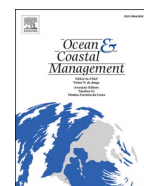




Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Mangrove degradation and tourism-driven economic dynamics in a Caribbean SIDS: Evidence from a VECM

Víctor Gómez-Valenzuela^{*}, Katerin Ramírez, Solhanlle Bonilla-Duarte

Instituto Tecnológico de Santo Domingo (INTEC), Av. Los Próceres 49, Los Jardines del Norte, Santo Domingo, D. N., 10602, Dominican Republic

ARTICLE INFO

Keywords:

Economic growth
Environmental degradation
Mangroves
Vector error correction model
Small island Developing States (SIDS)

ABSTRACT

This study investigates the macroeconomic implications of mangrove degradation in the Dominican Republic, a tourism-dependent small island developing state (SIDS), using a Vector Error Correction Model (VECM) with annual data for 1995–2023. The model examines dynamic relationships among real GDP, international tourist arrivals, tourism accommodation capacity, and mangrove natural capital. Results identify statistically significant ecological-economic linkages at both short-run and long-run horizons. In the short run, mangrove degradation is associated with significant negative effects on GDP growth, tourist arrivals, and accommodation capacity. Granger causality tests indicate that mangrove capital temporally precedes all three macroeconomic variables. In the long run, the Johansen cointegrating vector indicates a statistically significant positive relationship between mangrove capital and GDP, suggesting that ecosystem depletion constrains the economy's equilibrium growth path. The estimated annual economic exposure associated with observed degradation rates amounts to approximately USD 75 million, equivalent to 4.2% of the estimated value of coastal-marine ecosystem services. Robustness checks confirm the stability of the cointegrating relationship across pre-crisis and pre-COVID sub-periods. These findings position mangrove conservation as a macroeconomic policy priority in coastal tourism-dependent SIDS.

1. Introduction

Located in the heart of the Caribbean (see Fig. 1), the Dominican Republic (DR) has positioned tourism as a cornerstone of its economic growth strategy, ranking among the top three sources of foreign exchange, alongside exports and remittances (BCRD, 2018; Meyer, 2020). With a population of around 11 million and a territory of 48,448 km² shared with the Republic of Haiti (ONE, 2023), the country has developed a tourism model based on coastal enclaves, particularly along the Romana–Bayahibe–Punta Cana–Bávaro corridor and the northern areas of Puerto Plata and the Samaná Peninsula (BCRD, 2018; Duffy et al., 2015).

In 2023, the DR received over eight million international tourists, ranking first in the Caribbean and second in Latin America after Mexico (BCRD, 2024; Peralta Quesada, 2021). Tourism revenue reached USD 9000 million, accounting for approximately 9% of the country's GDP, while tourism-linked sectors contributed an estimated 18–20% of the total GDP (BCRD, 2018, 2024).

The DR coastal-marine ecosystems, which consist primarily of coral

reefs, mangroves, seagrass meadows, and salt marshes, are critical from both ecological and economic perspectives but are currently severely degraded (Eastwood et al., 2017; Steneck and Torres, 2023; Wielgus et al., 2010). The complexity of the situation arises from the interaction between local pressures, such as overfishing, unregulated tourism, and pollution, and global factors, including climate change (Kanhai et al., 2022; Landrigan et al., 2020).

According to Ruiz de Gauna et al. (2024), coastal-marine ecosystems in the DR generate approximately USD 1800 million annually in ecosystem services, equivalent to 20% of the tourism revenues and around 1.8% of Dominican GDP in 2023. As an SIDS, the DR is doubly vulnerable: both to the ecological degradation of its coastal assets and to the intensification of climate-related hazards (Galaitis et al., 2024; Steneck and Torres, 2023). These challenges pose a threat to biodiversity and the viability of tourism-led development. We hypothesize that ecosystem degradation limits short-term economic performance and influences long-term socio-ecological fragility of tourism growth in SIDS. This hypothesis motivates the central research question of this study: *To what extent does mangrove degradation affect short-run and*

^{*} Corresponding author.

E-mail addresses: victor.gomez@intec.edu.do (V. Gómez-Valenzuela), katerin.ramirez@intec.edu.do (K. Ramírez), solhanlle.bonilla@intec.edu.do (S. Bonilla-Duarte).

<https://doi.org/10.1016/j.ocecoaman.2026.108293>

Received 17 November 2025; Received in revised form 1 July 2026; Accepted 2 July 2026

Available online 8 July 2026

0964-5691/© 2026 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

long-run economic dynamics in a tourism-dependent small island developing state?

Although spatial techniques such as remote sensing and GIS-based coastal change analysis are common in studies of coastal degradation, this research takes a macro-ecosystem time-series approach to examine long-term socio-economic interactions. It focuses on the broader macroeconomic impacts of mangrove loss instead of its spatial distribution. This approach complements spatial analyses by revealing macroeconomic dynamics that spatial data alone cannot easily detect (Barbier and Cox, 2003; Xu et al., 2024). The macro-ecosystem econometric perspective in this study enhances, rather than replaces, the conventional spatial GIS-based methods used in coastal research. To address the research question, we employ a Vector Error Correction Model (VECM), which is well suited to this analytical context for three reasons. First, the VECM accommodates non-stationary time series through cointegration, allowing the estimation of both short-run dynamics and long-run equilibrium relationships without differencing away the permanent components of the series (Engle and Granger, 1987; Johansen, 1988). Second, it treats all variables as jointly endogenous, which is appropriate when tourism flows, economic growth, and ecological conditions may simultaneously influence one another (Diaye et al., 2022; Ouerfelli, 2008). Third, it is specifically designed for small annual macroeconomic datasets of the type available for SIDS economies, where structural VAR approaches with many parameters are infeasible (Elias et al., 2023; Paparoditis and Politis, 2018).

This study contributes to the literature in three ways. First, it extends tourism–environment research by examining macroeconomic and ecological dynamics jointly in a tourism-dependent SIDS. Second, it introduces mangrove natural capital as a macroecological state variable within a VECM framework, thereby complementing the spatial coastal management literature with a time-series perspective. Third, it provides evidence relevant to coastal governance by linking ecological degradation to macro-tourism vulnerability in the Dominican Republic. The remainder of the paper is structured as follows. Section 2 reviews the relevant literature. Section 3 describes the data and methodology.

Section 4 presents the empirical results. Section 5 discusses the findings in the context of the existing literature and their implications for management. Section 6 concludes.

2. Related literature

Understanding the relationship between economic growth and environmental degradation requires a multidimensional approach that reflects the interdependence between ecological change and development patterns (Acheampong and Opoku, 2023). This study conceptually refers to the Environmental Kuznets Curve (EKC) hypothesis (Alvarado and Toledo, 2017; Sarkodie and Strezov, 2019; Uchiyama, 2016), but it does not attempt to estimate an EKC-type nonlinear specification (e.g., quadratic income terms). Instead, the EKC is used as a reference within the broader debate on environment–growth dynamics, while the empirical analysis focuses on ecological–economic co-evolution in a tourism-dependent coastal system (Liu et al., 2022; Matias et al., 2022; Meyer, 2020; Pásková et al., 2024).

While most studies in the tourism–environment tradition focus on emissions, income, and aggregate degradation indicators (Khan et al., 2023; Liu et al., 2022), the coastal-management literature emphasizes mangroves, reefs, and shoreline ecosystems as spatially specific forms of natural capital (Barbier et al., 2011; Beck et al., 2022; Yamamoto, 2023). This study bridges these traditions by treating mangrove degradation as a macroeconomically relevant coastal state variable in a tourism-dependent island economy.

The EKC proposes an inverted-U relationship: in the early stages of growth, environmental degradation increases with income but later declines as higher incomes enable investment in cleaner technologies, regulation, and public awareness (Acaravci and Ozturk, 2010; Leal and Marques, 2022). Meta-analyses place the inflection point around USD 8910 per capita; however, this transition is not guaranteed, as it requires strong institutions and public policies to internalize externalities and avoid ecological overshoot (Lamperti et al., 2020; Rodríguez-Espíndola et al., 2022; Sarkodie and Strezov, 2019).



Fig. 1. Location of the Dominican Republic in the Caribbean

Note. Shows the geographic location of the Dominican Republic within the insular Caribbean. The map provides context for the country's exposure to regional tourism flows and pressures on coastal ecosystems. *Source: Own elaboration.*

In the DR, as in many SIDS, growth has been concentrated in tourism and resource-dependent sectors (Lowitt et al., 2015; Spencer, 2019). These economies often remain in the early EKC phase, where income gains still drive ecological degradation, compounded by low diversification and limited regulatory enforcement, which delay the transition to sustainable growth (Al-mulali et al., 2015; Alvarado and Toledo, 2017).

Fig. 2 illustrates this pattern. The GDP (*lngdpct*) shows a steady upward trend, while mangrove natural capital (*lncmmt*) exhibits a persistent decline. In the Dominican context, coastal areas such as Bávaro, Samaná, and Puerto Plata are vulnerable to flooding, erosion, and water scarcity, particularly amid rapid tourism expansion (Alvarez-Filip et al., 2011; Eastwood et al., 2017; MARENA and PNUMA, 2010; Roig-Munar et al., 2018). Mangroves, which buffer storms and store carbon, are often cleared to make way for infrastructure, weakening ecological resilience (Herrera Estévez, 2022; Kauffman et al., 2014; Sherman et al., 2003). This study employs a coevolutionary framework in which development and degradation mutually reinforce one another. In highly tourism-dependent SIDS, protecting coastal ecosystems is an economic as well as environmental necessity.

