Climate Change and Biodiversity Conservation in the Caribbean Islands

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Published by Elsevier Inc.

Abstract

Given the important role of climate on species distributions, climate change is expected to have effects on biodiversity conservation. Biodiversity on the Caribbean Islands is characterized by a broad range of distributions, from cosmopolitan species to many rare and endemic species that occupy limited geographic areas. Species most vulnerable to climate change include rare and endemic species in wet upper mountain cloud forests and species in restricted coastal habitats vulnerable to warming oceans and sea level rise. Tropical montane cloud forests harbor endemic and endangered species from many taxa. Rising temperatures, reduced precipitation, decreasing relative humidity, and increasing intensity of hurricanes all present conservation challenges for protecting these species as migration upward to favorable climates is not possible. Coastal habitats are local biodiversity hotspots throughout the Caribbean. Rising and warming seas change conditions by increasing salinity of landward habitats, increasing the likelihood of coral bleaching, and increasing storm surge effects throughout the coastal zone. The high density of people and coastal infrastructure in the Caribbean Islands creates scenarios that limit potential landward migration of species and habitats in response to changing coastal conditions and present challenges in prioritizing land use and conservation.

Introduction

The Caribbean has been widely recognized as a biodiversity hotspot (Myers et al., 2000; Roberts et al., 2002; Mittermeier et al., 2004; Shi et al., 2005). The region encompasses 2.75 million square kilometers and includes over 7000 islands and cays. The islands of the Caribbean form an arc running from the Yucatan peninsula of Mexico extending east and south to the northeastern coast of South America (**Fig. 1**). Principle island groups include the Greater and Lesser Antilles, the Bahamas, Cayman Islands, and Turks and Caicos Islands. There are 13 sovereign island nations and 12 territories with ties to Europe and the United States. The majority of the Caribbean Islands are relatively small, only 13 have an area over 1000 km^2. The terrestrial land area of the Caribbean Islands is ca. 230,000 km^2 and nearly 87% of this is in the five largest islands of Cuba, Hispaniola, Jamaica, Puerto Rico, and Trinidad. Together these have a land area of over 200,000 km^2. Key components to the biodiversity of the Caribbean include the high level of endemism on individual islands or island groups, the diversity of habitats, a long history of human introduction of species, and the tropical climate of the region.

The coastal and marine ecosystems are extremely important to the cultural, economic, and ecological fabric of Caribbean societies. Near shore environments of coral reefs, seagrass beds, beaches, mangroves, rocky shorelines, and estuaries create a matrix of habitats that are some of the most biologically diverse on earth. Coral reefs anchor the marine end of the ridge to reef continuum. They serve as a living barrier that attenuates the wave energy of storms on green and gray shoreline infrastructure. They are sensitive to both ocean warming and acidification and vulnerable to climate change wherever they occur. The Caribbean includes nearly 8% of the world's coral reefs (Bryant et al., 1998), which covers about 26,000 km^2 (Burke et al., 2004). Seagrass beds and mangroves cover about 66,000 km^2 and 11,560 km^2 respectively (Miloslavich et al., 2010). Over 12,000 species have been reported to occur in marine habitats in the Caribbean, dominated by mollusks, crustaceans, and fish (Miloslavich et al., 2010).

A complex matrix of terrestrial habitats influenced by climate, substrates, topography, and land use history supports a reported flora of 12,847 native and introduced species (Acevedo Rodríguez and Strong, 2008; Lugo et al., 2012), with a native flora of ca. 11,000 species (Acevedo-Rodríguez and Strong, 2007) including nearly 8000 endemic vascular plant species (Francisco-Ortega et al., 2007). Terrestrial vertebrates have been reported to include 1342 species, including 564 bird, 520 reptile, 189 amphibian, and 69 mammal species (Anadón-Irizarry et al., 2012). Vertebrate faunal diversity includes high levels of endemic species and genera as a result of speciation on islands and distinctive and isolated habitats such as the upper mountain cloud forests, fragmented

