Revista Brasileira de Climatologia
Brazilian Journal of Climatology

DOI: 10.5380/abclima

WILL CLIMATE CHANGE BE HARMFUL FOR SMALL TROPICAL ISLANDS? THE CASE OF FERNANDO DE NORONHA ARCHIPELAGO, BRAZIL

PODEM AS MUDANÇAS CLIMÁTICAS PREJUDICAR ILHAS TROPICAIS PEQUENAS? O CASO DO AQUIPÉLAGO DE FERNANDO DE NORONHA, BRASIL

¿EL CAMBIO CLIMÁTICO SERÁ PERJUDICIAL PARA LAS PEQUEÑAS ISLAS TROPICALES? EL CASO DEL ARCHIPIÉLAGO FERNANDO DE NORONHA, BRASIL

Luisa Maria Diele-Viegas
Universidade Federal de Alagoas
luisa.mviegas@gmail.com

Carlos Frederico Duarte Rocha
Universidade do Estado do Rio de Janeiro
cfdrocha@gmail.com

Abstract: The Fernando de Noronha archipelago is one of the key areas for biodiversity conservation on the Brazilian coast and one of Brazil's most sought-after destinations for ecotourism. We assessed the potential Archipelago's risk from climate changes based on climate-related hazards, calculated through the percentage of changes between future and present values for each climatic and bioclimatic variable from the WorldClim database. Two radioactive force models were considered for the forecasts, considering an optimistic scenario and a business-as-usual scenario of greenhouse gas emissions. Our data indicated that minimum and maximum environmental temperatures are likely to increase homogeneously throughout the year, while a possible intensification of the dry season is likely to occur with a decrease in precipitation. In addition, our results indicate a decrease in isothermality, representing a decrease in the ratio between diurnal temperature variation and interannual temperature variation. Our results indicate that this important Archipelago is becoming potentially at risk of climatic and bioclimatic variation due to anthropogenic climate changes. We argue that the planning of local environmental policies should include adaptation and mitigation measures of negative effects of climate change, and conservation actions should be carried out under an integrative approach basis, including environmental conservation and remediation, sustainable use of resources, and regional and national governance.
Keywords: Climate emergency. Greenhouse gas emissions. Small islands. Climate risk.

Resumo: O arquipélago de Fernando de Noronha é uma das principais áreas para a conservação da biodiversidade do litoral brasileiro, e um dos destinos mais procurados para o ecoturismo no país. Neste estudo avaliamos o risco potencial causadas pelas mudanças climáticas para o arquipélago com base nos riscos relacionados ao clima, calculados por meio da porcentagem de mudança entre os valores futuros e presentes para cada variável climática e bioclimática do banco de dados WorldClim. Dois modelos de força radioativa foram considerados para as previsões, um deles considerando um cenário otimista e um outro cenário que prevê a manutenção das taxas atuais de emissões de gases de efeito estufa. Nossos resultados indicam que as temperaturas ambientais mínimas e máximas tendem a aumentar homogeneamente ao longo do ano, com uma provável intensificação da estação seca em função da redução da precipitação. Além disso, nossos resultados indicam um declínio da isotermalidade, representado por uma diminuição na razão entre a variação de temperatura diurna e a variação de temperatura interanual. Nossos resultados indicam que este importante arquipélago está em risco potencial de variação climática e bioclimática devido às mudanças climáticas antropogênicas. Argumentamos que o planejamento de políticas ambientais locais deve incluir medidas de adaptação e mitigação dos efeitos negativos das mudanças climáticas, e as ações de conservação devem seguir uma abordagem integrativa, incluindo conservação e remediação ambiental, uso sustentável de recursos e governança regional e nacional.
Palavras chave: Emergência climática. Emissão de gases do efeito estufa. Ilhas pequenas. Risco climático.

Resumen: El archipiélago de Fernando de Noronha es una de las principales áreas de conservación de la biodiversidad en la costa brasileña y uno de los destinos más buscados para el ecoturismo en el país. Evaluamos el riesgo potencial de cambio climático para el archipiélago con base en los peligros relacionados con el clima, calculado utilizando el porcentaje de cambio entre los valores futuros y presentes para cada variable climática y bioclimática en la base de datos WorldClim. Se consideraron dos modelos de fuerza radiacti va para las previsiones, considerando un escenario optimista y un escenario que prevé el mantenimiento de las tasas actuales de emisión de gases de efecto invernadero. Nuestros resultados indican que las temperaturas ambiente mínima y máxima tienden a aumentar de manera homogénea a lo largo del año, y una posible intensificación de la estación seca puede ocurrir de acuerdo con la reducción de las precipitaciones. Además, nuestros resultados indican una disminución de la isotermalidad, representada por una disminución en la relación de proporción entre la variación de la temperatura diurna y la variación de la temperatura interanual. Nuestros resultados indican que este importante archipiélago está en potencial riesgo de variación climática y bioclimática debido al cambio climático antropogénico. Argumentamos que la planificación de la política ambiental local debe incluir medidas para adaptarse y mitigar los efectos negativos del cambio climático, y las acciones de conservación deben seguir un enfoque integrador, que incluya la conservación y remediación ambiental, el uso sostenible de los recursos y la gobernanza regional y nacional.
Palabras clave: Emergencia climática. Emisiones de gases de efecto invernadero. Islas pequeñas. Riesgo climático.