3. Materials and methods

Cointegration analysis is a powerful technique for exploring both short-term and long-term relationships among time series variables that are non-stationary but share a common stochastic trend. The period considered in our analysis covers 29 years of data (1995–2023). The empirical strategy in this study followed four interrelated steps: (i) testing for unit roots to establish the integration order of each variable; (ii) determining the presence of cointegration vectors through the Johansen test; (iii) estimating a VECM to capture short-term dynamics while maintaining long-term equilibrium, and (iv) approaching the economic exposure of mangrove natural capital degradation (Acheampong and Opoku, 2023; Durr, 1992; Ericsson, 1992; Ouerfelli, 2008).

3.1. Variable selection and model specification

Table 1 shows the variables used for this cointegration analysis. We used four endogenous variables: real GDP at the 2015 constant price (*lngdpct*), international tourist arrivals (*lnitrat*), number of available hotel rooms (*lntrmt*), and mangrove natural capital (*lncmmt*).

The chosen mangrove variable reflects functional ecosystem capacity rather than surface area. The indicator is sourced from the World Bank Wealth Accounting and Valuation of Ecosystem Services (WAVES) framework (series NW.NCA.MANG.TO) and combines physical volume estimates of mangrove extent, derived from remote sensing, with shadow prices reflecting the productive value of ecosystem services including coastal protection, fisheries support, and carbon sequestration (Barbier, 2015; Menéndez et al., 2018).

This functional approach is preferable to GIS-based surface area measures for macroeconomic time-series analysis, as it captures the regulatory and productive value of mangrove stocks rather than their spatial footprint alone, and provides the consistent annual observations required by VECM estimation (Xu et al., 2024). Three limitations of this indicator should be acknowledged. First, it is a national-level aggregate, thereby masking spatial heterogeneity across the Dominican Republic's coastal zones (Hagger et al., 2022). Second, the shadow prices embedded in the WAVES index are model-derived approximations and may not fully reflect local ecosystem service values (Barbier, 2015). Third, the indicator is available through 2020; values for 2021–2023 were projected using a simple OLS trend (Nadler and Kros, 2007), as discussed in the robustness analysis below. The deterministic specification includes an intercept in the cointegration space and no deterministic trend in the short-run VAR dynamics, following Ericsson (1992) and Johansen (1988).

All variables enter the model in natural logarithms so that estimated coefficients can be interpreted as elasticities and to reduce heteroscedasticity (Mancini et al., 2017; Mullahy and Norton, 2023). The baseline lag structure was selected using standard information criteria. To maintain consistency with the annual series, missing values for *lncmmt* in 2021–2023 were projected using a simple OLS trend (Nadler and Kros, 2007). To assess the potential influence of these imputed

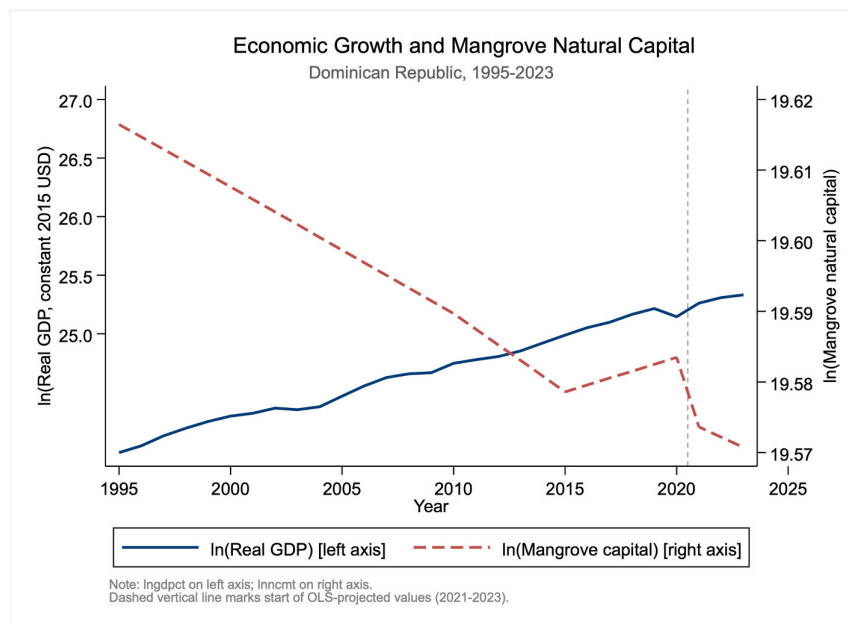


Fig. 2. Relationship between economic growth and mangrove natural capital

Note. Time series of the logarithm of real GDP (*lngdpct*) and mangrove natural capital (*lncmmt*) in the Dominican Republic, 1995–2023. The figure illustrates the sustained expansion of economic output alongside the gradual decline of mangrove natural capital over the sample period. Source: Author's elaboration.

Table 1
Variables used in the cointegration analysis.

Variable	Definition	Unit of Measure	Interpretation	Source
Ingdpct	Gross Domestic Product (GDP): total income from production of goods and services during an accounting period.	USD billion at constant 2015 prices (inflation-adjusted).	Measures the country's economic growth in real terms.	World Bank – World Development Indicators (NY.GDP.MKTP.KD)
Initat	Total number of international tourists arriving in the Dominican Republic during a given year.	Number of tourists	Represents the activity and volume of a key sector of the Dominican economy.	Central Bank of the Dominican Republic
Intrnt	Total number of tourist rooms available in the Dominican Republic.	Number of rooms (proxy of tourism infrastructure)	Reflects tourism infrastructure capacity as an engine of economic growth.	Central Bank of the Dominican Republic
Inncmt	Mangrove natural capital stock value from the World Bank WAVES framework (NW.NCA.MANG.TO). Combines physical volume estimates of mangrove extent (remote sensing) with shadow prices reflecting ecosystem services including coastal protection, fisheries support, and carbon sequestration. Available through 2020; values for 2021–2023 projected by OLS trend. Key limitations: (i) national-level aggregate, masking spatial heterogeneity; (ii) shadow prices are model-derived approximations; (iii) OLS projection for 2021–2023 assumes continuation of pre-pandemic trend.	Real chained 2019 US dollars from physical volume estimates within national wealth accounting.	Indicates the functional state of mangrove ecosystems and their implications for environmental sustainability and long-term economic resilience.	World Bank – Wealth Accounting (NW.NCA.MANG.TO)

Note. Variables included in the VECM analysis, with definitions, measurement units, interpretation, and data sources. All variables are expressed in natural logarithms. The mangrove natural capital variable (Inncmt) corresponds to the World Bank WAVES national wealth accounting indicator (NW.NCA.MANG.TO). Because the series is available only through 2020, values for 2021–2023 were projected using an OLS time trend. Source: Own elaboration based on the World Bank (World Development Indicators; Wealth Accounting) and the Central Bank of the Dominican Republic.

observations on the results, the VECM was re-estimated on the truncated sample 1995–2020 ($N = 26$, excluding all projected values). The truncated specification is dynamically unstable (the eigenvalue modulus of the companion matrix exceeds 3.109, well above the unit circle), indicating that excluding the post-2020 observations produces an explosive system that is not analytically coherent (Ericsson, 1992; Ouerfelli, 2008). This result reinforces the analytical necessity of the OLS-projected values for 2021–2023 to maintain the dynamic stability of the full-sample VECM. Accordingly, short-run coefficients from the truncated specification should be interpreted with additional caution, and the full-sample baseline (1995–2023) is retained as the primary model. The truncated-sample results are reported as a robustness check in the supplementary analysis.

$$gdpct_t = f(ita_t + trnt_t + ncm_t) \quad [1]$$

As indicated, t represents the period considered in our analysis (1995–2023). This relatively short period imposes analytical constraints on extrapolating our findings to broader economic cycles, thereby reducing the scope for policy recommendations beyond the short term (Elias et al., 2023; Ericsson, 1992).

$$\ln(gdpct_t) = \beta_0 + \beta_1 \ln(ita_t) + \beta_2 \ln(trnt_t) + \beta_3 \ln(ncm_t) + \varepsilon_t \quad [2]$$

Where: β_0 = intercept term and $\beta_1 \dots \beta_3$ are the long-run elasticities of GDP concerning each independent variable, and represents the error, which represents short-term deviations. This specification assumes that GDP is influenced by the level of international tourism activity, available infrastructure, and the functional capacity of mangrove ecosystems to support coastal economic activities (Ballut-Dajud et al., 2022; Elgin and Elveren, 2024; Jurgens et al., 2024; Schubert, 2010).

3.2. Unit root testing

The stationarity of each series was tested using the Augmented Dickey-Fuller (ADF) test with five lags. The general form of the ADF test is:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^p \delta_i \Delta Y_{t-i} + \varepsilon_t \quad [3]$$

Where.

- $\Delta Y_t Y_t - Y_{t-1}$, which is the first difference of Y_t .
- α : intercept term
- βt = time trend
- γ : coefficient on the lagged level of Y_t .
- δ_i : Coefficients on the lagged differences (to account for serial correlation).
- ε_t : error term

All variables were found to be integrated of order one (I(1)), justifying the use of cointegration methods (Durr, 1992; Ericsson, 1992). The lag length was selected using the Schwarz Criterion to minimize over-parameterization in a short sample, consistent with Paparoditis and Politis (2018).

3.3. Structural break analysis

Given that the sample period (1995–2023) encompasses major macroeconomic disruptions, including the global financial crisis (2008–2009), Atlantic hurricane events, and the COVID-19 pandemic (2020), the validity of the I(1) characterization and the long-run cointegrating relationship may be sensitive to structural breaks (Ericsson, 1992; Folke et al., 2004; McGlathery et al., 2013). In small samples such as the present one, the Johansen framework may exhibit size distortions in the presence of unmodelled breaks, making it important to verify the robustness of unit root and cointegration inferences (Johansen, 1991; Paparoditis and Politis, 2018). Two complementary approaches are used to address this concern.