https://doi.org/10.1016/B978-0-12-409548-9.12091-3

Encyclopedia of the World's Biomes, 2020, 114–125

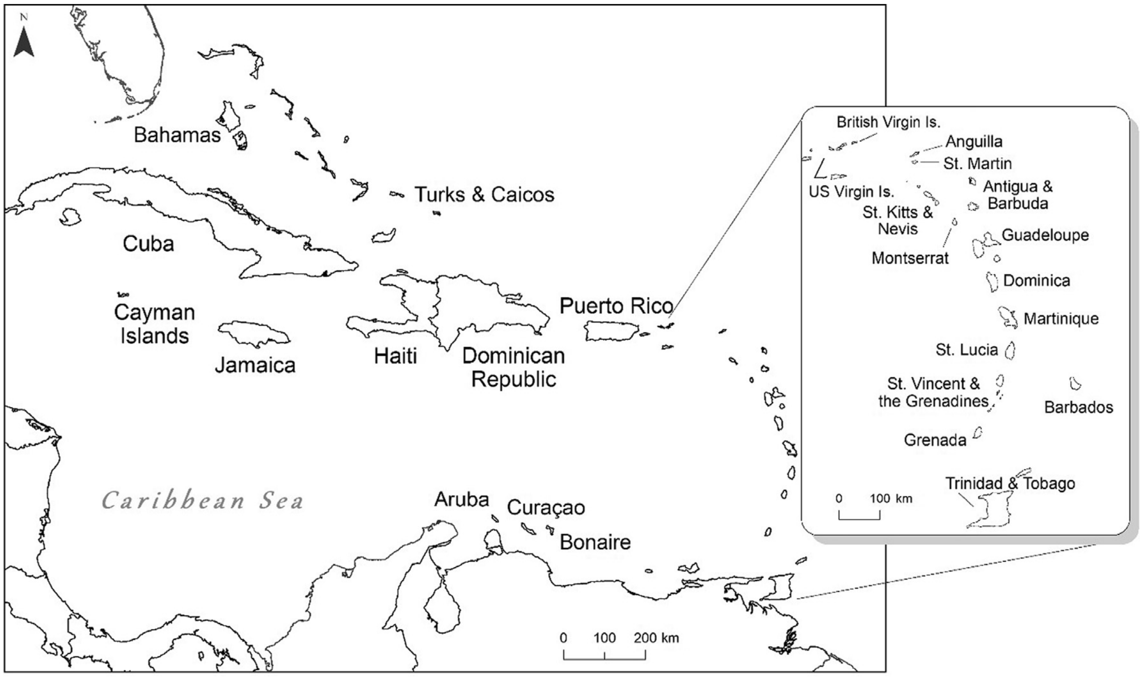

Fig. 1 The Insular Caribbean. From: González, G, and Heartsill-Scalley, T. (2016). Building a collaborative network to understand regional forest dynamics and advance forestry initiatives in the Caribbean. Caribbean Naturalist. Special Issue No. 1:245-256.

subtropical dry forests, and thousands of small dry islands and rocky cays. Less well documented but species rich groups of lichenized and other fungi, insects, spiders, and snails also show high levels of endemism due to insular isolation and the rich matrix of Caribbean Island habitats. In Puerto Rico alone over 1180 species of lichens have been recognized (Mercado-Díaz, 2009), with new endemic genera recently described (Mercado-Díaz et al., 2013; Mercado-Diaz et al., 2014) and estimates that the real lichen diversity of the island may reach about 2000 species—nearly 50% of the current checklist for North America (Mercado-Díaz et al., 2015). Fontenla (2003) reports endemism in butterflies of over 35% on the island of Hispaniola, and over 12% among the reported 1011 butterfly species for the Caribbean. The high degree of endemism and rarity across a wide range of taxa have implications as to the vulnerability of species to climate change.

Climate Change

Historically, the Caribbean region has experienced relatively stable seasonal rainfall patterns, moderate annual temperature fluctuations, and a variety of extreme weather events, such as tropical storms, hurricanes, and droughts. Variations in climate over the last 10,000 years have included drier conditions at the end of the last deglaciation (10–7 KY BP), wetter conditions in the early Holocene persisting over 4 k years, and a return to drier conditions in the late Holocene (Hodell et al., 1991). These changes are correlated with orbitally induced variations in seasonal insolation. However, the Caribbean climate is changing due to new atmospheric conditions in the Anthropocene, and is projected to be increasingly variable as levels of greenhouse gasses in the atmosphere increase. Climate change parameters affecting biodiversity in the Caribbean islands include the patterns of precipitation, increasing day and night time air temperatures, increasing sea surface temperature and acidity, sea level rise, and the predictability, frequency, and intensity of extreme climate events such as hurricanes and drought.

Rainfall

Caribbean islands typically experience a dry season from November through April and a wet season from May through October (Granger, 1985; Oliver, 2005; Taylor and Alfaro, 2005; Karmalkar et al., 2013). A characteristic of the Caribbean climate is what is known as the midsummer drought (MSD) (Magaña et al., 1999), which is a dry period (not necessarily a drought) during the wet season resulting in a bimodal cycle of precipitation. The timing and duration of the MSD varies across the Caribbean from early June in parts of the eastern Caribbean to late July around Cuba and the Bahamas, to non-existent in some eastern islands (Magaña et al., 1999; Curtis and Gamble, 2008; Gamble et al., 2008; Karmalkar et al., 2013). The timing, duration, and existence of the MSD in the Caribbean is important ecologically and as measures for modeling and downscaling projected climate for the Caribbean (Stoner et al., 2013; Hayhoe, 2013; Ryu and Hayhoe, 2014). The amount of rainfall varies considerably from drier northern to wetter southern islands, and mountainous topography interacting with the northeasterly trade winds creates steep gradients in rainfall over short distances on many islands (Granger, 1985; Sobel et al., 2011; Daly et al., 2003). These gradients drive many patterns in species distributions, ecosystem functions, and biodiversity in the Caribbean (Gould et al., 2006; González et al., 2013). Recent downscaling efforts (Bowden et al., 2018; Bhardwaj et al., 2018) are providing projected climate data at fine scales and allowing researchers to model potential effects on crops and ecosystems (Fain et al., 2018; Khalyani et al., 2016). An analysis of the potential effects of climate change on 200 plant species in Puerto Rico suggests that environmental suitability are projected to increase for low-altitude dry and warm climate species while it decreased for the high-altitude colder and wet climate species (Khalyani et al., 2019) (**Fig. 2**).

Air Temperature

Rising temperatures have been manifested as both increasing night time minimum temperatures and as a higher frequency of extreme heat days (Van Beusekom et al., 2015; Gould et al., 2018). Climate projections indicate these trends will likely continue and accelerate (Khalyani et al., 2016; Bhardwaj et al., 2018). Projections of more hot dry days, longer periods without rain, and warning night time temperatures have implications for direct and indirect effects on species (Khalyani et al., 2016). There are a number of endemic species adapted to the cool, wet, cloudy climates of the higher mountains in Puerto Rico, Jamaica, Hispaniola, and Cuba. Many species from several taxa will likely be adversely affected as rainfall decreases, temperature rises, and relative humidity drops below threshold levels for the formation of cloud forests in the Caribbean (Gould et al., 2018; Miller et al., 2018, Helmer et al., 2019) (**Fig. 3**). Secondary effects of rising temperatures and reduced rainfall include changes in the phenology of fruiting, flowering, and leaf fall that have effects on habitat conditions, nutrient cycling, plant reproductive fitness, and animal populations (PRCCC, 2013, Gould et al., 2018). Additionally, unusually dry vegetation increases the risk of fire (Monmany et al., 2017; Van Beusekom et al., 2018a).

