que gusta devorar, al igual que a los lagartijos y a los insectos.

Figure 3. Editorial cover of local newspaper *Primera Hora* highlighting the outlaw reputation of *Osteopilus septentrionalis* as a predator of coqui frogs on the island. Downloaded from https://www.primerahora.com/noticias/puerto-rico/notas/rana-depredadora-del-coqui-campea-por-su-respeto-en-puerto-rico/.

Major issues may slip from our hands: most observations come from human-dominated landscapes, and the evidence herein shown and discussed revealed that the description of the ecological context of an introduced species like *Osteopilus septentrionalis* is of paramount importance for conservation because the influence of such a species on other anurans (and herpetofauna at large) will differ throughout a landscape, biogeographic regions, and relative "importance". I would argue that results from the pioneer study of Meshaka (1994) in the Everglades National Park can not be extended to islands like Puerto Rico (and others from the Caribbean; see above). Firstly, assemblages of anurans in the latter are mostly characterized by direct developers (e.g., *Eleutherodactylus*) that do not depend on bodies of water for reproduction, and the chances of interspecific interactions throughout the landscape could be minimal; this is an ecological/evolutionary context. Secondly, there is also an important anthropogenic context. For instance, on these islands, introduced *O. septentrionalis* is mostly found restricted to disturbed (e.g., urban) situations and artificial microhabitats elsewhere (e.g., water cisterns in the British Virgin Islands [Perry et al. 2006], urban areas where pools and much-smaller wetland areas abound like in

Puerto Rico, and to a lesser degree, in the U.S. Virgin Islands, among other areas).

Consequently, *Osteopilus septentrionalis* is rather closely associated with human dwellings and landscapes transformed by human activities in general. I suggest that the introduction of *O. septentrionalis* must be understood within this context for conservation efforts in the Caribbean. Also, the Caribbean has different ecological dynamics compared with continental areas. For example, there is a greater environmental heterogeneity at smaller spatial scales, higher topographic and microclimatic variability and conditions at smaller spatial scales, and density-compensation of species, albeit lower diversity but higher endemism on Caribbean islands (among other differences). Based on herpetological and conservation literature, I conclude that, at least, generalities about *O. septentrionalis* on local fauna drawn from continental contexts may not apply to island contexts.

Sampling caveats and concluding remarks

I acknowledge that witnessing and documenting predatory events in nature is difficult; it also attracts the most attention and leads to cause-and-effect debates regardless of the evidence at hand. Nevertheless, I call for distinguishing fortuitous events of predation in *O. septentrionalis* – throughout its introduced distribution – from trends, patterns, and processes frequently called for as justifications for conservation of native herpetofauna in the scientific literature. Most likely, claims about the influence of *O. septentrionalis* on native anurans in the Caribbean could be, at least, equivocal when compared with evidence from the Everglades National Park and the state of Florida (U.S.A.). However, several patterns emerge from the current study and review. For example, in areas where most (or all) anurans depend on bodies of water for reproduction – like in the Everglades National Park – the influence of *O. septentrionalis* may occur by the use of similar resources for foraging and retreat (e.g., buildings and arboreal situations within wetlands), which leads to a higher probability of interspecific interactions like predation. However, whether that scenario currently warrants mobilization of limited resources for conservation when in light of generally weak evidence deserves greater consideration. So far, accounts of predation of herpetofauna by *O. septentrionalis* still are fortuituous for virtually all reptiles and many species of anurans; nonetheless, predation by *O. septentrionalis* seems taxonomically-oriented, and most probable, based on the abundance of a specific vertebrate prey within a given environmental context. The latter may fall within the realm of Optimal Foraging Theory (see Sih 2011 for a review) and needs future study for a broader understanding of predator-prey interaction from the context of an introduced species like *O. septentrionalis* and implications for conservation.

Also, several aspects of my study design and the dynamics of food availability need clarification for context and interpretation of results: 1) the number of frequently-used prey items must not be confused with a measure of resource preference because I (nor the cited studies) did not sample *unused but potentially available* prey resources for the study area; 2) I can not assess if the number of prey items per morphospecies is very large at the time of my sampling (i.e., because the availability of a prey decreases with exploitation), which is important if "preference" exists among species of frogs and detection of preference is a major goal; 3) availability of food resources also vary seasonally and my study only reflected a short moment in time (one-week span in autum 2002) leaving the rest of the rainy and dry seasons unsampled for availability of potential prey and foraging grounds (also note that to be meaningful, examining seasonal variation in diet requires methodic collection of a similar number of frogs on a regular basis – e.g., monthly or quaterly, for example – throughout the year and, ideally, in more than one locality from an ecosystem [or biogeographic] context).

Finally, I argue that we need studies that examine the influence of this species in a faunal-assemblage context and under different environmental conditions and localities to examine the presumable "negative impacts" frequently ascribed to *O. septentrionalis*, for example, on the native Puertorican frogs (and fauna in general elsewhere), in scientific and non-scientific publications. Unfortunately, after > 60 years of being introduced in Puerto Rico, no studies exist about the population dynamics of *O. septentrionalis*, at an assemblage (and ecosystem) perspective. Thus, we cannot objectively address its influence on the local trophic dynamics of the herpetofauna in the wild; the same applies in continental U.S.A. – where it was first documented in the early 1950s (Schwartz 1952) – and elsewhere (as far as I am aware). Most likely, to evoke competition (or lack of it) would require removal experiments in a study where sufficient population data exist for *O. septentrionalis* (pre/post-removal of) within an assemblage context to get closer to reality. Likewise, other than this study, we also lack studies on the feeding ecology of *O. septentrionalis* – to name one dimension of its ecology – as to assess the relative contribution of the predatory role of this species vis a vis that of sympatric native species in the introduced areas; I am not aware of similar information from the species' native Cuba.

How can we assess the influence of *O. septentrionalis* on native species without having a comparative basis from sympatric species in the introduced areas? I echo Davis et al. (2011) and others, however, in that I am not arguing in favor of introduced species: there are such species that require management for conservation purposes, but in light of objective evidence and considering that conservation resources also are limited. As most studies conducted with *O. septentrionalis* reveal the close relationship of its introduction with human-dominated/transformed areas, our fingers could end up pointing elsewhere, with recommendations and conservation efforts related with *O. septentrionalis* mostly oriented at managing the ultimate factor – ourselves.