First, Zivot-Andrews unit root tests were conducted for each series, allowing for a single endogenous break in the intercept (Zivot and Andrews, 2002). This test is preferable to imposing a known break date a priori, as it identifies the most likely break point from the data without requiring prior specification (Durr, 1992; Paparoditis and Politis, 2018). The results indicate that *lngdpct* (minimum $t = -3.640$, break at 2003), *initat* (minimum $t = -4.705$, break at 2019), and *lnncmt* (minimum $t = -4.290$, break at 2017) remain non-stationary even when a structural break is accommodated, as none of these statistics exceeds the 5% critical value of -4.80 . The series *intrnt* yields a minimum t -statistic of -5.669 (break at 1999), which rejects the null of a unit root at the 1% critical value of -5.34 . This result reflects the period of rapid hotel infrastructure expansion in the DR during the late 1990s and predates the global financial crisis, the 2010 Haiti earthquake, and the

COVID-19 pandemic. Given that the standard ADF test does not reject non-stationarity for $\ln trnt$ ($t = -2.692$, $p = 0.076$), and that maintaining the I(1) characterization for all four variables ensures internal consistency of the Johansen framework (Elias et al., 2023; Johansen, 1988), the baseline specification retains $\ln trnt$ as I(1) and acknowledges the Zivot-Andrews result as a limitation. Results are reported in Table A1.

Second, to verify that the long-run cointegrating relationship is not an artifact of pandemic-era dynamics or the global financial crisis, Johansen trace tests were conducted on two sub-period samples: the pre-crisis window (1995–2007, lag = 1) and the pre-COVID window (1995–2019, lag = 2). In small samples, sub-period testing provides a practical alternative to formal structural break correction within the Johansen framework, as it directly examines whether the cointegrating relationship persists across different historical regimes (Diaye et al., 2022; Durr, 1992; Ouerfelli, 2008). In both sub-periods, the trace statistic for the null of no cointegration ($r = 0$) substantially exceeds the 5% critical value of 47.21, reaching 61.83 in the pre-crisis window and 71.60 in the pre-COVID window, validating that the cointegrating relationship precedes both major disruptions and is not a statistical artifact of the post-2019 observations (Johansen, 1988; Paparoditis and Politis, 2018). Results are reported in Table A2.

3.4. Johansen cointegration test

A Johansen cointegration test was performed to identify long-run equilibrium relationships among the four non-stationary variables in the system (Ericsson, 1992; Papana et al., 2023). In the baseline specification with a constant in the cointegration space and two lags, the trace statistics reject the null hypotheses of no cointegration ($r = 0$) and of at most one cointegrating vector ($r \leq 1$), while failing to reject the null of at most two vectors ($r \leq 2$). Strictly speaking, the trace test therefore suggests the presence of two cointegrating relations (Diaye et al., 2022; Engle and Granger, 1987; Pirrò et al., 2025). However, given the short annual sample, the need to preserve interpretability, and the study's theoretical emphasis on a single macro-ecological long-run equilibrium linking growth, tourism, infrastructure, and mangrove capital, the baseline VECM is estimated using a parsimonious rank = 1 specification, while the rank = 2 model is treated as a robustness benchmark (Diaye et al., 2022; Zou, 2018). This modeling choice is consistent with the cointegration literature, which emphasizes that statistical rank selection must be interpreted jointly with theory, sample size, and model tractability rather than mechanically (Diaye et al., 2022; Durr, 1992; Johansen, 1988; Ouerfelli, 2008).

3.5. Vector Error Correction Model (VECM)

The VECM model is crucial for analyzing economic systems in which variables are cointegrated, as it integrates short-term fluctuations with equilibrium dynamics, making it invaluable for policy evaluation and forecasting in interconnected systems, such as GDP and natural capital (Elias et al., 2023; Ouerfelli, 2008). Based on the lag-selection criteria and the cointegration analysis, a VECM with two lags was estimated using a baseline specification with one cointegrating vector (Dao et al., 2017).

Model adequacy was evaluated using standard post-estimation diagnostics for vector error-correction models. Residual autocorrelation was assessed through Lagrange-multiplier tests (vecmar), normality through the multivariate Jarque-Bera procedure (vecnorm), and system stability through the eigenvalue condition implemented in the vecstable procedure, following standard practices in cointegrated macro-time series analysis (Durr, 1992; Ericsson, 1992; Ouerfelli, 2008; Winarno et al., 2021; Zou, 2018). Impulse-response functions (IRFs) were computed using orthogonalized shocks based on a Cholesky decomposition with ordering: $\ln gdp \rightarrow \ln itat \rightarrow \ln trnt \rightarrow \ln ncmt$, consistent with the assumption that ecological variables respond with lags to economic shocks (Inoue and Kilian, 2013).

$$\Delta Y_t = \alpha + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad [5]$$

Where: ECT_{t-1} is the error correction term and is the adjustment coefficient, while all other terms are defined as above (Barbier, 2015; Johansen, 1988). This system was estimated for each variable as a separate equation. For example, the GDP equation is specified as:

$$\begin{aligned} \Delta \ln gdp_t = & \alpha + \sum_{i=1}^p \Gamma_{gdp} \Delta \ln gdp_{t-i} + \sum_{i=1}^p \Gamma_{itat} \Delta \ln itat_{t-i} + \sum_{i=1}^p \Gamma_{trnt} \Delta \ln trnt_{t-i} \\ & + \sum_{i=1}^p \Gamma_{ncmt} \Delta \ln ncmt_{t-i} + \lambda_1 ECT_{t-1} + \varepsilon_{ncmt} \end{aligned} \quad [6]$$

Thus, analogous specifications were defined for the other three endogenous variables related to tourists' arrival ($\Delta \ln itat$), infrastructure ($\Delta \ln trnt$), and mangrove natural capital ($\Delta \ln ncmt$). Given the constraints of the time series (1995–2023), a set of Granger causality tests was conducted to explore the dynamic interactions among the variables of the VECM system (Granger, 1969; Williams and Cook, 2016), enhancing the analytical approach and exploring the temporal interaction among variables (see Table B1).

3.6. Estimating the economic exposure associated with mangrove degradation

To approximate the annual economic exposure associated with mangrove degradation, we employ a log-linear approach that combines the implied long-run elasticity of GDP with respect to mangrove natural capital (derived from the Johansen cointegrating vector) with the observed average annual log-decline in the functional capital index ($\ln ncmt$) (Barbier, 2015; Menéndez et al., 2018). The implied elasticity is extracted directly from the estimated cointegrating vector under the Johansen normalization with $\ln gdp$ set to unity; the coefficient on $\ln ncmt$ is -25.525 ($p = 0.011$), yielding an implied long-run elasticity of GDP with respect to mangrove capital of $+25.525$. The positive sign indicates that greater mangrove capital stock is associated with higher long-run GDP, consistent with the role of coastal ecosystems as productive natural infrastructure in tourism-dependent economies (Barbier, 2007; Beck et al., 2022). The calculation follows:

$$\Delta Y = \varepsilon * \Delta \ln ncmt * Y \quad [7]$$

Where ε is the elasticity of GDP to mangrove capital, $\Delta \ln ncmt$ is the estimated average log-change per year, and Y is the GDP associated with the coastal ecosystem-dependent sector. This index reflects changes in the productive and ecological functionality of mangroves, beyond surface area, and captures both biophysical degradation and anthropogenic pressures (Barbier, 2015; Menéndez et al., 2018). Stata software version 19 was used to perform the cointegration analysis.

4. Results

Before discussing unit roots, cointegration, and short-run dynamics, we evaluated the adequacy of the baseline VECM through standard residual diagnostics. As shown in Table 2, the Jarque-Bera diagnostics indicate that three of the four equations do not depart significantly from normality, whereas the mangrove-capital equation and the system-wide test reject normality. In small macro-ecological samples, however, departures from strict normality do not invalidate the cointegration structure or the interpretation of the adjustment dynamics, provided that the model remains dynamically coherent and free from major residual autocorrelation problems (Diaye et al., 2022; Ericsson, 1992; Ouerfelli, 2008; Zou, 2018).

Diagnostics in Table 2 also serve as robustness checks for the baseline specification. Residual autocorrelation tests, normality diagnostics, and stability conditions based on the eigenvalue modulus validate that the

Table 2
Standard diagnostic tests for the baseline VECM (rank = 1, lags = 2).

Test	Statistic	p-value	Interpretation
LM serial correlation, lag 1	9.007	0.913	Fail to reject H_0 of no residual autocorrelation
LM serial correlation, lag 2	14.453	0.565	Fail to reject H_0 of no residual autocorrelation
Jarque–Bera normality, D_{lngdpc}	3.577	0.167	Residuals do not depart significantly from normality
Jarque–Bera normality, D_{lnitnt}	2.490	0.288	Residuals do not depart significantly from normality
Jarque–Bera normality, D_{lntrnt}	1.456	0.483	Residuals do not depart significantly from normality
Jarque–Bera normality, D_{lnncmt}	23.568	<0.001	Residuals are not normally distributed
Jarque–Bera normality, system-wide	31.089	<0.001	System departs from multivariate normality
Eigenvalue stability (vecstable)	Max modulus: 0.774	—	All non-unit eigenvalues inside unit circle; VECM is dynamically stable

Note. LM serial-correlation tests are reported for lags 1–2, corresponding to the baseline specification. Residual normality is rejected for the mangrove equation and for the multivariate system, a common feature in small macroeconomic samples that does not invalidate the cointegration framework. All non-unit eigenvalues lie inside the unit circle, indicating that the estimated VECM is dynamically stable. Source: Own elaboration.

