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UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Instituto de Biociências
Câmpus do Litoral Paulista



DINÂMICA ESPAÇO-TEMPORAL DE MANGUEZAIS E SUAS RELAÇÕES COM VARIÁVEIS CLIMÁTICAS

PRYSCILLA RESAFFE CAMARGO

SÃO VICENTE

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PRYSCILLA RESAFFE CAMARGO

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RESUMO

Manguezais são vitais para a resiliência costeira, sequestro de carbono e biodiversidade, mas enfrentam ameaças crescentes frente as mudanças climáticas e pressões antropogênicas. Nas últimas décadas com o sensoriamento remoto a compreensão da dinâmica espaço-temporal dos manguezais tem avançado, porém pouca atenção tem sido dada para reconhecer a relação dessas mudanças com os fatores climáticos. Neste estudo utilizamos dois conjuntos de dados para investigar mudanças espaço-temporais das florestas de mangue: i) área anual (km²) das florestas de mangue entre 1985 e 2022 de áreas protegidas da Mata Atlântica; ii) dados climáticos (precipitação, temperatura do ar) obtidos de 30 estações meteorológicas. Para integrar o conjunto de dados, capturar padrões e interações complexas entre a dinâmica das áreas de manguezais e os fatores climáticos empregamos modelos aditivos generalizados (GAM). As principais descobertas são: i) A tendência é de crescimento dessas áreas, porém a variação espaço-temporal das florestas de mangue difere conforme as regiões e o tempo. Entre 1985 e 2022 os manguezais em Peruíbe e Iguape registraram crescimento moderado (+11%), por sua vez, os manguezais em Cananéia exibiram maior expansão (+28%), enquanto os manguezais de Antonina, Guaraqueçaba, Paranaguá e Guaratuba tiveram os menores ganhos (+5%). Os principais preditores das mudanças de áreas de florestas de mangue foram: a precipitação acumulada (Pacum) que impactou negativamente os manguezais em Peruíbe e Iguape. Porém o aumento das temperaturas máximas (Tmax) pode ter favorecido a expansão das florestas de mangues em Cananéia enquanto o aumento das temperaturas mínimas (Tmin) foi fator positivo em Antonina, Guaraqueçaba, Paranaguá e Guaratuba. Em conjunto, essas descobertas demonstram que a dinâmica dos manguezais é influenciada de maneiras distinta por fatores climáticos. Isso sugere que estratégias de conservação genéricas podem ser insuficientes para proteger esses ecossistemas, destacando a necessidade de abordagens específicas que considerem as particularidades de impacto de cada fator climático nas áreas de floresta de mangue.

Palavras-chave: precipitação, temperatura, modelos aditivos generalizados, MapBiomass, Google Earth Engine.

ABSTRACT

Mangroves are vital for coastal resilience, carbon sequestration and biodiversity, but are facing increasing threats from climate change and anthropogenic pressures. In recent decades, remote sensing has advanced studies of the spatiotemporal dynamics of mangroves, but little attention has been paid to recognizing the relationship between these changes and climatic factors. In this study we used two sets of data to investigate spatio-temporal changes in mangrove forests: i) annual area (km²) of mangrove forests between 1985 and 2022 in protected areas of the Atlantic Forest; ii) climate data (precipitation, air temperature) obtained from 30 weather stations. To integrate the data set and capture complex patterns and interactions between the dynamics of mangrove areas and climatic factors, we used generalized additive models (GAM). The main findings are: i) The spatio-temporal variation of mangrove forests differs according to region and time. Between 1985 and 2022, mangroves in Peruíbe and Iguape registered moderate growth (+11%), mangroves in Cananéia exhibited the greatest expansion (+28%), while mangroves in Antonina, Guaraqueçaba, Paranaguá and Guaratuba had the smallest gains (+5%). The main predictors of mangrove area changes were: cumulative precipitation (Pacum), which negatively impacted mangroves in Peruíbe and Iguape. However, increasing maximum temperatures (Tmax) may have favored mangrove expansion in Cananéia, while rising minimum temperatures (Tmin) had a positive effect in Antonina, Guaraqueçaba, Paranaguá, and Guaratuba. Together, these findings demonstrate that mangrove dynamics are distinctly influenced by climatic factors. This suggests that generic conservation strategies may be insufficient to protect these ecosystems, highlighting the need for tailored approaches that consider the specific impacts of each climatic factor on mangrove forest areas.

Keywords: precipitation, temperature, generalized additive models, MapBiomass, Google Earth Engine.

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1. PROBLEMÁTICA

Os manguezais são ecossistemas com relevância ecológica e socioeconômica, funcionando como berçários marinhos, barreiras naturais contra a erosão e sumidouros de carbono essenciais na mitigação das mudanças climáticas (Nagelkerken et al., 2008; Donato et al., 2011; Friess et al., 2020; Adame et al., 2021). Entretanto, esses ecossistemas únicos estão cada vez mais vulneráveis às pressões climáticas, oceanográficas e antropogênicas (Sippo et al., 2018; Fan et al., 2024). O aumento do nível do mar, mudanças de precipitação e temperatura do ar e do mar, além da intensificação das oscilações climáticas globais induzem mudanças na estrutura das florestas de mangue afetando sua capacidade de expansão, regeneração e armazenamento de carbono (Ward et al., 2016; Hickey et al., 2021; Friess et al., 2022). Apesar disso são escassos os estudos sobre dinâmica das florestas de mangue que investigam os efeitos integrados que múltiplos fatores climáticos exercem sobre as áreas de floresta de mangue ao longo do tempo em diferentes regiões.