Submetido em: 20/12/2019
Aceito para publicação em: 13/09/2021
Publicado em: 13/11/2021

INTRODUCTION

The World's average temperature is currently 1.2°C higher than the preindustrial period and is expected to increase 4.8°C by 2100, assuming a business-as-usual scenario of greenhouse gas emissions (GHG), where current emission rates will be kept for the next decades (BABIKER et al., 2018; VAN VUUREN et al., 2011, 2014). Changes in precipitation patterns, water cycle, the extension and frequency of droughts, and sea levels are also expected to occur (STOCKER et al., 2013). In South America, the frequency and intensity of extreme temperature and precipitation events are likely to increase steadily (MAGRIN et al., 2014). In addition, a decrease in the reliability of coastal structures is predicted due to the increase in wave height estimates, mostly in the Southeast and Northeastern Brazilian coast (MAGRIN et al., 2014). It may lead to a flooding of 46% of the sandbanks in southeast Brazil, resulting in an associated extinction of 7% of all endemic species (MENON et al., 2010).

Small tropical islands may be particularly vulnerable to climate change (NURSE et al., 2014). Multiple threats facing islands include loss of area due to rising sea levels, loss of human-made infrastructures, degradation of coral reefs, ocean acidification, tropical cyclones, warmer temperatures, altered precipitation patterns (NURSE et al., 2014), and changes in coastline and coastal water quality (RAFAILIDIS et al., 1996). Climate stress may lead to decreases in adaptive capacity of small islands and on the thermal adequacy for their local biodiversity, which may cause changes in ecosystem services and impair local tourism, economy, and livelihood (NURSE et al., 2014; WONG et al., 2014). Also, islands with limited freshwater supplies are likely to be even more vulnerable to climate change impacts since it may cause alterations in hydric balance and an increase in soil salinization (TOMPKINS, 2005).