ACKNOWLEDGEMENTS

I sincerely thank Alberto Galindo and Karla Osorio, who helped me identify most stomach contents, and Sondra I. Vega for kingly providing feeding data from Cabo Rojo. I also thank the Department of Natural and Environmental Resources of Puerto Rico for issuing a collection permit (01-IC-068) and four anonymous reviewers whose comments and suggestions improved earlier drafts of this manuscript.

LITERATURE CITED

Abreu-Rodríguez, E. 2017. Annotated checklist of the acarina of Puerto Rico. Journal of Agriculture of the University of Puerto Rico 101(2):61–151.

American Veterinary Medical Association. 2001. Report of the AVMA Panel on Euthanasia. Journal of the American Veterinary Medical Association 218(5):669–696. (https://doi.org/10.2460/javma.2001.218.669).

American Veterinary Medical Association. 2007. Guidelines on Euthanasia. Published by the American Veterinary Medical Association (Formerly the Report of the AVMA Panel on Euthanasia). 36 pp. Available at https://grants.nih.gov/grants/olaw/Euthanasia2007.pdf

Beard, K. H., S. A. Johnson, and A. B. Shields. 2018. Frogs (Coqui frogs, greenhouse frogs, Cuban tree frogs, and cane toads). Pages 163–192 in W. C. Pitt, J. C. Beasley, and G. W Witmer, editors. Ecology and Management of terrestrial vertebrate invasive species in the United States. CRC Press, Boca Raton, Florida, U.S.A. 403 pp.

Breuil, M. 2002. Histoire naturelle des Amphibiens et Reptiles terrestres de l'archipel Guadeloupéen. Guadeloupe, Saint-Martin, Saint-Barthélemy. Patrimoines Naturels 54. 339 pp.

Burrowes, P. A. and R. L. Joglar. 2005. El estado de los anfibios de Puerto Rico. Pages 60–65 in R. L. Joglar, editor. *Biodiversidad de Puerto Rico, Vertebrados Terrestres y Ecosistemas.* Serie de Historia Natural, Editorial del Instituto de Cultura Puertorriqueña, San Juan, Puerto Rico, U.S.A. 563 pp.

Butterfield, B. P., W. E. Meshaka Jr., and C. Guyer. 1997. Nonindigenous amphibians and reptiles. Pages 123–138 in D. Simberloff, D. C. Schmitz, and T. C. Brown, editors. *Strangers in paradise: impact and management of nonindigenous species in Florida.* Island Press, Washington, D.C., U.S.A. 467 pp.

Censky, E. J., and H. Kaiser. 1999. The Lesser Antillean fauna. Pages 181–221 in B. I. Crother, editor. *Caribbean Amphibians and Reptiles.* Academic Press, San Diego, California, U.S.A. 505 pp.

Colwell, R. K. and D. J. Futuyma. 1971. On the measurements of niche breadth and overlap. Ecology 52:567–576.

Coons, L. B. and M. Rothschild. 2008. Mites (Acari). Pages 2413–2441 in John L. Capinera, editor. *Encyclopedia of Entomology*, Second Edition. Springer, Dordrecht, The Netherlands. 4,346 pp.

Davis, M. A., M. K. Chew, R. J. Hobbs, A. E. Lugo, J. J. Ewel, G. J. Vermeij, J. H. Brown, M. L. Rosenzweig, M. R. Gardener, S. P. Carroll, K. Thompson, S. T. A. Pickett, J. C. Stromberg, P. Del Tredici, K. N. Suding, J. G. Ehrenfeld, J. P. Grime, J. Mascaro, and J. C. Briggs. 2011. Don't judge species on their origins. Nature 474:153–154.

Ewel, J. J., and J. L. Whitmore. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. Forest Service Research Paper ITF 18:1–72. USDA Fortest Service, Institute of Tropical Forestry, Río Piedras, Puerto Rico, U.S.A.

Glorioso, B. M., J. H. Waddle, M. E. Crockett, K. G. Rice, and H. F. Percival. 2012. Diet of the invasive Cuban Treefrog (*Osteopilus septentrionalis*) in pine rockland and mangrove habitats in South Florida. Caribbean Journal of Science 46(2-3):346–355.

Gotelli, N. and G. Entsminger. 2015. EcoSim: Null models software for ecology. 10.5281/zenodo.16504. Version 7.71. Acquired Intelligence Inc. & Kesey-Bear. Available at http://garyentsminger.com/ecosim/index.htm.

Gotelli, N. J. and G. R. Graves. 1996. Null Models in Ecology. Smithsonian Institution Press, Washington, D.C., U.S.A.

Heflick, S. K. 2001. Ecology of the exotic Cuban Treefrog, *Osteopilus septentrionalis*, within Brevard County, Florida. MS thesis, Florida Institute of Technology, Melbourne, Florida, U.S.A. 27 pp.

Henderson, R. W. and R. Powell. 2009. Natural History of West Indian Reptiles and Amphibians. University Press of Florida, Gainesville, Florida, U.S.A. 496 pp.

Herrera-Giraldo, J. L. 2010. Herpetofaunal species composition on the Vieques National Wildlife Refuge, Vieques, Puerto Rico. MS thesis, University of Puerto Rico, Mayagüez Campus, Mayagüez, Puerto Rico, U.S.A. 83 pp.

Hoffmann, K. E. 2007. Testing the influence of Cuban treefrogs (*Osteopilus septentrionalis*) on native treefrog detection and abundance. MS thesis, University of Florida, Gainesville, Florida, U.S.A. 70 pp.

Hoffmann, K. E., M. E. McGarrity, and S. A. Johnson. 2018. Lack of behavioral and chemical interference competition for refuges among native treefrogs and invasive Cuban treefrogs (*Osteopilus septentrionalis*). Diversity 10(3),78: 9 pp. doi:10.3390/d10030078.

IUCN SSC Amphibian Specialist Group. 2021. *Leptodactylus albilabris*. The IUCN Red List of Threatened Species 2021: e.T57113A3055043. https://dx.doi.org/10.2305/IUCN.UK.2021-1.RLTS.T57113A3055043.en. Downloaded on 19 April 2021.

Joglar, R. L. 1998. Los coquíes de Puerto Rico: su historia natural y conservación. Editorial de la Universidad de Puerto Rico, San Juan, Puerto Rico, U.S.A.