Sea Surface Temperature

Ocean surface waters have warmed globally by about 0.13 °F (0.07 °C) per decade between 1900 and 2016 (Jewett and Romanou, 2017). From 1955 to 2016 the waters of the northeast Caribbean increased at a rate of 0.23 °F (0.13 °C) per decade, and over the last two decades, the sea surface warming rate has reached 0.43 °F (0.24 °C) per decade (Boyer et al., 2013; Gould et al., 2018) (**Fig. 4**). One of the responses to ocean warming is bleaching of adult coral colonies. Prolonged or severe periods of high temperatures and extended coral bleaching can result in colony death. In 2005, a mass bleaching event, driven by 12 weeks of temperatures above the normal local seasonal maximum, affected the entire Caribbean region, resulting in the loss of 40–80% of the coral cover in the region (Donner et al., 2007; Selig et al., 2013; Gould et al., 2018) (**Fig. 5**).

Sea Level Rise

Since the middle of 20th century, relative sea levels have risen by about 0.08 in. (2 mm) per year on average along the coasts of Puerto Rico and the United States Virgin Islands. However, rates have been slowly accelerating since the early 2000s with an acceleration by a factor of about three starting in 2010–11. This recent acceleration agrees with what has been observed along the

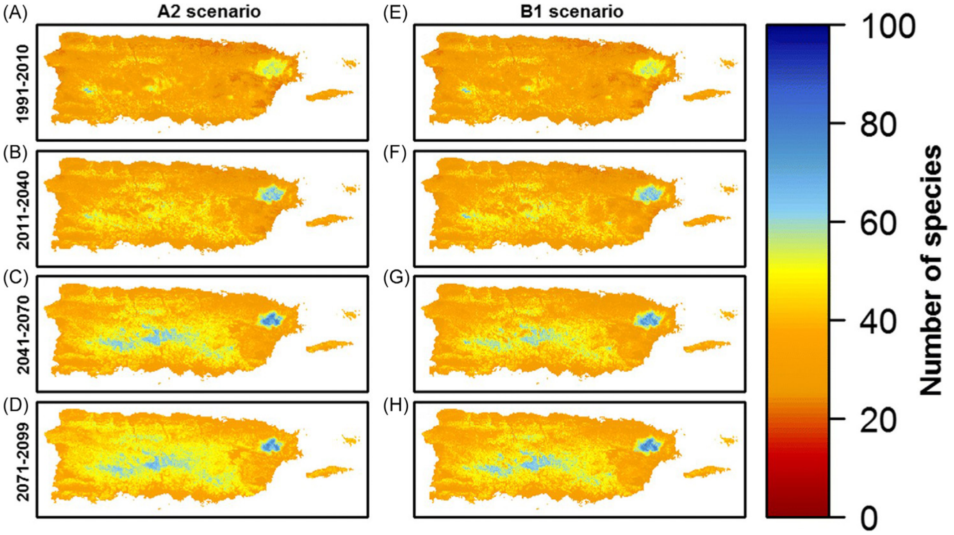

Fig. 2 Changes in the number of tree species as calculated from using the Spatially Explicit Species Assemblage Modeling framework (Guisan and Rahbek, 2011) for future periods under high (A–D) and low (E–H) carbon emission scenarios. From: Khalyani, A. H, Gould, W. A, Falkowski, M. J, Muscarella, R, Uriarte, M. and Yousef, F. (2019). Climate change increases potential plant species richness on Puerto Rican uplands. Climatic Change 16(2):587.).

Fig. 3 Cloud forests in the Luquillo Mountains of Northeastern Puerto Rico. Known locally as Elfin Woodland, these forests lie within the El Yunque National Forest and Luquillo Experimental Forests. The harbor a high percentage of endemic species form many taxonomic groups (Gould et al., 2006; González et al., 2013). Photo credit: Grizelle González, USDA Forest Service International Institute of Tropical Forestry.

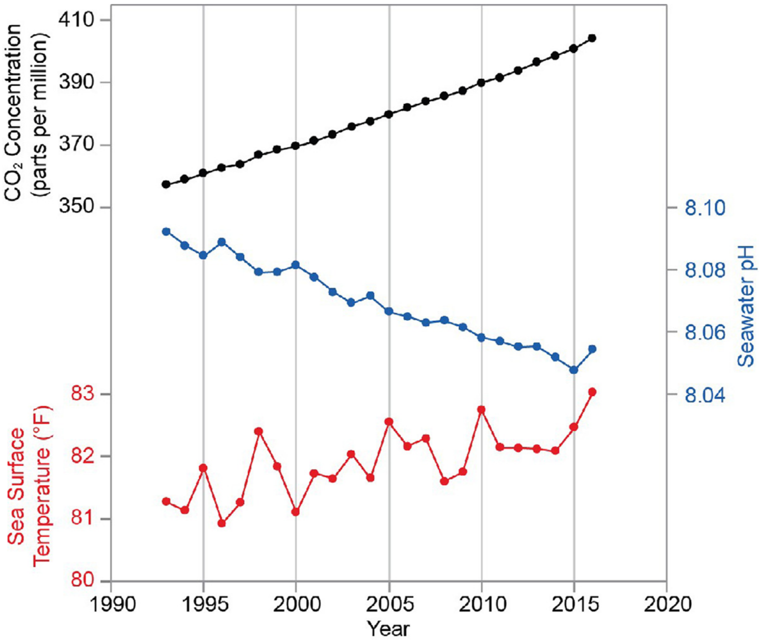

Fig. 4 Annual time series from 1993 to 2016 of atmospheric carbon dioxide (CO$_2$; *black line*), sea surface temperature (*red line*), and seawater pH (*blue line*) for the Caribbean region. (Gould et al., 2018; https://nca2018.globalchange.gov/chapter/20#fig-20-5.)