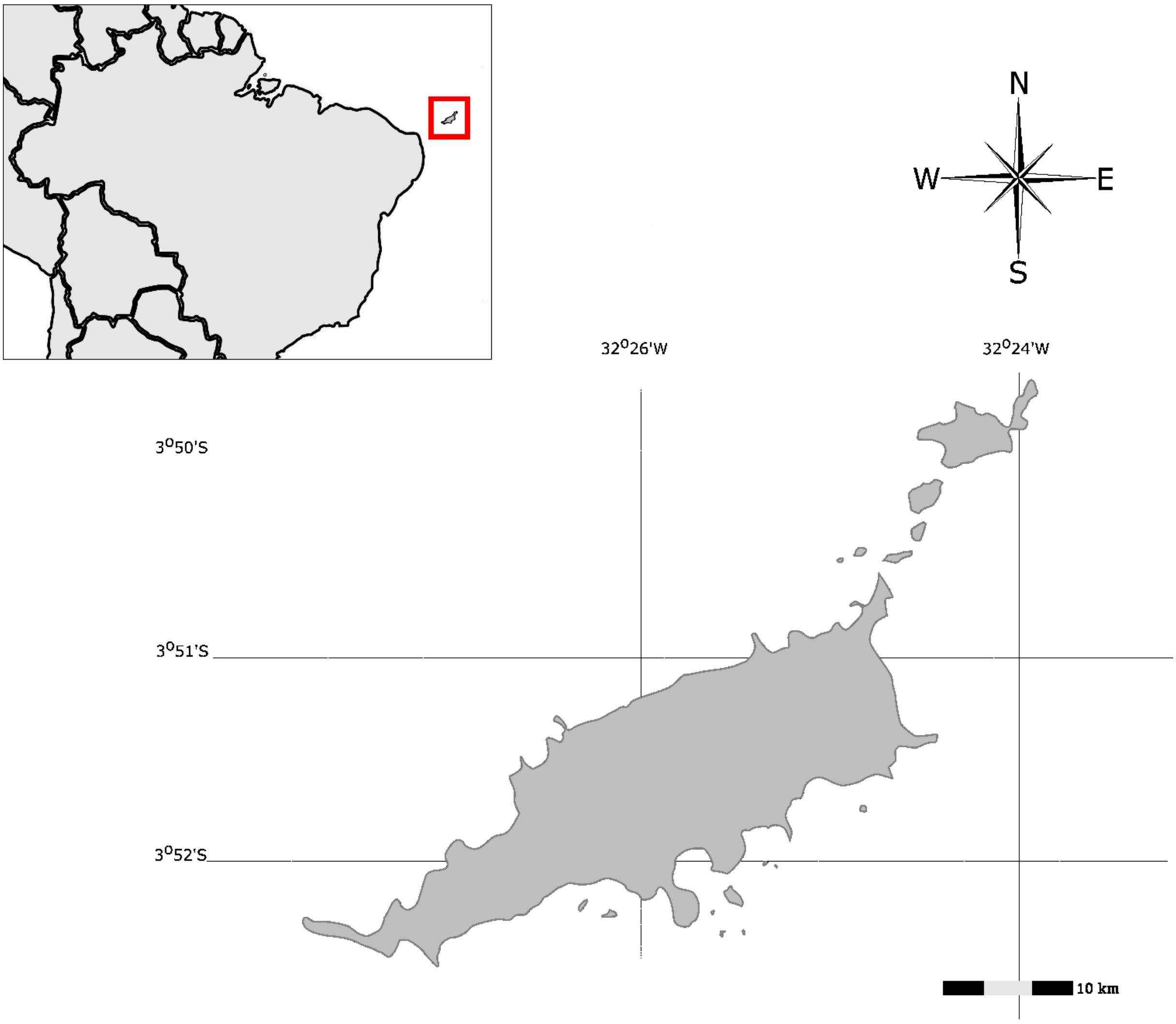
The Fernando de Noronha archipelago is the easternmost portion of Brazilian territory, located about 350 km from the coast. Originated from orogenic events, it consists of a main island surrounded by several islets and smaller islands of volcanic origin, which together have an estimated area of about 25 km^2 (ROCHA et al., 2009). The archipelago is under protection of two conservation units; the Parque Nacional Marinho de Fernando de Noronha (full protection) and the Área de Proteção Ambiental de Fernando de Noronha (sustainable use of natural resources). Ecotourism is the Archipelago's primary source of local economic activity, being the main Island one of the most searched destinies in the Brazilian Northeast (SOUZA; FILHO, 2011). The Archipelago is also a key site for biodiversity conservation, being a repository for the maintenance of marine biodiversity and a Global Centre of Bird Endemism (CLAUDINO-SALES, 2019). The Archipelago houses terrestrial endemic species, such as the lizard *Trachylepis atlantica* and the *Amphisbaena ridleyi* (ROCHA et al., 2009), besides housing the only remaining sample of Insular Atlantic Forest and Oceanic Mangrove in the South Atlantic region (CLAUDINO-SALES, 2019). The United Nations Educational, Scientific, and Cultural Organization (UNESCO) recognized its outstanding value to world biodiversity, promoting its inclusion on the World Heritage List (UNESCO, 2021). Thus, its preservation is paramount to avoid the extinction of many species and environments that are only – or mostly - found in these islands.

While many studies have investigated the potential impacts of climate change on species or groups of species (e.g., URETA et al., 2018; DIELE-VIEGAS et al., 2020), much less attention has been given to the risk of sensitive environments, such as small tropical islands like the Fernando de Noronha Archipelago. Accessing the potential effects of climate change on these environments is essential to support public policies to mitigate such impacts on local human populations and biodiversity. Therefore, we aimed to quantify the climate change risk in the Fernando de Noronha Archipelago, considering two GHG emissions scenarios, the first predicting a decrease in the emissions for the following years (RCP 4.5), and the second predicting the maintenance of the current rates of GHG emissions (RCP 8.5).

METHODS

The Fernando de Noronha Archipelago (3°51'S, 32°25'W, Figure 1) presents a tropical, oceanic climate, consisting of a wet season extending from February to July and a dry season from August to January (BARCELLOS et al., 2011). Despite the high interannual variability, the average annual air temperature is about 25 ± 2.5ºC, and the total annual precipitation is 1400mm (BARCELLOS et al., 2011). Its prevailing winds reach 11 ms^{-1} during the wet season, and waves can reach 4-5 m high in more energetic swells (BARCELLOS et al., 2011).

Figura 1 - Location and topography of Fernando de Noronha Archipelago. The map was generated based on the WGS84 datum, adopting the geographic coordinate system.