Nesta perspectiva, este estudo discute a dinâmica espaço-temporal das florestas de mangue em áreas protegidas da Mata Atlântica nos estados de São Paulo e Paraná frente aos fatores climáticos. O conjunto de resultados obtidos neste estudo poderá auxiliar em planejamentos de conservação e o manejo sustentável dos manguezais o que garante sua funcionalidade ecológica e os serviços ecossistêmicos.

2. INTRODUCTION

Mangroves are characterized by halophytic trees and shrubs typical of tropical and subtropical intertidal zones and constitute complex ecosystem influenced by the dynamics between marine and terrestrial environmental factors (Schaeffer-Novelli et al., 1990; Krauss et al., 2008; Lovelock et al., 2016). Recognized for their unique species composition, rich biological and socio-economic relevance, they provide multiple ecosystem services: (i) natural protection of the coastline against erosion, (ii) nursery and habitat for various species, (iii) water filtration and nutrient cycling, (iv) sequestration of carbon dioxide (CO₂), methane (CH₄) and (v) sediment retention (Kristensen et al., 2008; Taillardat et al., 2018; Sasmito et al., 2019; Hespen et al., 2022; Yan et al., 2024). Moreover, the collective economic valuation of mangroves has been estimated at \$194,000 per hectare (\$2.7 trillion per year), contributing to thirteen Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and

Production), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land) (Barbier et al., 2011; Costanza et al., 2014; Eyzaguirre et al., 2023).

Despite their ecological and socio-economic importance, mangroves face significant threats from climate change and human activities, with global losses exceeding with 20%–35% of global mangrove extent lost over the last 55 years (Polidoro et al., 2010; Hamilton & Casey, 2016; Goldberg et al., 2020).

Remote sensing technology has shown success in monitoring of spatial-temporal change in the mangrove forests in Brazil (Freitas et al., 2017; Pereira et al., 2016; Bosquilia & Muller-Karger, 2021; Diniz et al., 2019; Moschetto et al., 2021; Lassalle et al., 2022; de Lima Freires et al., 2023; Lopes et al., 2023; Lima Miranda et al., 2024; Vanin et al., 2024) and worldwide (Giri, 2011; Bunting, 2018; Halder et al., 2021; Bunting et al., 2022; S. Hamilton & Presotto, 2024). Although these studies are valuable for identifying changes in mangrove areas, they are inconclusive or absent in relation to factors that drive their spatial dynamics over time.

Nonetheless, most of the literature focuses mainly on the role of climatic variables, as for example: temperature (Cavanaugh et al., 2019; Kang et al., 2024a; Osland et al., 2016; Saintilan et al., 2014; Ward et al., 2016b) or precipitation (Chapman, 1976; G. B. de Lima & Galvani, 2010; Jennerjahn et al., 2017). But the interaction between these different variables and the impact of each one on the mangrove forest area is often neglected. In this context, our study has the following objectives:

- **To quantify and analyze the variation of mangrove forest areas between Peruíbe-Guaratuba in the period from 1985 to 2022.**
- **To analyze the historical series of climate data (precipitation and air temperature) from 30 meteorological stations to identify the patterns of climate dynamics between 1985 and 2022.**
- **To integrate the set of results to evaluate possible relationships between the spatio-temporal changes of mangrove forest areas and climate data.**

The results obtained in this study will provide essential information for the conservation and sustainable management of mangroves, ensuring their ecological functionality and the ecosystem services they offer to society.

3. CONCLUSION

Our study shows that during the period from 1985 to 2022 mangrove forest areas expanded, however, this growth did not occur in a continuous and uniform manner. Among the regions, the mangrove in Peruíbe and Iguape showed moderate gross gain (+11%), the mangrove in Cananéia showed the most stable growth pattern, with the highest gross gain (28%). In contrast, the mangrove in Antonina, Guaraqueçaba, Paranaguá and Guaratuba showed the lowest gross gain (5%) between 1985 and 2022. The spatial and temporal patterns with mangrove gains and losses among the regions characterize two main trends. The spatiotemporal variability revealed that between 1985 and 1999 was characterized by the lowest growth, with losses and gains. We identified a turning point in the year 2000, with a notable spread of mangrove areas across all regions. During the entire 2000–2022 period, mangrove areas were predominantly larger than in the first period, with the Cananéia mangrove showing the largest growth (+28%), followed by the Peruíbe and Iguape mangroves (+11%) and Antonina, Guaraqueçaba, Paranaguá and Guaratuba (+5%). The factors that explain this dynamic of mangrove forests were the combination of increased accumulated precipitation (negative effect) and increased air temperature (positive effect). While some areas showed greater growth, others had more limited responses. These findings reinforce the importance of considering the impact of each climate variable in understanding the response of mangroves to environmental changes and in guiding adaptive and region-specific conservation strategies.

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