southeastern U.S. seaboard, and rates of global and regional relative sea level rise are projected to continue to increase substantially this century, largely dependent on the amount of future greenhouse gas emissions. Relative sea levels are projected to rise by about 0.8, 1.2, or 2.8 ft in low, intermediate or high emissions scenarios, respectively, by 2050 across the region compared to levels in 2000 and by about 1.6, 3.6, or 10.2 ft, respectively, by 2100 (Zervas, 2009; Sweet et al., 2017; Gould et al., 2018) (**Fig. 6**).

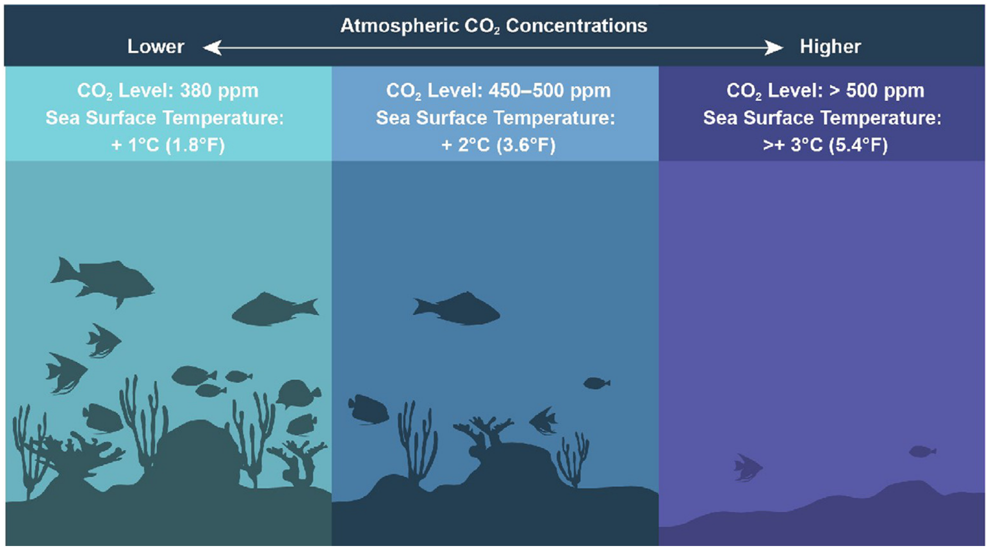

Fig. 5 Coral reefs are sensitive to sea surface temperatures. The condition of coral reefs has a big effect on biodiversity as so many species depend on healthy reef. The severity of effects increases as CO_2 levels and sea surface temperatures rise. If conditions stabilized with concentrations of atmospheric CO_2 at 380 ppm (parts per million), coral would continue to be carbonate accreting, meaning reefs would still form and have corals. At 450–500 ppm, reef erosion could exceed calcification, meaning that reef structure is likely to erode and coral cover is likely to decline dramatically. Beyond 500 ppm, corals are not expected to survive. (Gould et al. 2018; https://nca2018.globalchange.gov/chapter/20#fig-20-6).

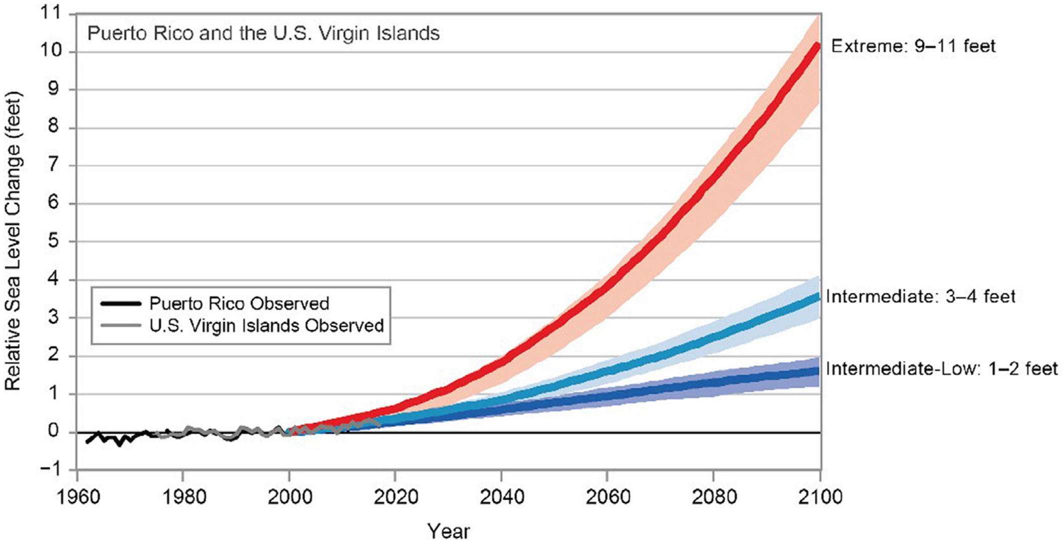

Fig. 6 Sea level rise trends in Puerto Rico and the U.S. Virgin Islands for the period 1962–2017. Projections are shown under three different scenarios of intermediate-low (1–2 ft), intermediate (3–4 ft), and extreme (9–11 ft) sea level rise. (Gould et al. 2018; *https://nca2018.globalchange.gov/chapter/20#fig-20-6*).