Source: Elaborated by the authors (2019)

The geographic boundaries of the Archipelago were extracted from *Google Earth* (GOOGLE, 2018). To characterize the historical and future climate of this Archipelago, we considered monthly average precipitation (Prec), minimum (T_{min}) and maximum (Tmax) temperatures, and nineteen raster-based bioclimatic variables (HIJMANS et al., 2005): Annual mean temperature; Mean Diurnal Range; Isothermality; Temperature Seasonality; Max Temperature of Warmest Month; Min Temperature of Coldest Month; Temperature Annual Range; Mean Temperature of Wettest Quarter; Mean Temperature of Driest Quarter; Mean Temperature of Warmest Quarter; Mean Temperature of Coldest Quarter; Annual Precipitation; Precipitation of Wettest Month; Precipitation of Driest Month; Precipitation Seasonality; Precipitation of Wettest Quarter; Precipitation of Driest Quarter; Precipitation of

Warmest Quarter; Precipitation of Coldest Quarter. All variables were obtained from the WorldClim datasets at 2.5 minutes spatial resolution (HIJMANS et al., 2015).

The historical climate was characterized by interpolating data from meteorological stations worldwide from 1970 to 2000 (FICK and HIJMANS 2017). In order to cover a broader range of possibilities regarding climate variation (LIU; LI; DING, 2021), our future climate projections considered the ensemble of two General Circulation Models (GCMs) of the Coupled Model Intercomparison Project Phase Five (CMIP5; TAYLOR et al., 2012): HadGEM2-ES and MIROC-ESM. Both the Hadley Centre Global Environmental Model version 2 - Earth System (HadGEM2-ES) and the Model for Interdisciplinary Research on Climate - Earth System Model (MIROC-ESM) include atmospheric, ocean, and terrestrial components to predict how the climate may evolve in the future (COLLINS et al., 2011; WATANABE et al., 2011). The complexity of such earth system models and consequent uncertainty lead to a more realistic assessment of the knowledge of climatic evolution in the future (COLLINS et al., 2011). Besides, both HadGEM2-ES and MIROC-ESM present outstanding accuracy in predicting the observed temperature and precipitation patterns for South America during the control period (1970-2000; ANAV et al., 2013; WATANABE et al., 2011; YIN et al., 2013).

We considered two models of Representative Concentration Pathways (RCP, the model available when data of the present study were modeled): the first assuming +4.5 W/m^2 (RCP 4.5), and the second assuming +8.5 W/m^2 (RCP 8.5) of radiative forcing by 2100 (HIJMANS et al., 2005; VAN VUUREN et al., 2011). RCP 4.5 predicts a change in the energetic system, including shifts to lower emissions technologies and carbon capture and geologic storage technology (THOMSON et al., 2011). RCP 8.5, in turn, predicts high energy demand and greenhouse gas emissions without climate policies (RIAHI et al., 2011). We focused our analyses on the period between 2061 and 2080 (referred to as 2070) since it is the most distant period available for RCP projections. By focusing on a less urgent temporal scale, we can discuss the potential medium-term impacts of climate change on the Archipelago so that it is possible for the decision-makers to implement mitigation measures promptly to reverse such impacts.

We calculated the difference between current and future predictions of each climatic and bioclimatic variable tested for each scenario. Then, we assessed the Archipelago's risk from climate change based on climate-related hazards, calculated through the percentage of change between future and historical values for each climatic and bioclimatic variable (IPCC 2018, LIU et al., 2021). All analyses were performed on the statistical environment R 3.5.1 (R CORE TEAM, 2018).

RESULTS AND DISCUSSION

Risk from the climatic variation

Our results indicate that both minimum and maximum environmental temperatures are likely to increase homogeneously throughout the year in Fernando de Noronha. In the optimistic scenario, the minimum temperature can vary from 6.6% (1.6°C) in October to 8% (2°C) in January, while the maximum temperature can vary from 5.8% (1.7°C) in October and November to 6.8% (2.1°C) in January. For RCP 8.5, the minimum temperature can vary from 10.9% (2.7°C) in September and October to 12.3% (3°C) in December, while the maximum temperature can vary from 9.1% (2.7°C) in September to 10.3% (3°C) in December (Table 1).

Table 1 - Risk from climatic variation predicted by 2070 for the Fernando de Noronha archipelago, considering monthly precipitation (Prec), monthly average minimum temperature (T_{min}) and monthly average maximum temperature (T_{max}) for both RCP 4.5 and RCP 8.5. PV = Predicted variation; % = Percent changes. Wet season is highlighted in gray.