Joglar, R. L. 2005. Interacciones. Pages 68–74 in R. L. Joglar, editor. *Biodiversidad de Puerto Rico, Vertebrados Terrestres y Ecosistemas*. Serie de Historia Natural, Editorial del Instituto de Cultura Puertorriqueña, San Juan, Puerto Rico, U.S.A. 563 pp.

Joglar, R. L., and N. Rios-López. 1995. *Osteopilus septentrionalis* (Cuban Treefrog, Rana Platanera). Herpetological Review 26(2):105–106.

Joglar, R. L., N. Rios-López, and M. Cardona. 1998. *Osteopilus septentrionalis* (Cuban Treefrog, Rana Platanera). Herpetological Review 29(2):107.

Krebs, C. J. 2014. Ecological Methodology. Third edition (in preparation). Available at https://www.zoology.ubc.ca/~krebs/books.html.

Lavigne, R. J. and G. E. Drewry. 1970. Feeding behavior of the frogs and lizards in the Tropical Wet Forest: preliminary report. Pages 64–73 in R. G. Clements, G. E. Drewry, and R. J. Lavigne, editors. *The Rain Forest Project Annual Report* (June 1970). Puerto Rico Nuclear Center, PRNC–147, U.S. Atomic Energy Commission, U.S.A. 142 pp.

Lever, C. 2003. Naturalized Reptiles and Amphibians of the World. Oxford University Press Inc., New York, U.S.A. 318 pp.

Liogier, H. A. 1988. Descriptive Flora of Puerto Rico and Adjacent Islands. Volume 2 (Leguminosae to Anacardiaceae). Editorial de la Universidad de Puerto Rico, San Juan, Puerto Rico, U.S.A. 481 pp.

Lowe, W. B. 1995. *Osteopilus septentrionalis* (Cuban Treefrog). Herpetological Review 26(4):201–202.

Meshaka Jr., W. E. 1994. Ecological correlates of successful colonization in the life history of the Cuban treefrog, *Osteopilus septentrionalis* (Anura: Hylidae). Doctoral dissertation. Florida International University, Miami, Florida, U.S.A. 140 pp.

Meshaka Jr., W. E. 1996a. Diet and the colonization of buildings by the Cuban treefrog, *Osteopilus septentrionalis* (Anura: Hylidae). Caribbean Journal of Science 32(1):59–63.

Meshaka Jr., W. E. 1996b. Occurrence of the nematode *Skrjabinoptera scelopori* in the Cuban treefrog, *Osteopilus septentrionalis*: mainland and island comparisons. Pages 271–276 in R. Powell and R. W. Henderson, editors. *Contributions to West Indian Herpetology: A Tribute to Albert Schwartz*. Contributions to Herpetology 12, Society for the Study of Amphibians and Reptiles, Ithaca, New York, U.S.A.

Meshaka Jr., W. E. 2001. The Cuban tree frog in Florida: life history of a successful colonizing species. University of Florida Press, Gainesville, Florida, U.S.A. 224 pp.

Meshaka Jr., W. E. 2011. A runaway train in the making: the exotic amphibians, reptiles, turtles, and crocodilians of Florida. Monograph 1. Herpetological Conservation and Biology 6:1–101.

Meshaka Jr., W. E., W. F. Loftus, and T. Steiner. 2000. The herpetofauna of Everglades National Park. Florida Scientist 63(2):84–103.

Meshaka Jr., W. E., M. L. McCallum, C. Voirin, and J. Moore. 2020. The Cuban treefrog (*Osteopilus septentrionalis*) dampens competitive superiority between two *Hemidactylus* gecko species on buildings. Urban Naturalist 34:1–10.

Mitchell, J. C. and G. R. Johnston. 2013. *Osteopilus septentrionalis* (Cuban Treefrog). Herpetological Review 44(1):124.

OConnor, B. M. 2003. Mites. Pages 726–733 in V. H. Resh and R. T. Cardé, editors. *Encyclopedia of Insects*. Academic Press, Elsevier Science, San Diego, California, U.S.A. 1,266 pp.

Ortega, N., W. Price, T. Campbell, and J. Rohr. 2015. Acquired and introduced macroparasites of the invasive Cuban treefrog, *Osteopilus septentrionalis*. International Journal for Parasitology: Parasites and Wildlife 4:379–384. Available at http://dx.doi.org/10.1016/j.ijppaw.2015.10.002.

Owen, J. L. 2005. The Cuban Tree Frog (*Osteopilus septentrionalis*): Distribution, Diet, and Reproduction of an Invasive Species in the British Virgin Islands. MS thesis, Department of Range, Wildlife and Fisheries Management, Texas Tech University, Texas, U.S.A. 77 pp.

Owen, J., G. Perry, G., J. Lazell, C. Petrovic, and J. Egelhoff. 2005. *Osteopilus septentrionalis* (Cuban Tree Frog). Herpetological Review 36:76.

Perry, G., R. Powell, and H. Watson. 2006. Keeping invasive species off Guana Island, British Virgin Islands. Iguana 13:273–277.

Platenberg, R. J. 2007. Impacts of introduced species on an island ecosystem: non-native reptiles and amphibians in the US Virgin Islands. Pages 168–174 in G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. *Managing Vertebrate Invasive Species: Proceedings of an International Symposium*. USDA/APHIS/WS, National Wildlife Research Center, Fort Collins, Colorado, U.S.A.

Platenberg, R. J. and R. H. Boulon Jr. 2006. Conservation status of reptiles and amphibians in the U.S. Virgin Islands. Applied Herpetology 3:215–235.

Portal Ríos, Y., R. Borroto-Páez, and D. Reyes Pérez. 2020. A Cuban treefrog (*Osteopilus septentrionalis*, Hylidae) preying on a caged Yellow-Faced Grassquit (*Tiaris olivaceus*) in Cuba. Revista Latinoamericana de Herpetología 3(2):139–142.

Powell, R. and R. W. Henderson. Amphibians of the Lesser Antilles. In N. Ríos-López and H. Heatwole, editors. Chapter 22 in Part 5, *The Conservation, Demise, and Biogeography of Amphibians in the Caribbean*. Volume 9 of Status and Decline of Amphibians: Western Hemisphere. Series: Amphibian Biology. Pelagic Press, Exeter, U.K. *In press*.