VECM satisfies standard specification requirements. In addition, lag-sensitivity checks were performed to verify that the qualitative interpretation of the system dynamics remains stable under alternative lag structures (Winarno et al., 2021). The Lagrange-multiplier tests do not reject the null hypothesis of no residual autocorrelation at the model-relevant lag order (lag 1: $p = 0.415$; lag 2: $p = 0.512$). As a sensitivity check, extending the LM test to lag 4 indicates residual correlation at lag 4 ($p = 0.008$), although the model-relevant lag order (lags 1–2) does not exhibit residual autocorrelation. Jarque–Bera tests indicate that the residuals in the GDP, tourism-arrival, and accommodation equations do not depart significantly from normality ($p = 0.198, 0.423$, and 0.764 , respectively), whereas the mangrove equation and the system jointly reject multivariate normality. System stability was assessed using the eigenvalue condition (vecstable), validating that the estimated VECM satisfies the stability requirement, with all eigenvalues lying inside the unit circle (Ericsson, 1992; Ouerfelli, 2008).

4.1. Unit root and stationarity tests

Stationarity is a prerequisite for valid inference in the Johansen framework, as it determines the order of integration and justifies the use of VECM (Johansen, 1988; Papana et al., 2023; Zou, 2018). We conducted Augmented Dickey–Fuller (ADF) tests on each of the four variables in logarithmic form, which serve as proxies for coastal ecosystem health (Dickey and Fuller, 1979; Paparoditis and Politis, 2018).

As shown in Table 3, none of the variables reject the null of a unit root. The test statistic for *lngdpct* is 0.287 ($p \approx 0.977$), while *lnitnt* and *lntrnt* yield statistics of -1.949 and -2.692 , respectively, which are still above the 5% critical value.

The variable *lnncmt*, representing natural capital from mangroves, yields a test statistic of -2.307 and a p-value of 0.170. These findings validate the presence of non-stationarity in levels, justifying the use of first differences or cointegration techniques (Dickey and Fuller, 1979; Engle and Granger, 1987; Papana et al., 2023).

Table 3
Augmented Dickey–Fuller (ADF) stationarity tests.

Variable	Level	ADF Statistic	Critical Value (5%)	p-value	Interpretation
lngdpct	I(1)	0.287	−3.000	0.977	Non-stationary in levels
Δlngdpct	I(0)	—	—	—	Stationary in first differences
lnitnt	I(1)	−1.983	−3.000	0.294	Non-stationary in levels
Δlnitnt	I(0)	—	—	—	Stationary in first differences
lntrnt	I(1)	−2.692	−3.000	0.076	Borderline non-stationary (see Zivot-Andrews Table A1)
Δlntrnt	I(0)	—	—	—	Stationary in first differences
lnncmt	I(1)	−2.303	−3.000	0.171	Non-stationary in levels
Δlnncmt	I(0)	—	—	—	Stationary in first differences

Note. Augmented Dickey–Fuller tests were estimated with five lags and a constant. All variables are treated as integrated of order one, I(1), for the VECM specification because they are non-stationary in levels and stationary after first differencing. The borderline result for *lntrnt* ($p = 0.076$) is further examined using the Zivot–Andrews test (Table A1), which identifies a structural break but does not alter the adopted integration order. Source: Own elaboration based on Stata output.

4.2. Johansen cointegration analysis

Because the analysis relies on 29 annual observations, the cointegration evidence should be interpreted cautiously. In small samples, Johansen tests may exhibit size distortions; for this reason, it is key to emphasize parsimony and contextual analytical diagnostics rather than a single specification interpreted as uniquely data-determined (Johansen, 1991; Paparoditis and Politis, 2018).

Given that all four variables are integrated of order one, the Johansen trace procedure was used to test for long-run equilibrium relationships among them. As reported in Table 4, the trace statistic for the null of no cointegration ($r = 0$) is 66.45, which exceeds the 5% critical value of 47.21. Likewise, the statistic for the null of at most one cointegrating vector ($r \leq 1$) is 36.74, also above its corresponding 5% critical value of 29.68. By contrast, the null of at most two vectors ($r \leq 2$) cannot be rejected, since the trace statistic of 12.75 falls below the critical value of 15.41.

Johansen trace statistics indicate the presence of two cointegrating relationships under the tested specifications. Given the limited annual sample (1995–2023) and the paper's interpretive objective, a

Table 4
Johansen cointegration test results (trend = constant, lags = 2, sample 1997–2023).

Null Hypothesis	Trace Statistic	Critical Value (5%)	Interpretation
$r = 0$	67.024	47.21	Reject — at least one cointegrating vector exists
$r \leq 1$	30.619	29.68	Reject — at least two cointegrating vectors suggested
$r \leq 2$	13.343*	15.41	Fail to reject — statistically selected rank. Baseline VECM adopts rank = 1 for parsimony; rank = 2 treated as robustness check.
$r \leq 3$	0.134	3.76	Fail to reject

Note. Johansen trace tests were estimated with a constant in the cointegration space, two lags, and an effective sample of 1997–2023 ($N = 27$). Although the trace statistic supports two cointegrating vectors ($r = 2$), the baseline specification adopts rank = 1 on theoretical and parsimony grounds, representing a single macro-ecological equilibrium linking economic growth, tourism, tourism infrastructure, and mangrove natural capital. The rank = 2 specification is evaluated as a robustness check. Source: Own elaboration.

parsimonious rank-1 VECM is retained as the baseline specification, with a rank-2 specification treated as a robustness reference rather than as the baseline interpretive model (Dao et al., 2017; Zou, 2018).

In short-term samples, over-parameterization can quickly erode interpretability and reduce the model's practical usefulness. For that reason, and consistent with the methodological literature on cointegrated systems, the baseline specification privileges parsimony and theoretical readability, while the rank = 2 formulation is treated as a robustness exercise rather than as the main interpretive model (Elias et al., 2023; Johansen, 1988; Ouerfelli, 2008). Substantively, the results still support the existence of a stable long-run linkage among economic growth, international tourism, tourism infrastructure, and mangrove natural capital in the Dominican Republic, which is consistent with the broader literature that understands coastal ecosystem services as productive inputs underpinning tourism-dependent development trajectories (Barbier, 2007; Matias et al., 2022; Wolf et al., 2024).

4.3. Estimation of the VECM

Table 5 presents the estimated coefficients, standard errors, test statistics, and significance levels for the four endogenous variables in first differences. Column 1 reports the $\Delta \ln gdpct$ equation; Column 2 the $\Delta \ln itat$ equation; Column 3 the $\Delta \ln trnt$ equation; and Column 4 the $\Delta \ln ncmt$ equation. The model includes two lags and is based on a single cointegrating vector identified in the Johansen analysis.

In the baseline VECM (lags = 2, rank = 1), the lagged short-run coefficient on mangrove natural capital in the GDP equation is -25.713 ($p = 0.001$). This magnitude should not be interpreted in isolation as implying a proportionally large one-period macroeconomic shock. Three considerations bound the interpretation. To begin with, the VECM is estimated in first differences of logarithms in which the coefficient captures the conditional system response to a unit change in $\Delta \ln ncmt$, not the response to a one-percent change in the level of mangrove capital (Barbier et al., 2008; McGlathery et al., 2013). Secondly, the average annual log-change in mangrove capital over the sample period is only -0.00163 (equivalent to a functional degradation

rate of approximately -0.16% per year), meaning that the realized annual contribution of mangrove dynamics to GDP fluctuations is bounded by this very small ecological variation (Barbier, 2007; Mancini et al., 2017; Matias et al., 2022). Finally, in slow-moving ecological systems where natural capital degrades gradually, differenced macroeconomic models may generate large coefficients precisely because the signal-to-noise ratio of ecological variation is low relative to macroeconomic volatility; the coefficient reflects the sensitivity of the system to ecological shocks, not the typical magnitude of those shocks (Brathwaite et al., 2021; Levin et al., 2013; Litzow and Hunsicker, 2016). For the above reasons, the short-run coefficient should be interpreted as a system-level sensitivity parameter, jointly with the impulse-response functions and the mean degradation rate, rather than as a stand-alone economic multiplier (Breitung et al., 2004; Zou, 2018). The nonlinear dynamic responses of coastal ecosystems further reinforce the need to rely on the VECM as a system rather than on individual coefficients in isolation (Barbier et al., 2008; McGlathery et al., 2013; Selkoe et al., 2015).

Here, the baseline cointegrating vector indicates the presence of a stable long-run relationship among GDP, international tourism arrivals, accommodation capacity, and mangrove natural capital within the Johansen multivariate cointegration framework (Johansen, 1988). Under the Johansen normalization, the coefficients for international tourist arrivals and accommodation capacity are statistically significant, whereas the coefficient for mangrove natural capital is not significantly different from zero (Johansen, 1991).

Rearranging the cointegrating relation to express GDP as the dependent variable yields an implied long-run elasticity of GDP with respect to mangrove natural capital of -2.544 . However, the coefficient is not statistically significant ($p = 0.737$) and should therefore be interpreted cautiously. In macro-ecological systems, ecological variables evolve slowly and exhibit limited interannual variation, which often leads to imprecisely estimated long-run parameters even when short-run transmission channels remain economically meaningful (Barbier et al., 2008; McGlathery et al., 2013).

Nevertheless, the statistically significant long-run coefficients

Table 5
Estimated short-run dynamics and long-run cointegrating vector (VECM, rank = 1, lags = 2).

