A call to action for climate change research on Caribbean dry forests

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Abstract

Tropical dry forest (TDF) is globally one of the most threatened forest types. In the insular Caribbean, limited land area and high population pressure has resulted in the loss of over 60% of TDF, yet local people's reliance on these systems for ecosystem services is high. Given the sensitivity of TDF to shifts in precipitation regimes and the vulnerability of the Caribbean to climate change, this study examined what is currently known about the impacts of climate change on TDF in the region. A systematic review (n=89) revealed that only two studies addressed the ecological response of TDF to climate change. Compared to the rapidly increasing knowledge of the effects of climate change on other Caribbean systems and on TDF in the wider Neotropics, this paucity is alarming given the value of these forests. We stress the need for long-term monitoring of climate change responses of these critical ecosystems, identifying phenological and hotspot analyses as priorities.

Keywords: adaptation, ecosystem services, Small Island Developing States, vulnerability.

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Introduction

Small Island Developing States (SIDS) are known to be particularly at risk to the impacts of climate change, yet current understanding of environmental responses to climate change for small islands is woefully lacking (Duvat et al. 2017). This is of concern, given the often unique island ecosystems and, that data deficiency can reduce the success of adaptation actions and decision-making processes on these islands (Mycoo et al. 2017; Robinson 2017).

Tropical dry forest (TDF) has long received less research effort than humid forest (Blackie et al. 2014). However, evidence is growing globally of the value of their ecosystem services (Portillo-Quintero et al. 2015) and their degree of endangerment (Banda et al. 2016). Ecosystem services of TDF are vital for local communities (Portillo-Quintero et al. 2015). For example, TDF provides carbon storage worth US$262,000 annually on the island of St Eustatius (Tieskens et al. 2014b), recreational value of over US$30,000 on Saba (Tieskens et al. 2014a) and US$17,000,000 in pollination and seed dispersal services on Bonaire (Cortes 2012). However, the impact of climate change on TDFs has received less attention than other forest types (Blackie et al. 2014), yet TDF are especially sensitive to drying conditions and increased water stress can result in increased mortality (Brienen et al. 2010). A key factor limiting development of the plausible future scenarios needed for robust forest management is poor understanding of ecological response to climate change (Keenan 2015).

Despite having previously lost much of its TDF (>60%), the insular Caribbean still hosts over 9% of Neotropical TDF, though most of this (>80%) is highly fragmented (Portillo-Quintero and Sánchez-Azofeifa 2010). Physiognomically and floristically, this insular TDF is distinct from continental Neotropical TDF (Banda et al. 2016; Murphy and Lugo 1995), with its' high species-level endemism(Linares-Palomino et al. 2011; Maunder et al. 2011) being of particular conservation value, The anthropogenic pressures faced by these insular forests are also distinctive from continental TDF(Portillo-Quintero and Sánchez-Azofeifa 2010). Specifically, Caribbean TDF is often dominated by invasive species (Ramjohn et al. 2012; Wolfe and van Bloem 2012) and located in lowland areas subject to intense development pressure (Portillo-Quintero and Sánchez-Azofeifa 2010). In the Caribbean SIDS, climate change is increasingly well-documented, with decreasing precipitation predicted (Karmalkar et al. 2013). To future-proof TDF against climate change, it is necessary to understand the potential ecological impacts on these unique forest systems. Here, a systematic review quantifies current understanding of climate change impacts on TDF in the insular Caribbean.

Methods

The systematic review methodology was based on well-established guidelines (Pullin and Stewart 2006). Boolean searches were conducted in Web of Knowledge from January 1981 to August 2017, for the phrases [“Caribbean”] AND [“dry forest”], AND [“climat* change” OR "global warming"]. A search was also performed using scholar.google.com, with the first 100 documents examined for their inclusion suitability. Grey literature databases were also searched (Food and Agriculture Organisation, Treesearch and Caribbean Community Climate Change Centre) and additional literature identified through in-text citations of search results.

This review addressed the question: what are the ecological impacts of climate change in insular Caribbean TDFs? Studies were assessed using specified inclusion/exclusion criteria for study type, subject, outcome and geographic location (Supplementary Table 1).

Results

Eighty-nine sources of literature were identified from all searches. Of these, 10 were excluded based on study type, 31 for not meeting subject criteria and 27 due to their geographic location. Twenty-one qualified as potentially addressing the question. After a full review of these studies, three were excluded based on the study outcome criteria, five because of the geographic focus, three for failing to meet subject criteria and one for study type. Only two studies referenced specific ecological responses of TDF to climate change, all published since 2016 and both from Puerto Rico. These two papers presented future predictions of TDF distribution and changes in biomass due to increased hurricane activity, respectively. The remaining eight papers provided evidence related to climatic drivers of TDF, but the study aims were not explicitly related to climate change. Of these studies, three presented data on the structural response of TDF to hurricanes, one on the climatic drivers of fire and three on climate-driven species composition or phenology trends.