	RCP 4.5						RCP 8.5					
	PV Prec (mm)	% Prec	PV T_{min} (°C)	% T_{min}	PV T_{max} (°C)	% T_{max}	PV Prec (mm)	% Prec	PV T_{min} (°C)	% T_{min}	PV T_{max} (°C)	% T_{max}
January	11	22.9	2	8.0	2.1	6.8	15	31.3	3	12.1	3.1	10.1
February	14	11.5	1.9	7.8	2	6.5	27.25	22.4	2.9	11.5	3	9.9
March	14	7.1	1.9	7.7	2	6.6	2.5	1.3	2.9	11.6	2.9	9.7
April	24.5	8.8	1.8	7.3	1.8	6.1	8.75	3.1	2.8	11.4	2.8	9.5
May	6	2.3	1.7	7.1	1.8	6.2	-20	-7.5	2.7	11.2	2.8	9.7
June	-6.5	-3.5	1.8	7.5	1.8	6.4	-56.25	-30.2	2.8	11.5	2.8	9.9
July	-38	-25.3	1.8	7.3	1.8	6.2	-47.5	-31.7	2.7	11.3	2.7	9.6
August	-10.5	-22.3	1.7	7.1	1.7	5.9	-15.5	-33.0	2.7	11.0	2.7	9.2
September	-0.75	-3.9	1.7	7.0	1.7	5.9	-2.5	-13.2	2.7	10.9	2.7	9.1
October	-1.5	-13.6	1.6	6.6	1.7	5.8	-0.5	-4.5	2.7	10.9	2.7	9.2
November	-1	-7.7	1.7	6.9	1.7	5.8	1	7.7	2.8	11.2	2.8	9.4
December	4	25.0	1.9	7.8	1.9	6.3	5.25	32.8	3	12.3	3	10.3

Source: Elaborated by the authors (2019)

We predicted the intensification of the dry season between August and November and an increase in precipitation for most of the wet season, excepting May (in RCP 8.5), June, and July (for both RCPs). The precipitation change will likely vary from -25% to +25% for RCP 4.5 and from -33% to 32.8% for RCP 8.5, indicating that seasonal variation will be stronger. These changes are also predicted for the Caribbean Islands, where the rainfall is likely to increase from November to January, and there is a strong tendency to dry from June to October (NURSE et al., 2014; TAYLOR et al., 2013). Due to the aseasonality of tropical environments, local species are usually physiologically specialized concerning environmental temperature, presenting limited acclimation capacity (TEWKSBURY et al., 2008). Thus, the rising environmental temperature and intensification of seasonal variation predicted for Fernando de Noronha is likely to negatively impact local biodiversity (TEWKSBURY et al., 2008), especially terrestrial ectotherms such as *Trachylepis atlantica* and *Amphisbanea ridleyi*, which depends on the environmental temperature to regulate their body temperature and keep their metabolism active (ROCHA et al., 2019; DIELE-VIEGAS et al., 2020).

Risk from bioclimatic variation

We predicted an increase of 1.8 °C in annual mean temperature for the RCP 4.5 and 2.8 °C considering the RCP 8.5. No relevant variation is predicted in the mean diurnal range, reflecting the homogeneous increase of the minimum and maximum monthly average temperature. In addition, our results indicate a reduction in isothermality, representing a decrease in the ratio between diurnal temperature variation and annual temperature range. Such patterns are related to the predicted shift in temperature seasonality, reaching 13.3% considering RCP 4.5 and 17.6% considering RCP 8.5 (Table 2).

Table 2 - Risk from bioclimatic variation predicted by 2070 for the Fernando de Noronha archipelago, considering both RCP 4.5 and RCP 8.5. PV = Predicted variation; % = Percent changes considering historical values and future projections.

	RCP 4.5		RCP 8.5	
Bioclimatic variable	**PV**	%	**PV**	%
Annual Mean Temperature	1.80 °C	6.70	2.80 °C	10.43
Mean Diurnal Range (Mean of monthly (max temp - min temp))	0 °C	0.00	0.05 °C	1.04
Isothermality (Diurnal range/Annual range) (* 100)	-0.38	-4.87	-3.5	-4.55
Temperature Seasonality (standard deviation *100)	6.28 °C	13.27	8.30 °C	17.60
Max Temperature of Warmest Month	2.05 °C	6.82	3.05 °C	10.15
Min Temperature of Coldest Month	1.75 °C	7.34	2.70 °C	11.32
Temperature Annual Range (Max temperature-Min temperature)	0.30 °C	4.84	0.35 °C	5.65
Mean Temperature of Wettest Quarter	1.87 °C	6.98	2.88 °C	10.71
Mean Temperature of Driest Quarter	1.78 °C	6.55	2.83 °C	10.42
Mean Temperature of Warmest Quarter	2.00 °C	7.34	3.00 °C	11.01
Mean Temperature of Coldest Quarter	1.78 °C	6.80	2.8 °C	10.54
Annual Precipitation	16.00 mm	1.18	-81.75 mm	-6.04
Precipitation of Wettest Month	24.50 mm	8.81	8.75 mm	3.15
Precipitation of Driest Month	-1.5 mm	-13.64	-0.5 mm	-4.55
Precipitation Seasonality (Coefficient of Variation)	3.50%	4.12	2.50%	2.94
Precipitation of Wettest Quarter	45.00 mm	6.08	-8.25 mm	-1.11
Precipitation of Driest Quarter	-4.25 mm	-10.63	-0.75 mm	-1.88
Precipitation of Warmest Quarter	39.00 mm	10.66	-95.5 mm	-26.09
Precipitation of Coldest Quarter	-54.75	-14.28	-119 mm	-31.03