Dep. Variable	Independent Variable	Coeff.	Std. Error	z-stat	p-value	Interpretation
$\Delta \ln gdpct$	ECT_{t-1}	-0.0842	0.0335	-2.52	0.012^{**}	GDP corrects $\sim 8.4\%$ /year toward long-run equilibrium
	$\Delta \ln itat_{t-1}$	-0.1953	0.0969	-2.02	0.044^*	Significant negative short-run effect of tourist arrivals on GDP
	$\Delta \ln trnt_{t-1}$	0.0290	0.1012	0.29	0.774	Not significant
	$\Delta \ln ncmt_{t-1}$	-25.713	7.836	-3.28	0.001^{***}	Strong negative short-run impact of mangrove degradation on GDP
	Constant	0.0053	0.0177	0.30	0.763	Not significant
$\Delta \ln itat$	ECT_{t-1}	0.0463	0.2276	0.20	0.839	No significant adjustment toward equilibrium
	$\Delta \ln ncmt_{t-1}$	-106.160	53.311	-1.99	0.046^*	Significant negative short-run association: mangrove degradation $\rightarrow$ tourism arrivals
$\Delta \ln trnt$	Constant	-0.1108	0.1202	-0.92	0.357	Not significant
	ECT_{t-1}	-0.0576	0.2079	-0.28	0.782	No short-run equilibrium adjustment for accommodation supply
	$\Delta \ln ncmt_{t-1}$	-94.775	48.690	-1.95	$0.052^\dagger$	Marginally significant: mangrove degradation $\rightarrow$ accommodation capacity
$\Delta \ln ncmt$	Constant	-0.0970	0.1098	-0.88	0.377	Not significant
	ECT_{t-1}	-0.0021	0.0008	-2.76	0.006^{**}	Mangrove stock converges slowly toward long-run equilibrium
	$\Delta \ln trnt_{t-1}$	0.0105	0.0023	4.63	$<0.001^{***}$	Positive: accommodation capacity expansion is associated with mangrove dynamics
	$\Delta \ln ncmt_{t-1}$	0.5633	0.1758	3.20	0.001^{***}	Strong persistence: previous mangrove conditions influence current changes
Long-run β (cointegrating vector)	Constant	-0.0010	0.0004	-2.54	0.011^*	Significant negative drift in mangrove capital
	$\ln itat$	-5.065	0.779	-6.50	$<0.001^{***}$	Mass tourism associated with lower long-run GDP (congestion/environmental pressure effects)
	$\ln trnt$	4.576	0.720	6.36	$<0.001^{***}$	Tourism infrastructure positively associated with long-run GDP
	$\ln ncmt$	-25.525	9.979	-2.56	0.011^*	Mangrove capital positively associated with long-run GDP. Implied elasticity = $+25.525$ (see Section 4.4).

Note. Results correspond to the baseline VECM estimated with rank = 1 and two lags ($N = 27$). The cointegrating vector is normalized on real GDP ($\ln gdpct$). The long-run coefficient for mangrove natural capital ($\beta = -25.525$; $p = 0.011$) implies a positive long-run elasticity of GDP with respect to mangrove capital of $+25.525$. Short-run coefficients associated with $\Delta \ln ncmt$ represent system-conditional responses to changes in mangrove natural capital and should not be interpreted as marginal effects in isolation. $^\dagger p < 0.10$; $^* p < 0.05$; $^{**} p < 0.01$; $^{***} p < 0.001$. Source: Own elaboration.

associated with tourism flows and accommodation capacity indicate that the tourism–growth nexus remains structurally embedded in the Dominican economy. These results are consistent with the view that tourism activity and tourism infrastructure constitute central drivers of long-run output dynamics in tourism-dependent coastal economies (Duffy et al., 2015; Peterson, 2023).

Under the Johansen normalization, GDP is positively associated with tourism infrastructure ($lntrnt$) and mangrove natural capital ($lnncmt$) and negatively associated with international tourism arrivals ($lnitatt$). However, only the coefficients for $lnitatt$ (-2.8162 , $p = 0.000$) and $lntrnt$ (2.7099 , $p = 0.000$) are statistically significant. The negative long-run association between GDP and tourist arrivals may reflect congestion dynamics and environmental pressures associated with mass tourism (Barbier and Cox, 2003; Hagger et al., 2022; Matias et al., 2022). Within the context of the Dominican tourism economy, rapid increases in visitor numbers may place pressure on coastal ecosystems and tourism infrastructure, potentially affecting destination attractiveness over time.

While the long-run parameters describe equilibrium relationships, the short-run dynamics are captured by the VECM adjustment terms. In the estimated model, changes in mangrove natural capital ($\Delta lnncmt$) exert statistically significant short-run effects on GDP (-25.163 , $p < 0.001$), international tourism arrivals (-120.7323 , $p = 0.016$), and tourism infrastructure capacity (-99.6449 , $p = 0.028$), indicating that ecological shocks are rapidly transmitted to key components of the tourism economy.

These short-run dynamics are further illustrated in the IRF presented in Fig. 3, which includes 95% confidence bands that allow the statistical uncertainty around the dynamic responses to be evaluated. The orthogonalized IRF traces the system's response to a one-standard-deviation shock in mangrove natural capital and provides a dynamic complement to the baseline VECM coefficients (Breitung et al., 2004; Winarno et al., 2021).

Fig. 3 shows that a negative ecological shock is followed by immediate declines across the three economic variables. Panel A indicates that GDP falls by approximately 0.02 log points. Panels B and C reveal stronger responses within the tourism system, with both international tourist arrivals and tourism infrastructure declining by more than 0.06 log points during the initial adjustment period. These dynamics highlight the short-run sensitivity of tourism-related variables to ecological disturbances (Beeharry et al., 2021; Sherman, 2017). Mangrove degradation appears to be rapidly transmitted to tourism markets and infrastructure, reinforcing the interpretation of coastal natural capital as a productive yet vulnerable input in tourism-dependent economies

(Davenport and Davenport, 2006; Sherman, 2017).

Interestingly, neither international tourism arrivals ($\Delta lnitatt_{t-1}$) nor tourism infrastructure ($\Delta lntrnt_{t-1}$) exhibits statistically significant short-run effects on GDP growth in the VECM specification. The coefficient for $\Delta lnitatt_{t-1}$ is -0.1154 ($p = 0.098$), suggesting a marginal and potentially negative effect, while the coefficient for $\Delta lntrnt_{t-1}$ is -0.0428 ($p = 0.610$), indicating no statistically significant effect.

Granger causality tests provide complementary evidence that reinforces these findings and helps interpret the economic consequences of ecosystem degradation (see Table B1). In the validated model (two lags, rank = 1), mangrove degradation Granger precedes both international tourism arrivals ($p = 0.003$) and tourism infrastructure capacity ($p = 0.029$). These variables, in turn, display significant long-run relationships with GDP within the VECM framework (see Table 5). These results should be interpreted as evidence of predictive precedence rather than structural causality, since Granger causality tests identify temporal ordering in the data but do not establish causal mechanisms.

The potential for joint determination among tourism development, economic growth, and mangrove degradation deserves explicit acknowledgment. In principle, all four variables in the system may be simultaneously influenced by common drivers, such as foreign direct investment, institutional quality, or climate shocks, that are not directly observed in the model (Acheampong and Opoku, 2023; Rajapaksa et al., 2019). The VECM framework partially addresses this concern: by treating all variables as endogenous and jointly modeling their dynamic interdependencies, it avoids the single-equation endogeneity problem that would affect a standard regression approach (Johansen, 1988; Ouerfelli, 2008). The bidirectional Granger precedence documented in Table B1, where tourism variables also precede mangrove capital, is itself evidence of this mutual determination and is consistent with the VECM's system-level design. Nevertheless, the model does not control for omitted drivers of the tourism–growth–ecosystem nexus, and the estimated coefficients should therefore be interpreted as conditional associations within the system rather than as structural causal effects (Engle and Granger, 1987; Williams and Cook, 2016). This limitation is discussed further in Section 5.

Once again, and given the limited sample size and the statistical uncertainty associated with some long-run parameters, the estimated magnitudes should be interpreted jointly with the system diagnostics and robustness checks rather than as stand-alone elasticities (Breitung et al., 2004; Papan et al., 2023; Pasková et al., 2024; Zou, 2018).

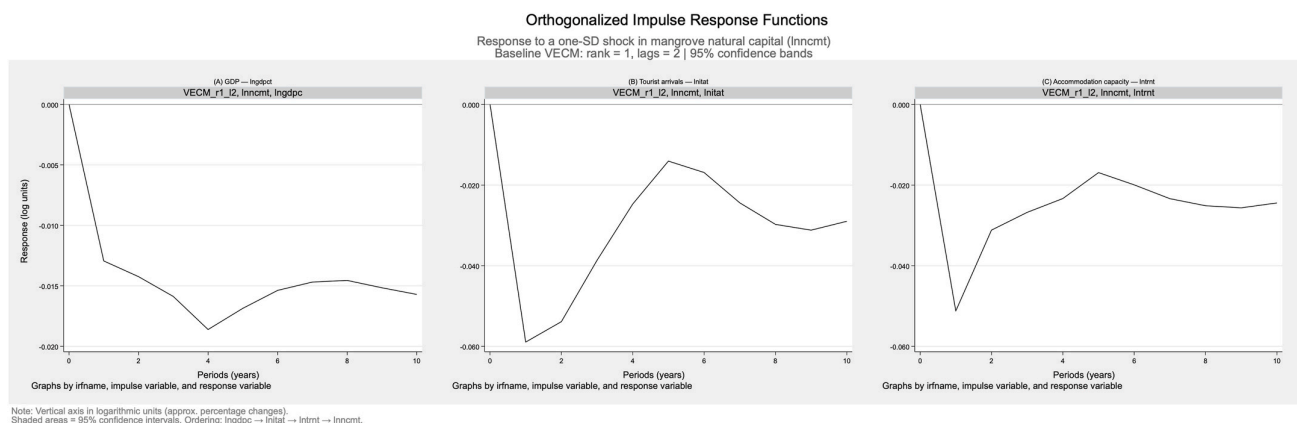


Fig. 3. Orthogonalized impulse response functions of the VECM system with 95% confidence bands

Note. Orthogonalized impulse–response functions (OIRFs) from the baseline VECM specification (rank = 1, lags = 2), showing the dynamic responses of (A) aggregate GDP ($lngdpct$), (B) international tourist arrivals ($lnitatt$), and (C) tourism infrastructure capacity ($lntrnt$) to a one-standard-deviation shock in mangrove natural capital ($lnncmt$). The horizontal axis represents the forecast horizon in periods (years), while the vertical axis reports responses in logarithmic units (approximately percentage changes). Cholesky ordering: $lngdpct \rightarrow lntrnt \rightarrow lnitatt \rightarrow lnncmt$. Source: Own elaboration.