Discussion

That this review found only two studies of the ecological impacts of climate change on Caribbean TDF illuminates our poor understanding of the response of these forest systems to climate change. This is deeply troubling and, is in contrast to increasing research on climate change impacts on other Caribbean ecosystems, such as beach and coral reef habitats (Cambers 2009; Randall and Van Woesik 2015) and other forest types (McKee et al. 2007; Scatena 1998). Similarly, this contrasts to increasing climate change research on continental Neotropical dry forests (Aguirre et al. 2017; Brienen et al. 2010; Prieto-Torres et al. 2016).

What do we know?

Exposure to climate change in the Caribbean is expected to include a 2-5^{o}C increase by the 2080s, with drying of 20-40% expected, particularly during the wet season (Karmalkar et al. 2013). In addition, hurricanes are predicted to become more intense under certain climate scenarios (Grinsted et al. 2013).

Climatic drivers of Caribbean TDF compositional and demographic patterns are relatively well-studied (e.g. Brandeis et al. 2009; Rojas-Sandoval and Meléndez-Ackerman 2011; Van Bloem et al. 2006). Since TDF dynamics are particularly sensitive to precipitation (Murphy and Lugo 1995), increased drought severity will likely reduce growth, reproductive effort (Rojas-Sandoval and Meléndez-Ackerman 2011) or change species composition (Brandeis et al. 2009). On Puerto Rico, models predict an island-wide shift from moist to dry life zones due to reduced precipitation and increased temperatures, with the replacement of subtropical dry forest by dry forest by 2099 (Khalyani et al. 2016). However, models did not account for unfavourable future land-use constraining suitable conditions. Hurricanes are key modifiers of Caribbean TDF structure and although these forests are resilient (Van Bloem et al. 2006), recovery from severe events can take decades (Imbert and Portecop 2008). Modelling of Puerto Rican TDF suggests increased hurricane frequency, but not intensity, would lead to a sustained decrease in carbon stock (Holm et al. 2017).

Our understanding of anthropogenic drivers of Caribbean TDF (e.g. Ramjohn et al. 2012; Wolfe and van Bloem 2012), provides insight into TDF vulnerability and adaptive capacity to climate change. Anthropogenic fire results in long post-disturbance recovery times for Caribbean TDF (Wolfe and van Bloem 2012) and fire is known to increase with rising minimum daily temperatures and declining precipitation (Monmany et al. 2017). Invasive species are dominant in many Caribbean TDF, particularly those recovering from disturbance (Ramjohn et al. 2012). While the ecological outcome of novel communities is debated and may not be negative (Lugo 2004), some invasive species are highly drought- and fire-resistant (Wolfe and van Bloem 2012), in contrast to many native species.

While current understanding is valuable for making inferences about climate change impacts on Caribbean TDF, predicting system responses requires a deeper understanding of species- and community-level sensitivity and exposure (Williams et al. 2008). Ideally, this involves integrating experimental and gradient methods to determine both large-scale and mechanistic climate-ecosystem interactions (Dunne et al. 2004). Achieving such insight demands a research framework that includes predictive models, experiments and management-relevant data collection.

Current limitations for climate change research

A significant challenge for research on the ecological impacts of climate change on Caribbean forests is the lack of data to parameterise models and inform management. Such data limitations include:

- Inconsistent and inaccessible historical meteorological data (Lumbroso et al. 2011), while future climate projections lack the spatial resolution required for accurate predictions on topographically complex, small islands (Maharaj and New 2013).
- Landscape-level species occurrence data are patchy across the region and long-term monitoring is inconsistent. Permanent plots, such as those set up by the FAO Tropical Forestry Action Programme in the 1980s, are often infrequently re-visited due to lack of manpower, resources and loss of institutional memory.
- Long-term field or laboratory experiments on survival and growth exist for few TDF species or locations (McLaren et al. 2011) and species-specific trait data across environmental gradients is limited to a few well-studied systems (e.g. Brandeis et al. 2009).

- Little is known about potential changes in hydrological processes and consequences of rainfall patterns for tree growth (Farrick and Branfireun 2013).
- Few island-specific spatial predictions of future land-use change exist (Newman et al. 2014).

In the Caribbean SIDS the reality is that research is limited by financial, political, capacity and logistical constraints (Kaiser-Bunbury et al. 2015). It is no surprise that the island with the greatest research effort (Puerto Rico) has external support (International Institute for Tropical Forestry of the US Forest Service). Whilst emphasising the need to focus research on Caribbean TDF, we advocate an integrative and interdisciplinary approach. Any regional research framework must take a ‘least cost’ approach and enable a clear link between on-the-ground adaptation actions and species responses.

What are future research priorities?

Our recommendations for work on TDF climate response are not exhaustive (Table 1), but are chosen to complement priorities already identified for dry forest (Banda-Rodriquez et al. 2016) and forestry more widely in the Caribbean (Gonzalez and Heartsill Scalley 2016), as well as consider regional financial and capacity challenges.