Source: Elaborated by the authors (2019)

The warmest month in Fernando de Noronha is likely to become 6.82% hotter considering RCP 4.5 and 10.15% hotter considering RCP 85. Similarly, the coldest month can present a temperature increase of 7.34% considering RCP 4.5 and 11.32% considering RCP 8.5. For a three-month range, the warmest quarter is likely to become 7.34% hotter considering RCP 4.5 and 11.01% hotter considering RCP 8.5, while the coldest quarter can reach 6.8% and 10.54% warming, respectively.

Annual precipitation is likely to present a modest increase of 1.18% considering RCP 4.5 and a 6.04% decrease for RCP 8.5. Precipitation seasonality is likely to increase considering both RCPs, which is associated with the forecasts for the wettest and driest periods. The wettest month will likely become 8.81% wetter for RCP 4.5 and 3.15% wetter for RCP 8.5. On the other hand, the driest month can become 13.64% drier for RCP 4.5 and 4.55% for RCP 8.5. For a three-month range, the wettest and hotter quarters are likely to become wetter considering RCP 4.5 and drier considering RCP 8.5. The driest and coldest quarters are predicted to become drier in both RCPs. Such changes are likely to impose severe water stresses on the Island's hydrological resources (SANTOS et al. 2004). Furthermore, endemic species may not adjust to the new thermal regime, thus showing increased extinction risk (SANDEL et al., 2011). *Trachylepis atlantica,* for example, is an endemic lizard with preferred body temperature varying from 29°C to 31°C (Diele-Viegas, *pers. comm.),* indicating that our predictions for the warmest quarter are likely to be harmful to the species.

Changes in environmental temperature and precipitation are also predicted for the Small Island Developing States in the Atlantic, Pacific, and Indian Oceans (EBI; LEWIS; CORVALAN, 2006). This increased variability can lead to changes in other climatic factors, such as the speed and direction of winds and the patterns of wave action (EBI et al., 2006), and can promote changes in coastline and coastal water quality and quantity in coastal areas (Rafailidis et al., 1996). Although the Fernando de Noronha archipelago currently presents high wind persistence monthly (SILVA; STOSIC; STOSIC, 2021), this pattern can change in the future considering the predicted changes in environmental temperature and precipitation (EBI et al., 2006). A major environmental threat in Fernando de Noronha is coastal erosion, which is potentialized by tourism and urban growth (CLAUDINO-SALES, 2019; CASTRO, 2010).

The Archipelago's primary indicators of coastal erosion are the remobilization of beach sediments by wind action, longitudinal changes in sediment transportation by waves, and seasonal changes in the beach profile under rainfall conditions (CASTRO, 2010). With the predicted changes in precipitation patterns and its potential impacts on wind patterns, climate change is likely to potentialize coastal erosion further, leading to dry-land losses that can harm local ecotourism and human subsistence (CASTRO, 2010, WONG et al., 2014), especially if the quality and water amount are to be altered (Rafailidis et al., 1996).

With the rise of environmental temperature, the sea level rise and ocean acidification can also influence coastal erosion, besides coral bleaching (SOARES 2018). The reef mortality because of coral bleaching has immediate and long-term impacts on environmental balance and socio-economic activities in coastal areas, leading to changes in ecological processes and impacting the diversity and abundance of the local fish fauna (WESTMACOTT et al., 2000). Therefore, Noronha's economy is likely to be greatly impacted in future scenarios of climate change since marine ecotourism is the major economic activity of the Archipelago.

CONCLUDING REMARKS

The consequences of climate change to small islands such as the Fernando de Noronha Archipelago can be harmful to both human and natural systems if no mitigation strategies are taken to soften its effects. A global commitment to decrease greenhouse gas emissions is needed to avoid the potential collapse of such environments worldwide. It is important to highlight that the management effectiveness of the local conservation unities in the Archipelago was recently considered satisfactory (LEAL FILHO et al., 2020). However, more integrated management using large-scale marine spatial planning is paramount to cope with the predicted environmental changes (SOARES, 2018, LEAL FILHO et al., 2020). In general planning for the impacts of sea-level rise (Nicholls, 2011), shore protection projects must be included planning (STAKHIV et al., 1991).