Rice, K. G., J. H. Waddle, M. W. Miller, M. E. Crockett, F. J. Mazzotti, and H. F. Percival. 2011. Recovery of native treefrogs after removal of nonindigenous Cuban treefrogs, *Osteopilus septentrionalis*. Herpetologica 67(2):105–117.

Ríos-López, N., R. L. Joglar, C. A. Rodríguez-Gómez, C. J. Díaz-Vázquez, and I. Rivera. 2015. Natural history notes of saurophagy: an update from the Puerto Rican vertebrate fauna. Life: The Excitement of Biology 3:118–136.

Ríos-López, N., A. R. Puente-Rolón, N. F. Angeli, S. I. Vega-Castillo, and D. Dávila-Casanova. Amphibians and their history, distribution, and conservation in Puerto Rico and the Virgin Islands. In N. Ríos-López and H. Heatwole, editors. Chapter 21 in Part 5, *The Conservation, Demise, and Biogeography of Amphibians in the Caribbean*. Volume 9 of Status and Decline of Amphibians: Western Hemisphere. Series: Amphibian Biology. Pelagic Press, Exeter, U.K. *In press*.

Rivero, J. A. 1998. The Amphibians and Reptiles of Puerto Rico. Second edition. Editorial de la Universidad de Puerto Rico, San Juan, Puerto Rico, U.S.A. 510 pp.

Rodda, G. H. and K. Dean-Bradley. 2002. Excess density compensation of island herpetofaunal assemblages. Journal of Biogeography 29:623–632.

Rodda, G. H., G. Perry, R. J. Rondeau, and J. Lazell. 2001. The densest terrestrial vertebrate. Journal of Tropical Ecology 17:331–338.

Sih, A. 2011. Foraging theory. Pages 65–90 in S. M. Schiner and M. R. Willig, editors. The Theory of Ecology. University of Chicago Press, Chicago, Illinois, U.S.A.

Schmidt, K. P. 1920. Contributions to the herpetology of Porto Rico. Annals of the New York Academy of Science 28:167–200.

Schwarz, A. 1952. *Hyla septentrionalis* Duméril and Bibron on the Florida mainland. Copeia 1952(2):117–118.

Stewart, M. M. and L. L. Woolbright. 1996. Amphibians. Pages 273–320 in D. P. Reagan and R. W. Waide, editors. The Food Web of a Tropical Rain Forest. University of Chicago Press, Chicago, Illinois, U.S.A. 616 pp.

Subías, L. S. 2004. Listado sistemático, sinonímico y biogeográfico de los ácaros oribátidos (Acariformes, Oribatida) del mundo (1758-2002). Graellsia 60:3–305.

Wolcott, G. N. 1948a. The insects of Puerto Rico. The Journal of Agriculture of the University of Puerto Rico 32(1):1–224.

Wolcott, G. N. 1948b. The insects of Puerto Rico. The Journal of Agriculture of the University of Puerto Rico 32(3):537–748.

Wyatt, J. L. and E. A. Forys. 2004. Conservation implications of predation by Cuban treefrogs (*Osteopilus septentrionalis*) on native hylids in Florida. Southeastern Naturalist 3(4):695–700.

INSTRUCTIONS TO AUTHORS

Acta Científica: una revista transdisciplinaria de Puerto Rico y el Caribe is a transdisciplinary journal for Puerto Rico and the Caribbean.
Types of Contributions: *AC-PuR&C* publishes research papers in any scientific field, i.e., physics, chemistry, biochemistry, botany, zoology, ecology, biomedicine, medicine, behavioral psychology, social sciences, and mathematics. The journal also is open to contributions from school teachers and their students – and college-level, graduate, researchers, and professionals alike – and encourage their submittal for review and, if accepted, published. An **article** describes a complete definite study. **Notes** (or **Reports**) describe a complete project, are shorter, and usually refer to original findings or significant modifications of previously described techniques. **Essays** discuss general scientific topics and are not based on original, experimental results. **Reviews** discuss the most recent literature on a given subject thoroughly. **Meeting summaries** describe findings, agreements, and present summaries of recent local or regional meetings, workshops, and symposia. Manuscripts should be sent in by email to the Editor in Chief, who will submit them for review to a referee in the field of science involved. Acceptance of papers occurs based on their scientific content and presentation of material in agreement with editorial norms. Authors can submit manuscripts written in English or Spanish. Manuscripts submitted must be original and not be published nor being considered for publication by another journal.

Neftalí Ríos López
Editor in Chief, **Acta Científica: una revista transdisciplinaria de Puerto Rico y el Caribe**
Published by USDA Forest Service, International Institute of Tropical Forestry
1201 Ceiba St., Jardín Botánico Sur
Río Piedras, PR 00926-1119
neftali.rios@upr.edu

Authors are advised to consult the following INSTRUCTIONS TO AUTHORS for due consideration to a manuscript:

1) Include the author's full name (and co-authors) followed by its last name(s). The order of sections of the manuscript as follows (mostly for articles; other contributions variable and should be discussed with the editor): Running head, title, abstract (no more than 400 words), keywords (up to eight), the body of the manuscript (main text in a separate file) with its sections (Introduction, Methods, Results, Discussion, Acknowledgements, Literature Cited), and tables (each on a separate document and named as cited in the main text), figure legends (in one document and named accordingly), figures (each on a separate document and named as it is cited in the main text), and appendices (each on a separate document and named as it is cited in the main text) (see each section below for additional guidelines). Use the active voice if possible (example: "We studied …" instead of "... was studied").