4.4. Approaching mangrove economic exposure

The implied long-run elasticity of GDP with respect to mangrove natural capital in the baseline rank-1 VECM is +25.525 ($p = 0.011$), derived from the Johansen cointegrating vector normalized on *lngdpc*. This coefficient is statistically significant and indicates that, in the long-run equilibrium, greater mangrove capital stock is associated with higher GDP, consistent with the interpretation of coastal ecosystems as productive natural infrastructure supporting tourism-dependent development (Barbier, 2007; Beck et al., 2022; Menéndez et al., 2018). The short-run dynamics and Granger-causality results reinforce this finding: mangrove degradation Granger-causes GDP ($p = 0.044$), tourist arrivals ($p < 0.001$), and hotel-room capacity ($p < 0.001$), while feedback effects from tourism variables to mangrove capital are also present, indicating bidirectional ecological-economic coupling. Following Granger (1969) and the cautionary discussion by Williams and Cook (2016), these results are interpreted as evidence of predictive precedence and temporal ordering rather than definitive proof of structural causation. The significant long-run elasticity and the consistent Granger causality provide a coherent analytical basis for estimating the economic exposure associated with mangrove degradation. Table 6 presents this estimate.

Using the observed mean annual log-decline in mangrove capital (-0.00163) over the full sample period, and applying the implied long-run elasticity of +25.525 ($p = 0.011$) to the estimated annual value of coastal-marine ecosystem services in the Dominican Republic, approximately USD 1800 million (Ruiz de Gauna et al., 2024), the annual economic exposure amounts to approximately USD 75.0 million, equivalent to 4.2% of the estimated value of coastal-marine ecosystem services. As a robustness check, applying the observed-only degradation rate from the truncated sample (1996–2020; -0.00132 , excluding OLS-projected values) yields a lower-bound estimate of approximately USD 60.7 million (3.4%). These estimates are reported in Table 6.

The estimated exposure should be interpreted as a cautionary indicative long-run scenario (reflecting the equilibrium relationship between mangrove capital and GDP under the observed rate of degradation) rather than as a realized annual loss (Williams and Cook, 2016). The calculation captures only the tourism–economy transmission channel and excludes other ecosystem services provided by mangroves, including coastal protection, fisheries support, and carbon sequestration, implying that the reported figure is a conservative lower bound of the total economic implications of mangrove degradation (Barbier et al., 2011; Shortridge et al., 2024).

The analysis, therefore, highlights the need for policy frameworks that integrate natural capital as a core component of tourism development strategies, particularly through instruments such as payments for ecosystem services (Beck et al., 2022; Menéndez et al., 2018). This approach would allow internalization of environmental externalities and enhance the resilience of the growth model.

It is also crucial to note that this analysis only considers mangrove ecosystems. It excludes the degradation of other critical coastal systems, such as coral reefs, seagrass beds, and marshes, which play complementary roles in biodiversity conservation, shoreline protection, and tourism attractiveness (Duarte et al., 2008; Eastwood et al., 2017; Spalding et al., 2017).

5. Discussion and policy implications

Returning to the central research question, to what extent does mangrove degradation affect short-run and long-run economic dynamics in a tourism-dependent SIDS? The results provide evidence at both temporal horizons. The results presented in Section 4, regarding the short-run dynamics and IRFs within the VECM framework, indicate that, in the Dominican context, ecological shocks lead to immediate declines in GDP, tourist arrivals, and tourism infrastructure (Elias et al., 2023; Matias et al., 2022; Ouerfelli, 2008). Regarding the long-run dynamics, the statistically significant cointegrating relationship between

Table 6

Estimated annual economic exposure associated with mangrove degradation (indicative long-run scenario).

Component	Value	Unit	Source/Note
Long-run elasticity (ϵ) — implied from cointegrating vector	+25.525	—	Derived from Johansen cointegrating vector (rank = 1, lags = 2). $\beta[\text{lnnemt}] = -25.525$; implied elasticity of <i>lngdpc</i> w.r.t. <i>lnnemt</i> = $-(-25.525) = +25.525$. Statistically significant: $p = 0.011$.
Average annual log-decline in mangrove capital — full sample (1996–2023)	−0.00163	Log-points/year	Calculated from Stata Fase 8 (includes OLS-projected values for 2021–2023). Equivalent to -0.163% annual functional degradation.
Average annual log-decline — observed subsample only (1996–2020)	−0.00132	Log-points/year	Calculated from Stata Fase 11 (observed data only, no imputed values). Robustness check for C1.
Estimated coastal-marine ecosystem services value	USD 1800 million	USD/year	Ruiz de Gauna et al. (2024): coastal-marine ecosystems in the DR generate approx. USD 1800 million annually in ecosystem services (1.8% of GDP, 2023).
Estimated annual economic exposure — full sample ($\Delta Y = \epsilon \times \Delta \ln K \times Y$)	USD 75.0 million	USD/year	$= 25.525 \times (-0.00163) \times 1,800,000,000$. Indicative long-run exposure scenario, not a realized annual loss. Coefficient is statistically significant ($p = 0.011$).
Estimated annual economic exposure — observed subsample	USD 60.7 million	USD/year	$= 25.525 \times (-0.00132) \times 1,800,000,000$. Robustness lower bound using observed-only degradation rate.
Exposure as % of coastal-marine ecosystem services value	4.2% (full)/ 3.4% (obs.)	%	Derived from $\epsilon \times$ average decline rate $\times 100$. Primary framing: 4.2% of the estimated USD 1800 million annual value of coastal-marine ecosystem services (Ruiz de Gauna et al., 2024).
Total national GDP (2023)	USD 100,366 million	USD (constant 2015)	World Bank WDI (NY, GDP.MKTP.KD). Source: Stata dataset.
Exposure as % of national GDP (full sample)	0.075%	%	USD 75.0 million/USD 100,366 million. Provided for context; primary framing uses ecosystem services base.

Note. Annual economic exposure was estimated as $\Delta Y = \epsilon \times \Delta \ln K \times Y$, where ϵ is the long-run elasticity obtained from the Johansen cointegrating vector, $\Delta \ln K$ is the observed mean annual change in mangrove natural capital, and Y is the estimated annual value of coastal-marine ecosystem services. The table reports both the baseline estimate and a robustness estimate based exclusively on observed mangrove data (1996–2020). Source: Own elaboration based on Stata output and Ruiz de Gauna et al. (2024).

mangrove capital and GDP indicates that mangrove natural capital functions as a long-run productive input whose depletion constrains the economy's equilibrium growth path (Acheampong and Opoku, 2023; Alvarado and Toledo, 2017).

5.1. Interpreting the findings

The above findings can be interpreted within a broader ecological–economic framework in which mangrove ecosystems function as

productive assets of natural capital (Barbier, 2007). In coastal tourism-dependent economies, mangroves provide ecosystem services that operate as natural infrastructure supporting economic activity, such as shoreline stabilization, storm protection, habitat provision, and landscape amenities that underpin tourism attractiveness and coastal resilience (Beck et al., 2022). From this perspective, the degradation of mangrove ecosystems is not only an environmental concern but also a macroeconomic issue affecting the stability and sustainability of tourism-led development trajectories (Leotaud et al., 2024; Menéndez et al., 2018). Based on the above, three key empirical findings anchor the discussion.

First, the VECM results indicate that environmental degradation, proxied by the indicative exposure of mangrove natural capital, is associated with a statistically significant negative short-run effect on economic growth. In the baseline specification (lags = 2, rank = 1), the lagged coefficient on mangrove capital in the GDP equation is -25.713 ($p = 0.001$). This magnitude should not be interpreted in isolation as implying proportionally large macroeconomic fluctuations. Over the analyzed period 1995–2023, the average annual log-change in mangrove capital is only -0.00163 , indicating very limited year-to-year ecological variation. In slow-moving ecological systems, small annual changes in natural-capital stocks may yield relatively large coefficients in differenced macroeconomic models without corresponding large realized macroeconomic shifts (Folke et al., 2004; Mancini et al., 2017; Selkoe et al., 2015).

Second, Granger-causality tests indicate predictive precedence from mangrove natural capital to several macro-tourism variables in the bivariate VAR exercises (Portella-Carbó et al., 2023; Siggiridou and Kugiumtzis, 2016). Specifically, mangrove degradation Granger-precedes GDP ($p = 0.044$), international tourism arrivals ($p < 0.001$), and accommodation capacity ($p < 0.001$). Following the original interpretation of the test (Granger, 1969) and subsequent methodological clarifications (Engle and Granger, 1987; Siggiridou and Kugiumtzis, 2016; Zou, 2018), these results are interpreted as evidence of temporal ordering rather than proof of structural causality. Nonetheless, the consistent predictive precedence observed across the GDP, tourism arrivals, and accommodation equations suggests that changes in coastal natural capital tend to precede adjustments in key tourism-related macroeconomic indicators.

Third, the tourism sector itself appears particularly sensitive to ecological degradation. The VECM results indicate that changes in mangrove natural capital have statistically significant short-run effects on both international tourist arrivals and accommodation capacity. These simultaneous effects on demand and supply variables point to a structural vulnerability of tourism-dependent coastal economies such as the Dominican Republic, where ecosystem services provided by mangroves (such as shoreline stabilization, storm protection, and landscape quality) form part of the natural infrastructure supporting tourism activity (Barbier, 2015; Beck et al., 2022).