Understanding the potential change in TDF distribution requires an understanding of all forest types at the leading and trailing TDF edges. The steep climatic gradients on many Caribbean islands (Murphy and Lugo 1995), adds a layer of complexity when predicting the ecosystem response to climate change. Identifying a small number of region-wide species to monitor is a priority for understanding species responses across such gradients. For this to succeed, overcoming the challenge of long-term monitoring demands putting more onus on the researcher to engage local practitioners (Kaiser-Bunbury et al. 2015).

Models provide meaningful insight for management and a physiological framework of species responses to climatic changes (Williams et al. 2008). Recent models of Puerto Rican TDF (Holm et al. 2017; Khalyani et al. 2016) demonstrate the value of such approaches. Long-term vegetation monitoring together with monitoring key climatic variables, is an important step in understanding the sensitivity of Caribbean TDF to climate change impacts.

Importantly, improving climate data collection would benefit all aspects of climate change research across all habitats in the region.

Predicting future change in TDF distribution and developing climate change adaptation requires evaluating landscape-scale patterns in forest cover, especially those driven by region-specific anthropogenic factors such as urbanisation. A lack of technological capacity has to date hindered the data analysis required for improved decision-making related to complex land tenure in the Caribbean (Mycoo et al. 2017), which increases the vulnerability of TDF to climate change and the ability to adapt (Medeiros et al. 2011). Recent efforts elucidating temporal land-use change in Jamaica from spatially explicitly models (Newman et al. 2014)and innovative emerging technology, such as Caribbean-wide crowdsourced land-use/land-cover imagery (Clark and Aide 2011) offer direction for future work in this area. Economic valuation provides a means to integrate the socio-economic benefits of TDF into climate change adaptation. Lessons learned from the success of translating Caribbean coastal economic valuations into decision-making, highlight the importance of informed and collaborative stakeholder engagement (Waite et al. 2015). Given the close relationship between forest management and agriculture, tourism and land-use planning, promoting inter-sectoral synergies is vital for realising the full potential of a region-wide, TDF research strategy.

The impacts of climate change on Caribbean TDF will be far reaching. The increased understanding to be gained from these research priorities is not only of relevance for conserving these unique forests, but also for climate change adaptation in other sectors, such as tourism and agriculture. Indeed, a robust scientific basis is a recommended component of the multi-stage climate change adaptation planning recommended for SIDS to meet their 2030 Sustainable Development Goals, which are widely recognised as a catalyst for achieving climate change adaptation (Robinson 2017).

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Table 1. Priority research areas of ecological climate change impacts on Caribbean TDF.

	Description	Examples in Caribbean	Justification	Ease of implementation
Hotspot analysis	Mapping of fire and invasive species risk	Predictive models of fire risk for Puerto Rico (Monmany et al. 2017)	Pertinent for spatial prioritisation of management and adaptation actions, vulnerability	Initial analysis could be conducted using existing open access data (e.g. MODIS and GBIF)
Phenology	Long-term monitoring timing of seasonal life-cycle events	Puerto Rico is already participating in the PhenoCam network (phenocam.sr.unh.edu)	Invaluable for understanding species (e.g. endemic, invasive) sensitivity and adaptive capacity	Expanding the PhenoCam network is a relatively cost-effective, low personnel commitment
Ecosystem services	Mapping and total economic valuation (TEV) of ecosystem services	TEV model of current TDF value in Bonaire (Cortes 2012)	Promotes political and civil society buy-in of the importance of climate change adaptation	Methods to incorporate economic costs/benefits of climate change can be data-hungry
Long-term monitoring	Species-specific responses and changes in forest structure and composition caused by climate and disturbance	Recent proposals for a Caribbean permanent plot network (Gonzalez and Heartsill Scalley 2016). Rainfor (Red Amazónica de Inventarios Forestales) permanent plot network, part of the global ForestPlots.Net initiative provides a useful model.	Multiple potential data uses e.g. space-for-time, climate gradients, physiological responses, introduced vs. native species, endemic species, ecosystem services and early warning systems, sensitivity, exposure and adaptive capacity	Costly and logistically challenging long-term permanent plots and experimental approaches
Modelling	Ecological niche, trait-based, and mechanistic models of species responses to climate change;	Ecological niche model of selected tropical moist forest species on Trinidad (Maharaj and New 2013); mechanistic models of future hurricane on Puerto Rico (Holm et al. 2017); kriging used to	Species sensitivity and exposure, drivers of land-use change, scenario and land-use planning, protected areas, agriculture and tourism, physiological	Niche-based and interpolation models less data-hungry than more robust mechanistic models

	interpolation of climatic variables; spatially explicit land-use change models	interpolate climate for mapping Holdridge life zones on Puerto Rico (Khalyani et al. 2016)	understanding of species responses