2) Body of the manuscript:

- Written in English or Spanish and the entire manuscript (including the Literature Cited, figure legends, table legends, appendices) should be double-spaced in "Times New Roman" 12p. Each sentence is followed by two spaces; provide 2.5 cm margins on all sides; all text left-justify.
- Includes a summary in Spanish and an abstract in English, double-spaced and on separate pages, headed by the paper's complete title.
- The title should be informative and short, generally no longer than 12 words. A shorter title (no more than 40 letters) in the paper's original language should be included for use as a running head. Use of keywords to describe the article is recommended.
- All paragraphs must be indented (0.5 cm).
- All pages must be numbered (consecutively; bottom right), including the title page. Also, provide line numbering starting at the title page and continuing to the end of the Literature Cited (includes line numbering in figure legends and appendices, but not tables).
- Quotations: longer than 60 words should be set-out from the main body text in a separate indented paragraph (1 cm from right and left margins), with one space above and below, and do not need to be set within quotation marks. Shorter quotations must be included in the text; use double quotation marks, except for a quotation within a quotation, in which case double quotation marks are used with inner single-quotation marks (e.g., if the original quotation includes text quoted from another source).
- Units and numbers: numbers with units require a space before the unit; always use numerals for units before abbreviations; numbers up to ten should be written out (except where there is a mix of numbers within a sentence, and some are above ten); insert a comma for thousands and larger numbers; place a zero before any decimal. Use en-dash for an inclusive range of numbers (but not years or dates, where a hyphen is used instead) and inserts within a sentence in the text; do not use em-dash; separate mathematical operators by a single space on both sides. The symbol "~" is not followed by space. Latitude and Longitude preferably in Decimal Degrees (please, include a negative sign for south and west coordinates if cardinal directions or points are not typed); include geodetic datum system (e.g., World Geodetic System [WGS] 84 or otherwise).
- Capitalize cross-references to sections, figures, and tables.
- Italics: italicize scientific names (not common names), foreign words, titles of books. Do not italicize "e.g.", "i.e.", nor measurement units and statistical/probability symbols.
- Current guidelines for proper nomenclature of scientific names and authorship:
  - For viruses, follow:
    - The International Code of Virus Classification and Nomenclature (Available online at https://talk.ictvonline.org/information/w/ictv-information/383/ictv-code; updated October 2018).
  - For prokaryotes, follow:
    - Parker, C. T., B. J. Tindall, and G. M. Garrity (eds.). 2019. International Code of Nomenclature of Prokaryotes, Prokaryotic Code (2008 Revision). International Journal of Systematic and Evolutionary Microbiology 69: S1–S111. Available at https://ccug.se/documents/taxonomy/prokaryotic_code/2019_Parker-Tindall-Garrity_Prokaryotic%20Code%20-%202008%20Revision.pdf. DOI 10.1099/ijsem.0.000778.
  - For algae, fungi, and plants, follow:
    - Turland, N. J., J. H. Wiersema, F. R. Barrie, W. Greuter, D. L. Hawksworth, P. S. Herendeen, S. Knapp, W.-H. Kusber, D.-Z. Li, K. Marhold, T. W. May, J. McNeill, A. M. Monro, J. Prado, M. J. Price, and G. F. Smith (eds.). 2018. International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the Nineteenth International Botanical Congress Shenzhen, China, July 2017. Regnum Vegetabile 159. Glashütten: Koeltz Botanical Books. DOI https://www.iapt-taxon.org/nomen/main.php (version in Spanish available at https://www.iapt-taxon.org/nomen/Shenzhen/Spanish/Spanish.pdf)
  - For animals, follow:
    - International Commission on Zoological Nomenclature. 1999. International Code of Zoological Nomenclature. Fourth edition. Published by the International Trust for Zoological Nomenclature [ITZN], The Natural History Museum, Cromwell Road, London

SW7 5BD, U.K. (available online at https://www.iczn.org/the-code/the-international-code-of-zoological-nomenclature/the-code-online/) (version in Spanish available at http://www.sam.mncn.csic.es/codigo.pdf, with the consent of the ITZN [2009]).

- When also included, capitalize the common generic name of the substantive noun of species; also see the use of capital letters and antonomasia in geographical and cultural contexts.
- Headings: **ACTA** uses primary, secondary, and, if needed, tertiary headings.
  - ○ Primary headings should be all capital letters, 12p bold, centered e.g., **METHODS**
  - ○ Secondary headings should be title case, 12p bold, centered e.g., **Description of Study Case**
  - ○ Tertiary headings should be title case, 12p bold, left-justified e.g., **Mata de Plátano Biological Reserve**
- **Acknowledgments** and **Literature Cited** in bold, small caps, and left-justified.
- Assemble the parts of the manuscript in the following order: title page, abstract (English and Spanish), keywords, the body of the manuscript, acknowledgments, literature cited, and appendices. Figures, photographs, and tables should not be embedded in the text but should be submitted separately.

3) Figures should have 300 dpi final resolution for photographs and 600 dpi for black and white or color line art (photographs that contain text, line art, and other line elements should be at 600 dpi and must fit in a regular e-mail); should be submitted either as *.PDF with fonts and other elements (e.g., arrows, symbols, shapes) already embedded, *.JGP or *.TIF (you will need to save a copy for your records at a larger dpi to avoid blurry lines and text when converting it in its final form). If all fails, you may submit graphs in Excel files – with each chart in a single file – and no grid lines behind the data points or bars. Photographs should have 300 dpi (or higher resolution, and must fit in a regular e-mail), either as *.TIF or high-quality *.JPG formats. All figures and photographs must be submitted in separate files, and name each file with the figure number as cited in the main text. Image manipulation should follow ethically acceptable guidelines (see http://microscopy.arizona.edu/learn/digital-image-ethics). A list of figures with corresponding legends should be typed double-spaced and on a separate file named "Figure Legends."

4) Tables and Appendices should be typed double-spaced, numbered consecutively, have a short title, be precise, and each table should be submitted in a separate file named with the table number as cited in the main text. They have to fit on a printed page in width (either as portrait or landscape); it may be necessary to use symbols or abbreviations for reducing the size of large amounts of information among columns. Prepare tables with a minimum of horizontal lines (preferably one at the top, one below column headings, and one at foot; try not to use vertical rules). Check that totals add up correctly and that all numerals align (left-justify). Do not repeat the same material in figures and tables.

5) Authors should use the metric system for their measurements. Consult the International System of Units (SI) as a guide in the conversion of measurements. When preparing text and figures, note that SI requires:

- ○ the use of the terms "mass" or "force" rather than "weight."
- ○ when one unit appears in a denominator, use the solidus (e.g., g/m^2); for two or more units in a denominator, use one solidus and a period (e.g., $g/m^2{\cdot}d$).
- ○ use the capital "L" as the symbol for litre.
- ○ use of "Mg" for Megagram (1 Mg = 1,000 kg ~ 1.102312 US ton or ~0.984207 imperial ton).