In other words, the short-run dynamics, the Granger-precedence tests, and the statistically significant long-run cointegrating relationship indicate that mangrove degradation operates across multiple temporal scales. This synthesis is consistent with the ecological-economic perspective advanced by Barbier (2007) and with empirical evidence showing that coastal ecosystems function as productive natural capital whose degradation is progressively transmitted to economic performance through tourism-dependent development pathways (Beck et al., 2022; Leotaud et al., 2024). In the DR, the results suggest that ecological shocks are transmitted rapidly through tourism-related channels. At the same time, persistent deterioration in mangrove natural capital constrains the economy's long-run equilibrium, reinforcing recent evidence on the macroeconomic relevance of blue-carbon ecosystems and coastal resilience (Acheampong and Opoku, 2023; Litzow and Hunsicker, 2016). The estimated annual economic exposure of approximately USD 75.0 million (4.2% of the value of coastal-marine ecosystem services) provides an indicative lower-bound benchmark for

these long-run implications, consistent with previous studies emphasizing that conventional economic valuations capture only part of the services generated by coastal ecosystems (Barbier et al., 2011; Beck et al., 2022; Ruiz de Gauna et al., 2024). Because the calculation captures only the tourism–economy transmission channel and excludes nonlinear ecological interactions and other ecosystem services, it should be interpreted as a conservative benchmark rather than as a comprehensive estimate of the economic costs associated with mangrove degradation (Levin et al., 2013; Shortridge et al., 2024).

From a coastal management perspective, the results provide evidence consistent with an ecosystem-based approach, in which mangrove conservation is treated as a productive asset and ecological infrastructure within tourism planning rather than a peripheral environmental objective (Barbier, 2007). In tourism-dependent SIDS, mangroves contribute to shoreline stabilization, storm buffering, habitat quality, and landscape value, all of which condition the resilience of coastal tourism systems (Barbier, 2015; Beck et al., 2022).

From a policy perspective, the findings highlight the importance of integrating economic instruments into environmental governance frameworks to promote pro-environmental behavior and internalize ecological externalities (Ling and Xu, 2021; Rajapaksa et al., 2019; Schubert, 2010; Wang et al., 2021). Instruments such as payments for ecosystem services (PES), ecological zoning, or conservation-based incentives can help shift the behavioral calculus of land-use decisions in coastal areas (Coria and Sterner, 2011; Ekpe, 2013). Furthermore, the synergistic and nonlinear dynamics among coastal ecosystems imply the presence of ecological hysteresis (Litzow and Hunsicker, 2016). Once a system crosses certain degradation thresholds, restoring it may require disproportionately greater effort or may be infeasible altogether (McGlathery et al., 2013; Selkoe et al., 2015).

In the DR, coastal tourism development and mangrove conservation involve overlapping institutional responsibilities between the Ministry of Environment and Natural Resources, coastal zoning regulations, and the Ministry of Tourism and its development planning frameworks. Rapid tourism expansion in areas such as Samaná Bay and its surrounding areas (including North and South areas around the bay, such as Miches) and Bávaro–Punta Cana illustrates the governance challenges associated with integrating mangrove conservation into tourism-led coastal development strategies (Duffy et al., 2015; Eastwood et al., 2017; MMARN/ORPALC/PNUMA, 2025; Ruiz de Gauna et al., 2024).

It implies stronger coordination between tourism expansion, coastal zoning, and mangrove protection in rapidly developing coastal territories such as Samaná, Bávaro–Punta Cana, and Puerto Plata, where ecological resilience and tourism infrastructure are closely interdependent (Herrera Estévez, 2022; MMARN/ORPALC/PNUMA, 2025; Steneck and Torres, 2023). More importantly, it does not reflect the opportunity costs associated with losing services that are not easily substitutable, such as shoreline stabilization, habitat provisioning, and the cultural and aesthetic value of intact landscapes (Barbier, 2015; Beck et al., 2022). In the absence of clear market signals, these services tend to be undervalued or ignored in decision-making, increasing the risk that quantified indicative exposure is misinterpreted as permission to convert ecosystems (Balmford et al., 2002; Barbier et al., 2008). The baseline rank-1 VECM, the system diagnostics, and the rank-2 robustness model support the existence of a meaningful ecological-economic linkage. However, they also require cautious interpretation of long-run magnitudes and policy extrapolations.

The answer to the study's central question is multi-scalar and contingent. For tourism-dependent SIDS, the evidence presented here suggests that ecosystem conservation should be treated not merely as an environmental externality but as an important component of long-term macroeconomic policy (Lionetti and Gonzalez, 2012; Liu et al., 2022; Meyer, 2020; Portella-Carbó et al., 2023). The findings discussed here are consistent with recent work on blue-carbon ecosystems, coastal resilience, and tourism vulnerability, which emphasizes that mangroves and associated coastal habitats generate regulating and amenity services

that are economically relevant yet systematically undervalued in coastal development decisions (Beck et al., 2022; Herr et al., 2017; Ruiz de Gauna et al., 2024; Wolf et al., 2024).

5.2. Framing limitations

A limitation of the analysis discussed here concerns potential endogeneity beyond what the VECM framework captures. Although the multivariate VECM treats all variables as jointly endogenous, it does not explicitly control for unobserved common drivers that may simultaneously influence tourism flows, economic growth, and mangrove degradation. Factors such as foreign direct investment in coastal tourism infrastructure, the quality of environmental governance and regulatory enforcement, and climate-related shocks, including hurricanes, sea-level rise, and coral bleaching events, could affect all four variables in the system and generate spurious associations if omitted (Acheampong and Opoku, 2023; Galaitis et al., 2024; Schubert, 2010). In a small island developing state context with limited data availability, incorporating these controls directly into the VECM is not feasible without severe over-parameterization (Elias et al., 2023; Paparoditis and Politis, 2018).

The robustness of the cointegrating relationship across sub-periods, including the pre-crisis window (1995–2007) and the pre-COVID window (1995–2019), provides indirect evidence that the estimated long-run equilibrium is not driven primarily by these major disruptions. Although formal structural-break tests were not conducted due to the limited sample size, the stability of the cointegrating relationship across alternative estimation windows increases confidence in the robustness of the long-run results (Durr, 1992; Zou, 2018).

More specifically, four categories of omitted variables merit discussion. First, foreign direct investment (FDI) in coastal tourism infrastructure is a plausible driver of both hotel room expansion (*lntrmt*) and mangrove degradation (*lnncmt*), as large-scale resort development has historically involved coastal land conversion in the Dominican Republic (Duffy et al., 2015; Eastwood et al., 2017). The absence of an FDI control means that part of the estimated association between tourism infrastructure and mangrove capital may reflect this common driver rather than a direct ecological-economic link. Secondly, climate-related shocks, including Atlantic hurricane events, coral bleaching episodes, and sea-level rise, affect both coastal ecosystem health and tourism demand simultaneously, and their exclusion from the model may introduce omitted variable bias in the short-run equations (Galaitis et al., 2024; Spencer, 2019; Wolf et al., 2024). In third place, institutional quality and environmental regulatory enforcement condition the rate at which economic growth translates into ecosystem degradation. In contexts of weak enforcement, the EKC transition toward environmental improvement is delayed or absent, as is the case in many SIDS (Al-mulali et al., 2015; Alvarado and Toledo, 2017; Schubert, 2010). Fourth, environmental regulations specific to coastal zones (including protected area designations, mangrove harvesting restrictions, and coastal zoning) could independently affect *lnncmt* and *lnitmt* in ways the model does not capture (Ekpe, 2013). Incorporating these variables directly into the VECM is not feasible given the sample size of 29 observations and the risk of severe over-parameterization in a four-variable system already operating near its degrees-of-freedom limit (Paparoditis and Politis, 2018). Future research using longer time series or panel data across multiple SIDS should explicitly address these omissions (Acheampong and Opoku, 2023; Lionetti and Gonzalez, 2012).

Finally, it is important to clarify the limits of this study and the scope of the variable used to represent ecosystem degradation. The analysis focuses exclusively on mangroves, which were selected for both empirical and theoretical reasons. Moreover, the variable represents a functional measure of mangrove natural capital rather than a direct ecological indicator of ecosystem condition. It therefore does not capture dimensions such as habitat quality, species composition, or ecosystem integrity. Therefore, the study does not capture the full complexity of coastal-marine ecosystem dynamics. Coral reefs, seagrass

beds, and marshlands also play crucial roles in biodiversity, shoreline protection, and cultural ecosystem services (Beck et al., 2022; Brander et al., 2007; Spalding et al., 2017; Wolf et al., 2024).

6. Conclusions

This study provides evidence of an ecological-economic linkage between mangrove degradation and macro-tourism dynamics in the Dominican Republic using annual data for 1995–2023. The baseline rank-1 VECM identifies statistically significant effects at both the short-run and long-run horizons. In the short run, mangrove degradation is associated with significant declines in GDP growth ($p = 0.001$), tourist arrivals ($p = 0.046$), and accommodation capacity ($p = 0.052$), while the error correction term validates that GDP adjusts toward its long-run equilibrium at a rate of approximately 8.4% per year ($p = 0.012$). In the long run, the Johansen cointegrating vector yields a statistically significant coefficient on mangrove natural capital ($p = 0.011$), implying that greater mangrove capital stock is associated with higher GDP in equilibrium. These findings support the interpretation that coastal ecosystem degradation constitutes a material economic risk in this tourism-dependent SIDS context, not only through short-run disruptions but also through its long-run impact on the economy's productive capacity.