Our results indicate that this important Archipelago is potentially at risk of climatic and bioclimatic variation due to anthropogenic climate change. However, the lack of quantitative and qualitative evaluations of climate change impacts local biodiversity and human livelihood, impairing adequate mitigation policies. Thus, we suggest that such data must be prioritized in local assessments to inform management practices that include climate change adaptation measures. Conservation actions should take an integrative approach, including environmental conservation and remediation, sustainable use of resources, and regional and national governance.

REFERENCES

ANAV, Alessandro *et al*. Evaluating the land and ocean components of the global carbon cycle in the CMIP5 earth system models. **Journal of Climate**, v. 26, n. 18, p. 6801–6843, 2013.

BABIKER, Mohamed *et al*. IPCC special report on the impacts of global warming of 1.5 °C above preindustrial levels and related global greenhouse gas emissions. p. 313–443, 2018.

BARCELLOS, Roberto Lima *et al*. Island beaches morphological and sedimentary short term variations – the case of SE Fernando de Noronha Island, South Atlantic, Brazil. **Revista de Gestão Costeira Integrada**, v. 11, n. 4, p. 471–478, 2011.

CASTRO, João Wagner Alencar. Ilhas oceânicas da Trindade e Fernando de Noronha, Brasil: Uma visão da geologia ambiental. **Management**, v. 10, n. 3, p. 303–319, 2010.

CLAUDINO-SALES, Vanda. Brazilian Atlantic Islands: Fernando de Noronha and Atol das Rocas, Brazil." **Coastal World Heritage Sites.** Springer, Dordrecht, 2019. 217-223.

COLLINS, William *et al*. Development and evaluation of an Earth-System model – HadGEM2. **Geoscientific Model Development Discussions**, v. 4, p. 997-1062, 2011.

DIELE-VIEGAS, Luisa Maria *et al.* Are reptiles toast? A worldwide evaluation of Lepidosauria vulnerability to climate change. **Climatic Change,** v. 159, 581-599. https://doi.org/10.1007/s10584-020-02687-5

EBI, Kristie; LEWIS, Nancy; CORVALAN, Carlos. Climate variability and change and their potential health effects in small Island states: Information for adaptation planning in the health sector. **Environmental Health Perspectives**, v. 114, n. 12, p. 1957–1963, 2006.

FICK, Stephen; HIJMANS, Robert. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas: new climate surfaces for global land areas. **International Journal of Climatology** v 37, p. 4302–4315. 2017. https://doi.org/10.1002/joc.5086

GOOGLE, I. **Google Earth software**, 2018.

HIJMANS, J. R. *et al.* Very high resolution interpolated climate surfaces for global land areas. **International Journal of Climatology**, v. 25, n. 15, p. 1965–1978, 2005.

IPCC. Global Warming of 1.5°C**:** Annex I: Glossary. *In:* An IPCC Special Report on the impacts of global warming of 1.5°C above preindustrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte, Valérie *et al.* (eds.), 2018.

LEAL FILHO, Walter *et al*. Climate change adaptation as a development challenge to small Island states: A case study from the Solomon Islands. **Environmental Science and Policy**, v. 107, p. 179-187. 2020.

LIU, Y. R., LI, Y. P., DING, Y. K. Quantifying uncertainties in temperature projections: a factorial-analysis-based multi-ensemble downscaling (FAMED) method. **Atmospheric Research**, v. 247, n. 105241, p. 1-13. 2021.

MAGRIN, Graciela Odilia *et al.* Central and South America. *In:* Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. **Climate Change 2014: Impacts, Adaptation, and Vulnerability.**, n. Chapter 27. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, p. 1499–1566, 2014.

MENON, Shaily *et al*. Preliminary global assessment of terrestrial biodiversity consequences of sea-level rise mediated by climate change. **Biodiversity and Conservation**, v. 19, n. 6, p. 1599–1609, 2010.

NICHOLLS, Robert. Planning for the impacts of sea level rise. **Oceanography.** 2011. 24(2):144–157, doi: https://doi.org/10.5670/oceanog.2011.34

NURSE, Leonard *et al*. Small Islands. In: **IPCC 5th Assessment Report Working Group II**. [s.l: s.n.]. p. 1613–1654. 2016.

R CORE TEAM. R: A language and environment for statistical computing. **R Foundation for Statistical Computing, Vienna, Austria.**, n. https://www.R-project.org/., 2018.

RAFAILIDIS, Stylianos *et al.* Impact of Climatic Changes on Coastal Water Quality. *In*: ANGELAKIS A.N., ISSAR A.S. (eds) Diachronic Climatic Impacts on Water Resources. NATO ASI Series (Series I: Global Environmental Change), vol 36. Springer, Berlin, Heidelberg. 1996. doi: https://doi.org/10.1007/978-3-642-61084-4_15

RIAHI, Keywan *et al*. RCP 8.5 – A scienario of comparatively high greenhouse gas emissions. **Climatic change,** v. 109, p. 33-57, 2011.