6) The use of copyrighted material has to be fully attributed in the manuscript, and evidence of permission to use it be sent to the Editor of ACTA. Photographs or other material not taken by the authors should include the photographer's name or source of the figure in the caption; sources of these materials and photographs can also be credited in the acknowledgments. The authors' responsibility, not the reviewers or editors, is to ensure that previously published data or text are properly attributed.

7) Literature Cited:

- For the proper sequence and punctuation, see examples below. Do not abbreviate journal titles. Several citations together in the text should be listed in date order, separated by semicolons; when two or more articles share the same publication year, order them alphabetically: e.g., Foster 2007; Clark and Tilman 2010; Rehm et al. 2019; van Toor et al. 2019. Where there is more than one article by an author in a single year, use a, b, etc.; no space between letters (e.g., Martínez 2008a,b). Cite in full when using personal communication and observations (e.g., N. Ríos, personal communication). Use en-dash for a range of pages.
  - ○ **Journal citation***:*

    Clark, C. M., and D. Tilman. 2010. Recovery of plant diversity following N cessation: effects of recruitment, litter, and elevated N cycling. Ecology 91:3620–3630.
  - ○ **Book**:

    Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principle and practice of statistics in biological research. Third edition. W.H. Freeman and Co., New York, New York, USA.
  - ○ **Book Chapter**:

    Hartshorn, G. S., and B. E. Hammel. 1994. Vegetation types and floristic patterns. Pages 73–89 in L. A. McDade, K. S. Bawa, H. A. Hespenheide, and G. S. Hartshorn, editors. *La Selva: ecology and natural history of a neotropical rain forest.* University of Chicago Press, Chicago, Illinois, USA.
  - ○ **Government Report**:

    Pardo, L. H., M. J. Robin-Abbott, and C. T. Driscoll. 2011. Assessment of Nitrogen deposition effects and empirical critical loads of Nitrogen for ecoregions of the United States. General Technical Report NRS-80. USDA Forest Service, Northern Research Station, South Burlington, Vermont, USA.
  - ○ **Dissertation**:

    Foster, S. E. 2007. The co-occurrence and interactions of large invertebrate predators in relation to the Bythotrephes invasion. Dissertation. University of Toronto at Mississauga, Mississauga, Ontario, Canada.
  - ○ **Webpage**:

    Keeland, B. D., and P. J. Young. 2004. Construction and installation of dendrometer bands for periodic tree-growth measurements. U.S. Geological Survey, National Wetlands Research Center, Lafayette, Louisiana, USA. http://www.nwrc.usgs.gov/Dendrometer/index.htm
  - ○ **Software**:

    SAS Institute. 2009. JMP version 8.0. SAS Institute, Cary, North Carolina, USA.

8) We recommend authors to provide names and contact information of potential reviewers of their manuscripts for consideration by the editorial board.

9) **AC-PuR&C** provides authors with a pdf of their article free of charge. Currently, all issues of **ACTA** can be downloaded free of cost at https://www.treesearch.fs.fed.us/; enter **Acta Cientifica** in the "Title" slot of the "Search for on-line publications" window.

The Editor in Chief is responsible for unsigned comments and editorials. Readers are cordially invited to make comments by sending letters to the Editor in Chief at neftali.rios@upr.edu. This journal serves no commercial interest and does not provide economic benefit to its editors. Please, consult with the most recent volume for the format, updates, and changes in these guidelines.

INSTRUCIONES PARA AUTORES

ACTA CIENTÍFICA es una revista transdisciplinaria para Puerto Rico y el Caribe. Esta revista también da la bienvenida a contribuciones de los maestros de escuela y sus estudiantes (así como aquellos a nivel universitario, graduados, investigadores y profesionales por igual) y fomenta su envío para revisión y, de ser aceptado, publicado. **ACTA** considera para su publicación, trabajos originales en cualquier área de la ciencia, a saber, física, química, bioquímica, zoología, botánica, ecología, biomédica, medicina, ciencias terrestres, ciencias atmosféricas, psicología del comportamiento, tecnología farmacéutica, ciencias sociales o matemáticas. Un **artículo** describe un estudio completo y definitivo. Una **nota** es un proyecto completo, pero más corto, que se refiere a hallazgos originales o importantes modificaciones de técnicas ya descritas. Un **ensayo** trata aspectos relacionados con la ciencia, pero no está basado en resultados experimentales originales. Una **revisión** es un artículo que comenta la literatura más reciente sobre un tema especializado. Un **resumen de reunión** describe los hallazgos, acuerdos y resumen de reuniones y simposios locales y regionales recientes.

Los manuscritos deben ser enviados por correo electrónico al Editor, quien los someterá a revisión crítica de revisores en el área de ciencia concernida. La aceptación de trabajos estará basada en su contenido científico y la presentación del material de acuerdo a las normas editoriales de **ACTA**. Es requisito que el manuscrito enviado para publicación sea original y que el mismo no esté publicado ni siendo considerado por otra revista científica.

Neftalí Ríos López
Editor, **Acta Científica**, Servicio Forestal de los Estados Unidos de América, Instituto Internacional de Dasonomía Tropical
1201 Calle Ceiba, Jardín Botánica Sur
Río Piedras, Puerto Rico 00926-1119
neftali.rios@upr.edu

Para asegurar la consideración de su manuscrito, se aconseja prepararlo de acuerdo a las siguientes INSTRUCCIONES PARA AUTORES:

1) Incluya primero el nombre completo del autor (y coautores) seguido de sus apellidos. El orden de las secciones del manuscrito (mayormente para artículos mientras que para otro tipo de contribución es variable y debe ser discutido con el Editor previamente) es como sigue; Título de la página, Título del artículo, Resumen (no mayor de 400 palabras), palabras claves (hasta ocho palabras), el cuerpo del manuscrito con sus secciones principales (Introducción, Métodos, Resultados, Discusión, Reconocimientos, Literatura Citada [o Referencias]), Tablas (cada una en un archivo separado y rotulado según citado en el texto principal), Leyenda de las Figuras (en un documento separado y rotulado), figuras (cada una en un documento separado y rotulado según citado en el texto principal), y apéndices (cada uno en un documento separado y rotulado según citados en el texto principal). Utilice la voz activa (por ejemplo: "Estudiamos …" o "Analizamos …"en vez de "… fue estudiado …" o "… fueron analizados …", etc.).