Biodiversity and Conservation

Protected area networks are a widely adopted strategy for conserving biodiversity and to mitigate the adverse effects of climate change (Dudley et al., 2010; Naughton-Treves et al., 2005). About 20% of the land base of the insular Caribbean is designated as protected area (UNEP-WCMC and IUCN, 2019). In this region, islands vary in the degree of protection from less than 5% on the island of Barbados to 60–70% on the islands of Guadeloupe and Martinique (Table 1). However, under new and changing climate conditions, species are shifting their distribution ranges, which means protected areas today may not be effective in the near future (Bustamante et al., 2018; Armsworth et al., 2018).

Island geography, sea level rise, and development can limit options for species migrations. As an example, in recent decades in Puerto Rico residential development increased adjacent to most of the island's protected areas, limiting capacity to expand and

Table 1 Relative and actual amount of marine and terrestrial protected areas for Caribbean Island.

	Terrestrial				*Marine*	
	Area protected (km^2)	*Total area (km^2)*	*Percent*	*Area protected (km^2)*	*Total area (km^2)*	*Percent*
Cuba	18,481	111,643	16.6	15,819	365,756	4.3
Hispaniola (DR)	12,727	48,510	26.2	48,625	270,774	18.0
Hispaniola (Haiti)	1954	27,390	7.1	1813	123,867	1.5
Bahamas	4930	13,458	36.6	47,355	597,705	7.9
Jamaica	1760	11,059	15.9	1860	246,488	0.8
Puerto Rico[a]	1356	9041	16.0	3078	176,163	1.8
Trinidad and Tobago	1595	5213	30.5	37	75,798	0.1
Guadeloupe	1170	1679	69.7	90,958	91,039	99.9
Martinique[b]	706.64	1150	61.4	47,916	47,644	100.0
Turks and Caicos	452	1018	44.4	150	154,242	0.1
Dominica	168	766	22.0	10	28,749	0.0
Antigua and Barbuda	85	455	18.6	197	108,492	0.2
Curacao	71	451	15.8	12	30,535	0.0
Barbados	6	444	1.3	10	185,020	0.0
Saint Vincent and Grenadines	92	410	22.4	80	36,511	0.2
US Virgin Islands	52	376	13.8	306	36,030	0.9
Grenada	37	374	9.8	23	26,282	0.1
Bonaire, Sint Eustatius, Saba	92	323	28.4	2756	25,112	11.0
Cayman Islands	31	289	10.8	93	119,605	0.1
Saint Kitts and Nevis	62	271	22.9	408	10,263	4.0
Aruba	36	189	18.9	0	25,214	0.0
British Virgin Islands	16	176	9.1	3	80,529	0.0
Montserrat	11	101	11.1	0	7628	0.0
Saint Martin/Sint Maarten	8	96	8.3	1074	1567	68.5
Anguilla	6	86	7.3	32	92,654	0.0
Saint Barthélemy	5	25	20.4	4244	4318	98.3
Total	45,909.64	234,993	21.7	266,859	2,967,985	16.1

[a] Puerto Rico values based on Castro-Prieto et al., 2019.

[b] Martinique estimates based on information from the Critical Ecosystems Partnership Fund (CEPF, 2010).

From UNEP-WCMC and IUCN. (2019). Protected planet: The world database on protected areas (WDPA)/database on other effective area-based conservation measures [On-line], September 2019, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net. except where noted.[a,b]

adapt to new climatic conditions (Castro-Prieto et al., 2017, **Fig. 7**). Within montane protected areas, limited ability for upward migration along elevational climatic gradients increases the vulnerability of upper montane species. For example, as climate changes, climate constrained infectious disease may be driving changes in amphibian species ranges within natural areas. Analyses of historical records and recent frog acoustic samplings in the protected El Yunque National Forest (EYNF) in the Luquillo Mountains of Northeastern Puerto Rico suggest shifts in anuran distributions, where incidence of disease moves upward, and low elevation areas have lost at least six anuran species in the last 25 years (Campos-Cerqueira and Aide, 2017). Similarly, in a study of bird distributions along the elevational and climatic gradient in these mountains, most of the bird species studied (72%) did not present elevational shifts in their ranges but there is evidence of a significant upward shift in the range of eight species (Campos-Cerqueira et al., 2017).

Sea level rise affects terrestrial habitats through salinization of coastal wetlands and aquifers, through increased rates of erosion, and through inundation. These represent changes in habitat characteristics important in governing species distributions and biodiversity. Potentially, marine habitats can shift landward or increase in growth to adapt to rising seas, and terrestrial species can migrate landward to accommodate new salinity gradients. However, the coastal zones throughout the Caribbean are where most people live and build roads, airports, hospitals, hotels, and power plants. Infrastructure represents a significant barrier to the landward migration of species adapting to sea level rise (Yu et al., 2019). The conflicts between development and natural resource protection will only increase as natural areas are reduced by sea level rise and coasts are hardened to protect infrastructure and mitigate erosion (**Fig. 8**).

In addition to shifting climate means affecting species distributions, extreme climate events such as high temperatures, hurricanes, droughts, and flooding are all projected to increase with a warming climate, and species distributions will be affected (Van Beusekom et al., 2018b; Wunderle, 2018; Lloyd et al., 2019; Khalyani et al., 2019; Helmer et al., 2019). Extreme events can increase mortality rates and, under new climatic regimes, promote shifts in the distribution of habitats and species.