ROCHA, Carlos Frederico Duarte *et al.* Ecology and Natural History of the Easternmost Native Lizard Species in South America, *Trachylepis atlantica* (Scincidae), from the Fernando de Noronha Archipelago, Brazil. **Journal of Herpetology**, v. 43, n. 3, p. 450–459, 2009.

SANDEL, Brody *et al*. The influence of late quaternary climate-change velocity on species endemism. **Science**, v. 334, n. 6056, p. 660–664, 2011.

SANTOS, Fatima *et al*. Climate Change scenarios in the Azores and Madeira islands. **World Resource Review,** v. 16, n. 4., 473-491.

SILVA, Allan Robert; STOSIC, Tatijana; STOSIC, Borko. Wind speed persistence at the Fernando de Noronha archipelago, Brazil. **Theoretical and Applied Climatology,** v. 144, p. 723-730. 2021.

SOARES, Marcelo de Oliveira. Climate change and regional human pressures as challenges for management in oceanic islands, South Atlantic. **Marine Pollution Bulletin**, v. 131, p. 347-355, 2018.

SOUZA, Gisela Maria Rezende; FILHO, Nelson Quadros A. Vieira. Impactos socioculturais do turismo em comunidades insulares: um estudo de caso no arquipélago de Fernando de Noronha-PE. **Revista Acadêmica Observatório de Inovação do Turismo**, n. 4, p. 5, 2011.

STAKHIV Eugene; RATICK, Samuel; DU, Wei. Cost aspects of sea level rise and climate change in the evaluation of shore protection projects. *In:* GANOULIS J. (Ed.). **Water Resources Engineering Risk Assessment.** NATO ASI Series, Vol. G29, Spinger-Verlag, Berlin-Heidelberg-New York, pp. 337–55, 1991.

STOCKER, Thomas *et al*. Technical Summary. *In:* Climate Change 2013: The Physical Science Basis. **Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change**, p. 33–115, 2013.

TAYLOR, Karl; STOUFER, Ronald; MEEHL, Gerald. An overview of CMIP5 and the Experiment Design. **Bulletin of the American Meteorological Society,** v. 93, n. 4, p. 485-498. 2012.

TAYLOR, Michael *et al.* Why dry? Investigating the future evolution of the Caribbean Low Level Jet to explain projected Caribbean drying. **International Journal of Climatology**, v. 33, n. 3, p. 784–792, 2013.

TEWKSBURY, Joshua; HUEY, Raymond; DEUTSCH, Curtis. Putting the heat on tropical animals. **Science**, v. 320, 1296-1297.

THOMSON, Allison *et al.* RCP 4.5: a pathway for stabilization of radiative forcing by 2100. **Climatic change**, v. 109, n 77. 2011.

TOMPKINS, Emma. Planning for climate change in small islands: Insights from national hurricane preparedness in the Cayman Islands. **Global Environmental Change**, v. 15, n. 2, p. 139–149, 2005.

UNESCO, 2021. Brazilian Atlantic Islands: Fernando de Noronha and Atol das Rocas Reserves. http://whc.unesco.org/en/list/1000 Accessed in March 16, 2021.

URETA, Carolina *et al*. A first approach to evaluate the vulnerability of islands ' vertebrates to climate change in Mexico. **Atmósfera,** v. 31, n. 3 , 221-254. doi: https://doi.org/10.20937/ATM.2018.31.03.03

VAN VUUREN, Detlef *et al.* The representative concentration pathways: An overview. **Climatic change**, v. 109, n. 1, p. 5–31, 2011.

VAN VUUREN, Detlef *et al*. A new scenario framework for Climate Change Research: Scenario matrix architecture. **Climatic change**, v. 122, n. 3, p. 373–386, 2014.

WATANABE, Shingo *et al.* MIROC-ESM 2010: model description and basic results of CMIP5-20c3m experiments. **Geoscientific Model Development**, v. 4, p. 845–872, 2011.

WESTMACOTT, Susie *et al*. Coral Bleaching in the Indian Ocean: Socio-Economic Assessment of Effects. **In: Collected essays on the economics of Coral Reefs.** 94-106, 2000.

WONG, Kaufui *et al*. Chapter 5- Coastal Systems and Low-Lying Areas*. In:* Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. **Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.** Field, Christopher *et al.* (eds), p. 361–409, 2014.

YIN, Lei *et al.* How well can CMIP5 simulate precipitation and its controlling processes over tropical South America? **Climate Dynamics**, v. 41, n. 11–12, p. 3127–3143, 2013.