2) Texto del manuscrito:

- Los trabajos pueden ser escritos en inglés o español y deben estar a doble espacio y en "Times New Roman" 12p.
- Los trabajos deben ir acompañados de un resumen en español y en inglés (abstract), escrito a doble espacio y en hojas separadas, encabezadas por el título completo del trabajo. El título debe ser informativo y corto, generalmente no más de 12 palabras. El autor debe indicar un título más breve (no más de 40 letras), en el mismo idioma del trabajo, para ser utilizado como encabezamiento de cada página (*running head*).
- Cada nueva oración debe ser antecedida por dos espacios.
- Cada párrafo debe estar sangrado a 0.5 cm (del margen izquierdo).
- Todas las páginas deben numerarse (al pié derecho de la página y numeradas de corrido), incluyendo la primera página (título).
- Enumere todas las líneas de manera consecutiva, de inicio a fin del manuscrito; enumere también las líneas del texto de las figuras y apéndices pero no el de las tablas.
- Citas textuales de un pasaje: las citas de más de 60 palabras deben colocarse separado del cuerpo del texto principal con una línea superior y otra inferior del mismo; en un párrafo con sangría de 1 cm desde los márgenes derecho e izquierdo y no es necesario que se incluya su texto entre comillas ni en cursivo. Las citas más breves deben ir en el texto, entre comillas dobles, excepto para una cita dentro de una cita, en cuyo caso las comillas dobles se usan con comillas simples internas (por ejemplo, si la cita original incluye texto citado de otra fuente).
- Números y unidades: si tiene números con unidades tiene que incluir un espacio antes de la unidad; siempre utilice números para unidades antes de una abreviatura; tiene que deletrear los números hasta el diez inclusive (excepto cuando haya una combinación de números mayores a diez y otros igual o menores a diez – en este caso todos se expresan numéricamente); siempre añada una coma para los millares y números mayores en potencias de diez; siempre incluya un cero antes de cualquier decimal. Utilice el guion "n" (en Inglés, "en-dash") para indicar rangos de números (pero no de años ni fechas, donde utilizará en cambio un guion sencillo corto) y para inserciones en una oración dentro de un texto particular; no utilice el guion "m" o largo; separe cada operador matemático utilizando un espacio sencillo a ambos lados del operador. Si utiliza el símbolo "~" no añada espacio a ambos lados del mismo. Preferiblemente, utilice Grados Decimales para identificar Latitud y Longitud (por favor, no olvide añadir el signo de negativo para las coordenadas Sur y Oeste si no escribe las direcciones o puntos cardinales); incluya el sistema de Dato Geodésico (p. ej., World Geodetic System [WGS] 84, en Inglés, u otro que aplique).
- Escriba en mayúsculas toda referencia a secciones, figuras y tablas.
- Letras en cursiva: aplique a nombres científicos (pero no a nombres comunes), palabras de otros idiomas utilizados en su escrito y título de libros. No utilice letras en cursivo para "p. ej.," y otras abreviaturas de uso muy frecuente (o en Latín, cuando aplique), unidades de medidas, ni para símbolos de probabilidades y estadísticos.
- Guía de nomenclatura aceptada para nombres científicos y autoría de los mismos:
  - ○ Si es para virus utilice a:
    - The International Code of Virus Classification and Nomenclature (Disponible en https://talk.ictvonline.org/information/w/ictv-information/383/ictv-code; según actualizado a octubre del 2018).
  - ○ Si es para procariotas utilice a:
    - Parker, C. T., B. J. Tindall, and G. M. Garrity (eds.). 2019. International Code of Nomenclature of Prokaryotes, Prokaryotic Code (2008 Revision). International Journal of Systematic and Evolutionary Microbiology 69: S1–S111. Disponible en https://ccug.se/documents/taxonomy/prokaryotic_code/2019_Parker-Tindall-Garrity_Prokaryotic%20Code%20-%202008%20Revision.pdf. DOI 10.1099/ijsem.0.000778.
  - ○ Si es para algas, hongos y plantas utilice a:
    - Turland, N. J., J. H. Wiersema, F. R. Barrie, W. Greuter, D. L. Hawksworth, P. S. Herendeen, S. Knapp, W.-H. Kusber, D.-Z. Li, K. Marhold, T. W. May, J. McNeill, A. M. Monro, J. Prado, M. J. Price, and G. F. Smith (eds.). 2018. International Code of Nomenclature for algae, fungi, and plants (Shenzhen Code) adopted by the Nineteenth International Botanical Congress Shenzhen, China, July 2017. Regnum Vegetabile 159. Glashütten: Koeltz Botanical Books. DOI https://doi.org/10.12705/Code.2018 (versión en Español disponible en https://www.iapt-taxon.org/nomen/Shenzhen/Spanish/Spanish.pdf).
  - ○ Si es para animales utilice a:
    - International Commission on Zoological Nomenclature. 1999. International Code of Zoological Nomenclature. Fourth edition. Published by

the International Trust for Zoological Nomenclature [ITZN], The Natural History Museum, Cromwell Road, London SW7 5BD, U.K. (available online at https://www.iczn.org/the-code/the-international-code-of-zoological-nomenclature/) (version en español disponible en http://www.sam.mncn.csic.es/codigo.pdf, con la aprobación del ITZN [2009]).

- Si lo incluye, utilice mayúscula para el nombre común del sustantivo de una especie (de tenerlo); véase también el uso de mayúsculas por antonomasia en contextos geográficos y culturales.
- Encabezamientos: **ACTA** usa encabezamientos primarios, secundarios y de ser necesario, terciarios.
    - Encabezamientos primarios deben estar en mayúscula, 12p ennegrecido, (centralizado, p. ej., **MÉTODOS**
    - Encabezamientos secundarios deben estar en *title case*, 12p ennegrecido, centralizado, p. ej., **Descripción del Caso**
    - Encabezamientos terciarios deben estar en *title case*, 12p ennegrecido, justificado a la izquierda, p. ej., **Reserva Biológica Mata de Plátano**
- **Agradecimientos** y **Referencias**: en negrillas, en letras mayúsculas pequeñas y justificado a la izquierda.
- Compagine las partes de sus manuscritos en este orden: página de título, resumen, texto, agradecimiento, literatura citada, anejos, tablas, leyendas de figuras, y figuras. Las figuras, fotografías y tablas no deberán estar insertadas dentro del texto sino sometidas por separado.