Protected areas are one of several mechanisms that can support biodiversity conservation in what has been described by Castro-Prieto et al. (2019) as an integrated system for the conservation of nature (**Fig. 9**). This includes recognizing four mechanisms in addition to protected area networks, i.e., the role of laws and regulations that protect species, habitats, and ecosystems;

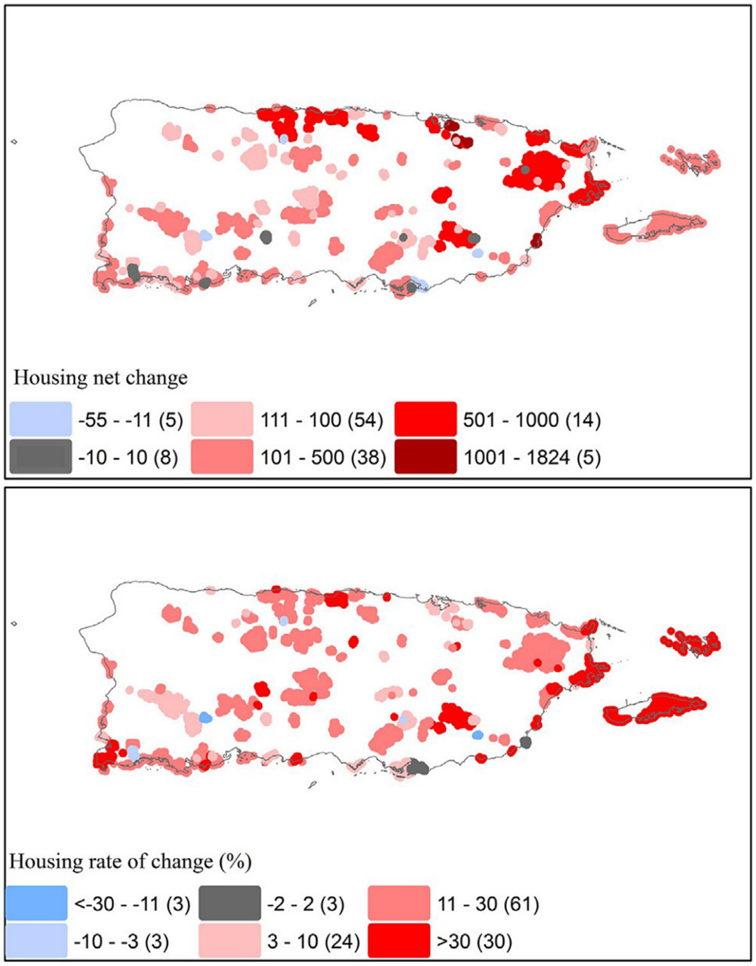

Fig. 7 Housing net change and the rate of change within 1-km of the protected areas in Puerto Rico (Castro-Prieto et al., 2017).

Fig. 8 Hawksbill turtle nest near Humacao, Puerto Rico, hemmed in by housing development and subject to hurricane damages from nearby infrastructure. Photo credit Carlos E. Diez González.

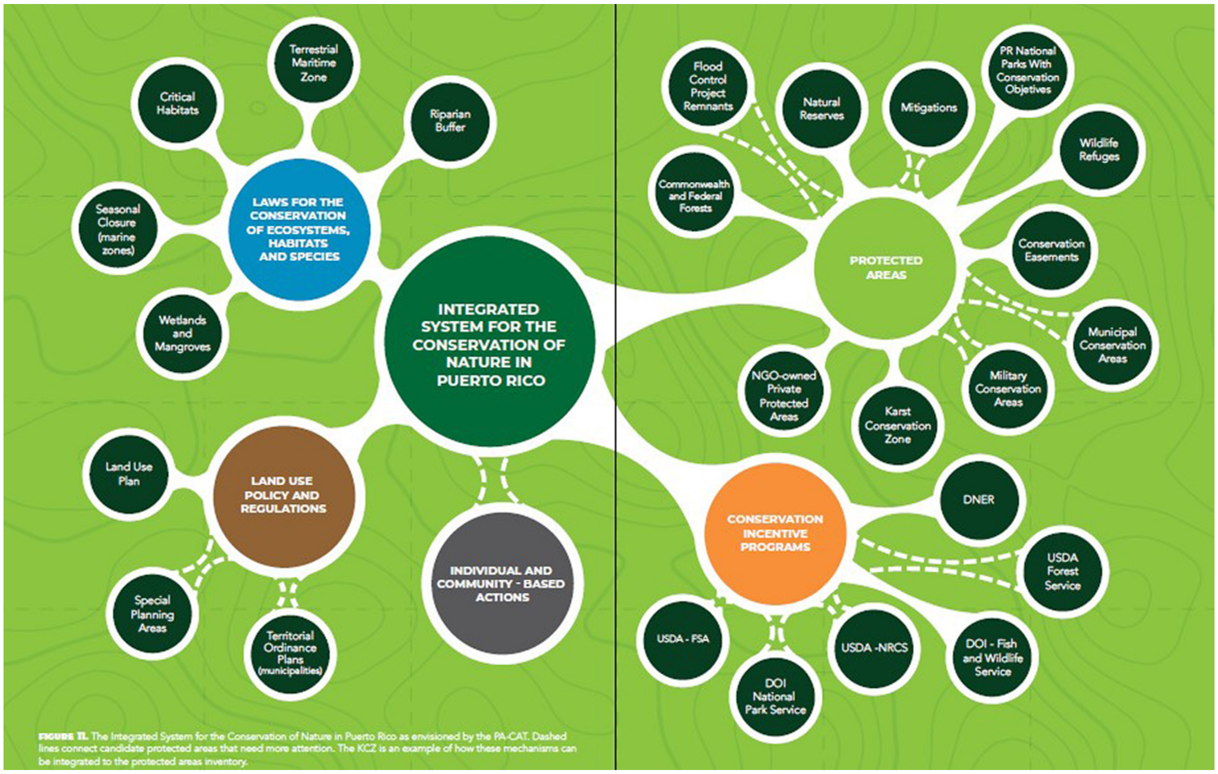

Fig. 9 An envisioned integrated system for the conservation of nature in Puerto Rico, which includes the protected areas and other land conservation mechanisms available in the island.

land use policies and regulations; incentive programs; and individual and community based actions. This integrated approach is important considering the magnitude of climate change effects and the recognition that management and effectiveness of biodiversity protection within protected area networks varies widely (Kairo et al., 2003; Visconti et al., 2019). Research is ongoing as to how well protected areas accomplish different aspects of biodiversity conservation, particularly in light of climate change (Rincón-Díaz et al., 2018; Armsworth et al., 2018; Maharaja et al., 2019). The integrated approach also recognized that biodiversity is a component not only of wildlands and protected areas, but also of working lands. Climate change has effects on biodiversity relevant to food security and agriculture. For example, forecasts based on long-term honey yield records and bioclimatic variables suggest a reduction on average yield and in areas suitable for honey production in Puerto Rico under multiple scenarios of climate change (Delgado et al., 2012). Additionally, projected climate trends suggest that increases in mean temperature and decreases in precipitation could result in the reduction of highly suitable growth conditions for *Coffea arabica* in this century (Fain et al., 2018). Balancing food security, conservation and economic development while dealing with climate risks is an ongoing issue across the Caribbean Region (Knowles et al., 2015; Gould et al., 2017; Gould et al., 2018).

Conclusions

The nature of governance of natural resources is particularly diverse in the Caribbean. Support for conservation and climate related research and adaptation practices from North American, Latin American, and European research institutes, governmental agencies, Universities, and local and global conservation organizations is extensive if not always coordinated (Gould et al., 2018, **Fig. 10**). Working across boundaries can be one way to reduce climate change vulnerabilities. As an example, an interagency effort allowed the development of a comprehensive protected areas database and the quantification and mapping of other conservation mechanisms that contribute to a larger picture of land conservation in Puerto Rico (Castro-Prieto et al., 2019).

Climate change risks are increasing and effects are being experienced by natural resource managers in the Caribbean. Islands don't have much space for large protected areas or for shifting and expanding their current boundaries. Targeted mechanisms can make the best use of resources—i.e., protecting those rare habitats from disturbance or implementing management to maintain some kind of condition will help maintain species of interest and biodiversity. There is a long history of information on climate and conservation research in the Caribbean. However, it is not always used for planning and management applications. Efforts to deliver

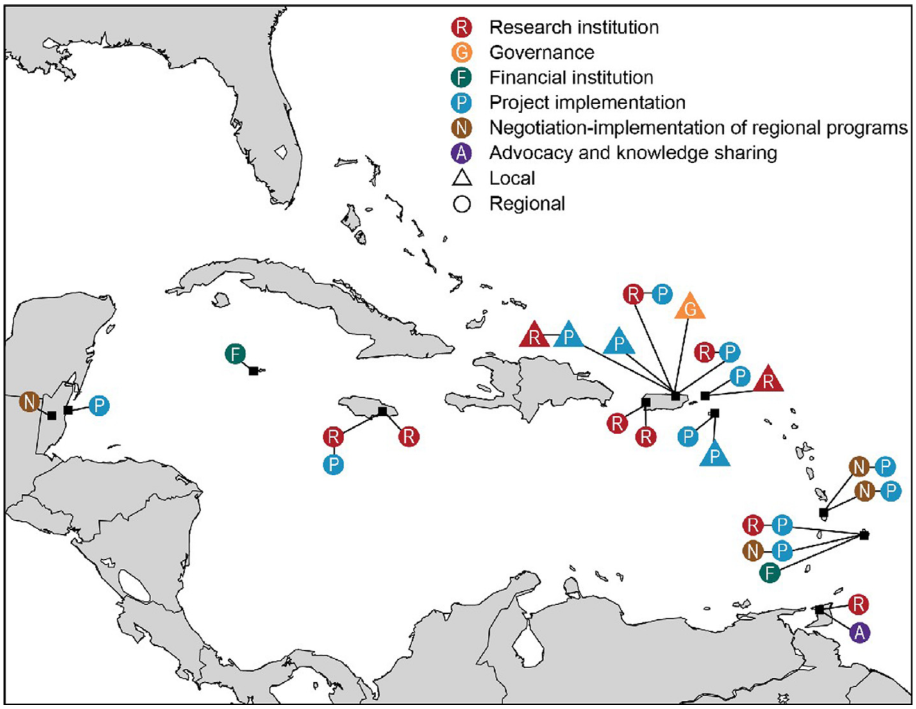

Fig. 10 Location of selected organizations working on climate risk assessment and management in the Caribbean region. Regional efforts to address climate challenges include the implementation of adaptation measures to reduce natural, social, and economic vulnerabilities, and actions to reduce greenhouse gas emissions (Gould et al., 2018; http://nca2018.globalchange.gov/chapter/20#fig-20-18).

science-based knowledge to agencies, universities, institutions and land managers dealing with vulnerable species and habitats will help organizations to act fast and adapt to climate change and weather variability. Regional and locally based vulnerability assessments focused on effects on biodiversity, modeling of projected climate change effects species that provide key ecological/and agricultural services, and assessing the effectiveness of adaptive practices are important components to reduce vulnerability to climate change. Actions that reduce the vulnerability to future risks include preparing for disturbance with nurseries and mitigation methods. Integrating species of interest with infrastructure in coastal and agricultural or working lands. Aligning best practices with mechanisms, incentives, and education of conservation practices in working lands that integrate biodiversity (e.g.,multistory cropping, alley cropping, corridors) (Álvarez-Berríos et al., 2018). Monitoring and managing to reduce cumulative effects. Collaborating internationally to share capacity, regional vulnerability assessments, and knowledge. Enjoying what we have—value and appreciation are key to conservation. Research needs include better quantifying values provided by nature, additional area covered by downscaling climate data, and modeling linking downscaling to species distributions, ecosystem services, and climate vulnerabilities.