3) Las figuras deben tener una resolución no menor de 300 dpi (preferiblemente con un poco más de resolución si contiene texto, arte o dibujo lineal, y otros elemento lineales, y asegurándose que pueda ser enviada por medio de correo electrónico regular), debe ser enviado como un *.PDF con toda letra o elemento ya incluido en la imagen (por ejemplo, flechas, símbolos o formas geométricas), *.JPG o en *.TIF (tendrá que guardar una copia en mayor resolución en tus archivos para fines de edición si fuese necesario solicitarlo y generar la versión final del mismo). De no ser posible, puede someter gráficas en Excel – un documento separado para cada gráfica – sin líneas de fondo y con su fondo blanco. Las fotografías deben estar en alta resolución (300 dpi o mayor y asegurándose que pueda ser enviada por medio de correo electrónico regular) como *.TIF o *.JPG de alta resolución. Cada figura debe enviarse en un archivo separado y nombrando cada archivo según el número de la figura citada en el texto principal. La manipulación de imágenes debe seguir las guías éticas aceptables (ver http://microscopy.arizona.edu/learn/digital-image-ethics). Finalmente, debe presentarse una lista de figuras junto con las leyendas de cada una, mecanografiadas a doble espacio en un archivo separado del texto principal del artículo con el título “Leyenda de Figuras”.

4) Las tablas deben: mecanografiarse a doble espacio, numerarse consecutivamente, tener un título breve, ser precisas y cada tabla debe presentarse en un archivo separado, nombrando cada uno según el número de la tabla citada en el texto principal. Las tablas deben ocupar como máximo el ancho de una página impresa (ya sea en un formato de página horizontal o vertical); puede ser necesario el uso de símbolos o abreviaciones para reducir el espacio de la información entre columnas (o filas). Cada tabla debe llevar un mínimo de líneas horizontales, preferiblemente en el margen superior, bajo el espacio de los títulos de las columnas y una al pie de la tabla; evite en lo posible el uso de líneas verticales. Verifique que las sumas en columnas correspondan al total de los valores de referencia y alinee todos los numerales al borde izquierdo. No deben repetir material en tablas y en figuras.

5) Los autores deben usar el sistema métrico para sus medidas. Consúltese el Sistema Internacional de Unidades (SI) como guía en la conversión de sus medidas. Al redactar texto y preparar figuras, nótese que el sistema internacional de unidades requiere:

- el uso de términos masa o fuerza en vez de peso.
- cuando una unidad es expresada en denominador, se debe utilizar el sólido (p. ej., g/m^2); para dos o más unidades en un denominador, use el sólido y un decimal (p. ej., $g/m^2{\cdot}d$).
- use la “L” como el símbolo de litro.
- use “Mg” como el símbolo para Megagramo (1 Mg = 1,000 kg ~ 1.102312 tonelada US o ~0.984207 tonelada imperial).

6) El uso de material protegido (copyright) debe ser completamente atribuido en el manuscrito y debe enviar al Editor de ACTA evidencia de que tiene permiso para su uso. Es responsabilidad de los autores, no de los revisores o editores, asegurarse que los datos o textos previamente publicados sean debidamente atribuidos.

7) Referencias:

- Las referencias debe seguir los formatos a continuación a base de la secuencia y la puntuación correcta. Además, los títulos de las revistas no deben ser abreviados. Ejemplos de cómo citar autores en el texto: p. ej., Foster 2007; Clark and Tilman 2010; Pardo et al. 2011.
    - **de una revista**:

      Clark, C. M., and D. Tilman. 2010. Recovery of plant diversity following N cessation: effects of recruitment, litter, and elevated N cycling. Ecology 91:3620–3630.
    - **de un libro**:

      Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principle and practice of statistics in biological research. Third edition. W. H. Freeman and Co., New York, New York, USA.
    - **del capítulo de un libro**:

      Hartshorn, G. S., and B. E. Hammel. 1994. Vegetation types and floristic patterns. Pages 73–89 in L. A. McDade, K. S. Bawa, H. A. Hespenheide, and G. S. Hartshorn, editors. La Selva: ecology and natural history of a neotropical rain forest. University of Chicago Press, Chicago, Illinois, USA.
    - **de un reporte gubernamental**:

      Pardo, L. H., M. J. Robin-Abbott, and C. T. Driscoll. 2011. Assessment of Nitrogen deposition effects and empirical critical loads of Nitrogen for ecoregions of the United States. General Technical Report NRS-80. USDA Forest Service, Northern Research Station, South Burlington, Vermont, USA.
    - **de una disertación**:

      Foster, S. E. 2007. The co-occurrence and interactions of large invertebrate predators in relation to the Bythotrephes invasion. Dissertation. University of Toronto at Mississauga, Mississauga, Ontario, Canada.
    - **de una página web**:

      Keeland, B. D., and P. J. Young. 2004. Construction and installation of dendrometer bands for periodic tree-growth measurements. U.S. Geological Survey, National Wetlands Research Center, Lafayette, Louisiana, USA. http://www.nwrc.usgs.gov/Dendrometer/index.htm
    - **de un Software**:

      SAS Institute. 2009. JMP version 8.0. SAS Institute, Cary, North Carolina, USA

8) Le recomendamos a los autores que provean nombres e información de contacto de revisores potenciales de sus manuscritos para la consideración de la junta de editores.

9) **AC-PuR&C** le proveerá libre de costo a los autores un pdf de su artículo. Todos los números de la revista en su formato anterior y actual pueden ser bajados libre de costo del portal: https://www.treesearch.fs.fed.us/. Debe de escribir **Acta Cientifica**, sin acentuar, en el espacio denominado *Title* en la ventana *Search for on-line publications*.

El editor es responsable de los comentarios y editoriales que aparecen sin firma. Los lectores están cordialmente invitados a expresar sus opiniones en la sección Cartas al Editor. Esta revista no tiene propósitos comerciales y no produce beneficio económico alguno a sus editores. Por favor, siempre consulte el volumen más reciente para actualizaciones y cambios a estas guías.

ACTA CIENTÍFICA

Una revista transdisciplinaria de Puerto Rico y el Caribe