Given the high level of biodiversity throughout the Caribbean, it is not easy to prioritize what is most at risk. Two priority areas from an example in Puerto Rico are found across the Caribbean (Fig. 11). They include wet mountain tops and cloud forests, and the marine and terrestrial coastal zone. The high number of endemics in island cloud forests, and the lack of ability to migrate from mountain tops, makes this a key habitat in the conservation of biodiversity. Additionally, species adapted to the coastal zones throughout the Caribbean are subject to multiple stressors of warming oceans, acidifying oceans, rising seas, and increasing constraints of development and infrastructure. Coastal species are often more cosmopolitan that cloud forest species, with relatively fewer endemics. However, coastal habitats tend to be local biodiversity hotspots do to the matrix of marine, wetland, and upland habitats. Sea level rise and salinization often trap coastal habitats between rising seas and infrastructure, limiting capacity for inward migration, and putting coastal biodiversity at risk and a priority for biodiversity conservation.

Acknowledgments

Thanks to Edgardo González and Sandra Soto Bayó for figure on habitats in Puerto Rico vulnerable to climate change. Thanks to Carlos E. Diez González for turtle and coastal erosion photographs. Thanks to Olga Ramos for figure identifying the Insular Caribbean. All research at the USDA Forest Service International Institute of Tropical Forestry is done in collaboration with the University of Puerto Rico.

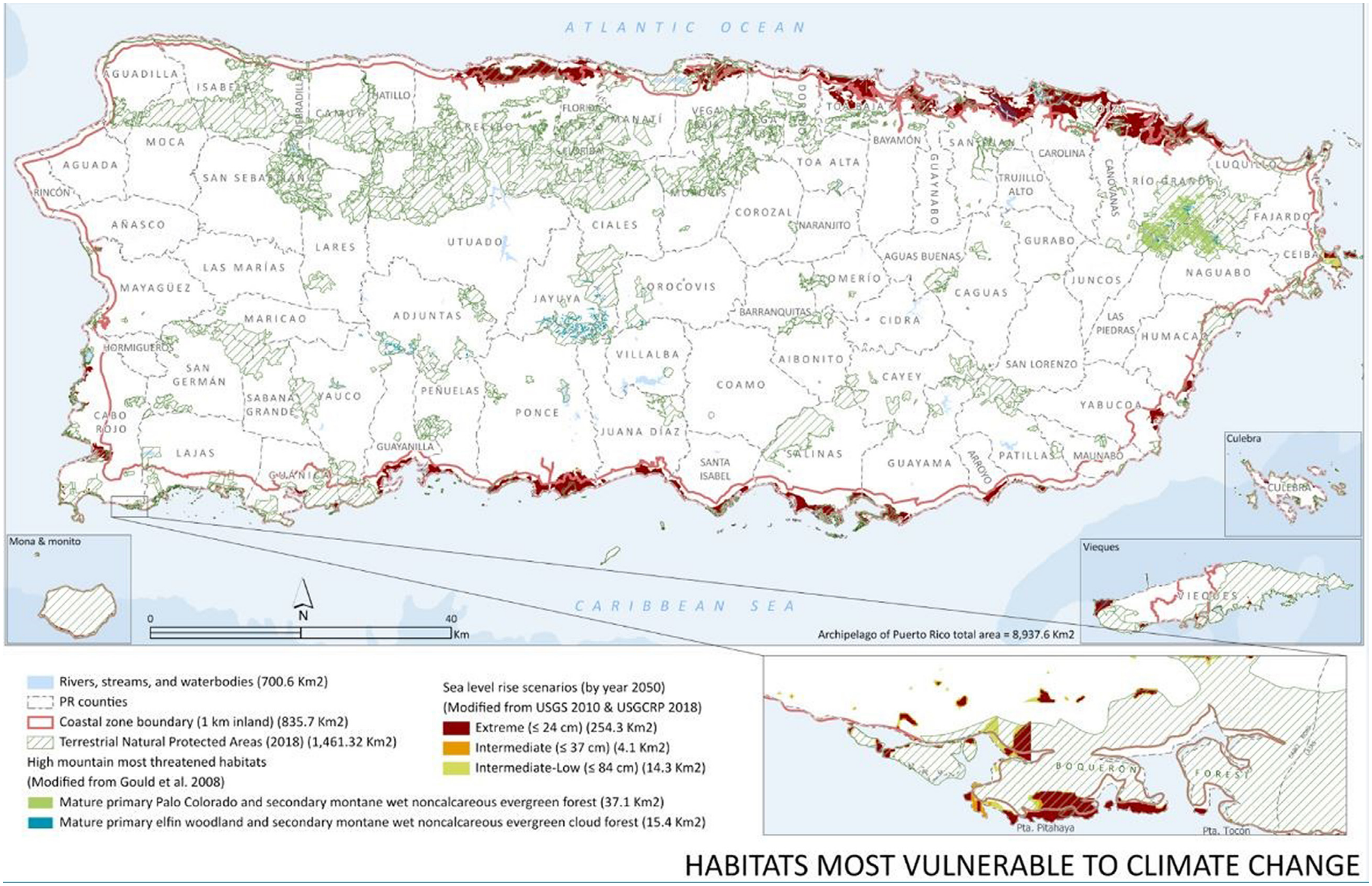

Fig. 11 Habitats in Puerto Rico most vulnerable to climate change as identified by resource managers. Coastal areas and high elevation ecosystems area some of the vulnerable environments where effects might have significant natural and physical results.

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