Four core findings emerge from this analysis. First, there is a statistically significant negative short-run effect of mangrove degradation on GDP growth (coefficient = -25.713 , $p = 0.001$), underscoring the vulnerability of productive systems to ecological decline even when the annual rate of degradation is slow (-0.163% per year on average). Second, the Granger tests indicate that mangrove capital has predictive precedence over GDP ($p = 0.044$), tourism arrivals ($p < 0.001$), and accommodation capacity ($p < 0.001$), while bidirectional feedback from tourism variables to mangrove capital is also present, consistent with joint ecological-economic determination. Third, the long-run cointegrating vector identifies a statistically significant positive relationship between mangrove capital and GDP ($p = 0.011$), providing evidence that the ecological-economic linkage extends beyond short-run fluctuations to the system's structural equilibrium. Fourth, applying the implied long-run elasticity ($+25.525$) to the observed degradation rate and the estimated value of coastal-marine ecosystem services, the estimated annual economic exposure associated with mangrove degradation amounts to approximately USD 75.0 million (4.2% of the value of coastal-marine ecosystem services), with a robustness lower bound of USD 60.7 million (3.4%) using observed-only data (1996–2020). These findings are consistent with the view that ecological constraints play a more central role in shaping development trajectories in tourism-dependent SIDS than is typically assumed in aggregate environment–growth frameworks (Barbier, 2015; Elias et al., 2023; Schubert, 2010).

The analysis is not without limitations. The time series, while relatively long by Caribbean standards, operates near the degrees-of-freedom limit of the four-variable VECM, which constrains the inclusion of additional controls. Four categories of omitted variables are particularly relevant: foreign direct investment in coastal tourism infrastructure; climate-related shocks, including hurricanes and coral bleaching events; institutional quality and environmental regulatory enforcement; and coastal zone management regulations. These factors may simultaneously influence tourism flows, economic growth, and mangrove degradation, implying that some degree of residual endogeneity may remain despite the multivariate VECM specification. Accordingly, the estimated coefficients should be interpreted as conditional associations rather than structural causal effects (Acheampong and Opoku, 2023; Galaitis et al., 2024).

Additionally, values for *lnncmt* in 2021–2023 were projected using OLS trend extrapolation, as the World Bank WAVES indicator is not yet available beyond 2020; while the truncated-sample robustness check highlights the qualitative direction of results, the short-run coefficients from the full-sample model should be interpreted with this caveat in mind (Ericsson, 1992). The Zivot-Andrews test further flags a structural

break in hotel infrastructure (*Intrnt*) in 1999 that the standard ADF test does not detect, an additional limitation acknowledged in the baseline unit root characterization (Zivot and Andrews, 2002).

Future research should expand the analytical framework in four directions. First, incorporating spatially explicit and multi-ecosystem indicators would improve ecological realism; remote-sensing data on mangrove extent, fragmentation, and shoreline exposure would complement the aggregate functional indicator used here and capture spatial heterogeneity across the Dominican Republic's coastal zones (Hagger et al., 2022; Xu et al., 2022). Second, extending the analysis to panel data for multiple Caribbean or SIDS economies would increase statistical power, allow explicit control for omitted time-invariant confounders, and enable cross-country comparison of the ecological-economic transmission channel (Lionetti and Gonzalez, 2012). Third, incorporating FDI flows, climate shock indices, and institutional quality measures into structural VAR or SVAR frameworks would address endogeneity and omitted-variable concerns identified in the present study (Galaitis et al., 2024; Rajapaksa et al., 2019). Fourth, as the World Bank WAVES indicator becomes available for post-2020 years, re-estimation without OLS projection will allow a fully observed assessment of the post-pandemic recovery trajectory of mangrove capital and its economic implications.

In summary, this study underscores that ecological degradation is not merely a peripheral concern but a fundamental threat to sustainable development. The consistent empirical links between natural capital, tourism flows, and infrastructure point to the need for integrated, adaptive policy strategies.

CRediT authorship contribution statement

Víctor Gómez-Valenzuela: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Katerin Ramírez:** Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. **Solhanlle Bonilla-Duarte:** Methodology, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2026.108293>.

Annex A. Robustness Tables (added for R2)

Table A1

Zivot-Andrews unit root tests with endogenous structural break

Variable	Min. t-stat	Break Year	CV 1%	CV 5%	Interpretation
<i>Ingdp</i>	−3.640	2003	−5.34	−4.80	Fail to reject $H_0 \rightarrow I(1)$ with structural break
<i>lnit</i>	−4.705	2019	−5.34	−4.80	Fail to reject $H_0 \rightarrow I(1)$ with structural break
<i>Intrnt</i>	−5.669	1999	−5.34	−4.80	Reject H_0 at 1% — structural break at 1999 (rapid hotel expansion). ADF standard test ($t = -2.692$, $p = 0.076$) fails to reject; ZA result noted as limitation. $I(1)$ characterization maintained for VECM consistency.
<i>lnncmt</i>	−4.290	2017	−5.34	−4.80	Fail to reject $H_0 \rightarrow I(1)$ with structural break

Note. Zivot-Andrews tests allowing for a single endogenous structural break were estimated using AIC-based lag selection (maximum three lags). Three variables remain consistent with an $I(1)$ process after allowing for structural breaks. Although *Intrnt* rejects the null hypothesis at the 1% level, it is retained as $I(1)$ to preserve a common integration order across variables in the baseline VECM. Source: Own elaboration.

Table A2

Johansen trace test: sub-period robustness for structural breaks

Sub-period	N (eff.)	Lags	Trace stat ($r = 0$)	CV 5%	Conclusion
1995–2007 (pre-financial crisis)	12	1	61.83	47.21	Cointegration supported before financial crisis
1995–2019 (pre-COVID)	23	2	71.60	47.21	Cointegration supported before the Covid-19 pandemic
1995–2023 (full sample — baseline)	27	2	67.02	47.21	Baseline specification

Note. Johansen trace tests ($H_0: r = 0$) were estimated for three sample windows. Cointegration is supported in all specifications, indicating that the estimated long-run equilibrium is not driven solely by recent observations. The 1995–2007 model uses one lag because of the smaller effective sample; the remaining specifications use two lags, consistent with the baseline model. Source: Own elaboration.

Annex B. Granger causality tests

Table B1

Granger causality Wald tests (bivariate VAR, 2 lags)

Dependent Variable	Granger-causing Variable	Chi-square	p-value	Interpretation
Ingdp	lnncmt	4.068	0.044*	Mangrove capital Granger-causes GDP
lnncmt	Ingdp	3.675	0.055†	Weak reverse predictive effect
lnit	lnncmt	48.231	<0.001***	Mangrove capital Granger-causes tourism arrivals
lntrnt	lnncmt	14.704	<0.001***	Mangrove capital Granger-causes tourism infrastructure
lnncmt	lnit	9.959	0.002**	Tourism arrivals Granger-cause mangrove capital
lnncmt	lntrnt	4.604	0.032*	Tourism infrastructure Granger-causes mangrove capital

Note. Granger causality Wald tests were estimated from bivariate VAR models with two lags. The results indicate predictive precedence (temporal ordering) rather than structural causality (Granger, 1969; Williams and Cook, 2016). Significant bidirectional relationships between mangrove natural capital, tourism arrivals, and tourism infrastructure are consistent with dynamic ecological-economic feedbacks. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Source: Own elaboration.

Data availability

Data will be made available on request.

References

- Acaravci, A., Ozturk, I., 2010. On the relationship between energy consumption, CO2 emissions, and economic growth in Europe. *Energy* 35 (12), 5412–5420. <https://doi.org/10.1016/j.energy.2010.07.009>.
- Acheampong, A.O., Opoku, E.E.O., 2023. Environmental degradation and economic growth: investigating linkages and potential pathways. *Energy Econ.* 123, 106734. <https://doi.org/10.1016/j.eneco.2023.106734>.
- Al-mulali, U., Tang, C.F., Ozturk, I., 2015. Estimating the Environmental kuznets curve hypothesis: evidence from Latin American and Caribbean countries. *Renew. Sustain. Energy Rev.* 50, 918–924. <https://doi.org/10.1016/j.rser.2015.05.017>.
- Alvarado, R., Toledo, E., 2017. Environmental degradation and economic growth: evidence for a developing country. *Environ. Dev. Sustain.* 19 (4), 1205–1218. <https://doi.org/10.1007/s10668-016-9790-y>.
- Alvarez-Filip, L., Gill, J.A., Dulvy, N.K., Perry, A.L., Watkinson, A.R., Côté, I.M., 2011. Drivers of region-wide declines in architectural complexity on Caribbean reefs. *Coral Reefs* 30 (4), 1051–1060. <https://doi.org/10.1007/s00338-011-0795-6>.
- Ballut-Dajud, G.A., Sandoval Herazo, L.C., Fernández-Lambert, G., Marín-Muñoz, J.L., López Méndez, M.C., Betanzo-Torres, E.A., 2022. Factors affecting wetland loss: a review. *Land* 11 (3).
- Balmford, A., Bruner, P., Cooper, P., Costanza, R., Farber, S., Green, R.E., Jenkins, M., Jefferiss, P., Jessamy, V., Madden, J., Munro, K., Myers, N., Naeem, S., Paavola, J., Rayment, M., Rosendo, S., Roughgarden, J., Trumper, K., Turner, R.K., 2002. Economic reasons for conserving wild nature. *Science* 297 (5583), 950–953. <https://doi.org/10.1126/science.1073947>.
- Barbier, E.B., 2007. Valuing ecosystem services as productive inputs. *Econ. Policy* 22 (49), 178–229. <https://doi.org/10.1111/j.1468-0327.2007.00174.x>.
- Barbier, E.B., 2015. Valuing the storm protection service of estuarine and coastal ecosystems. *Ecosyst. Serv.* 11, 32–38. <https://doi.org/10.1016/j.ecoser.2014.06.010>.
- Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* 81 (2), 169–193. <https://doi.org/10.1890/10-1510.1>.
- Barbier, E.B., Koch, E.W., Silliman, B.R., Hacker, S.D., Wolanski, E., Primavera, J., Granek, E.F., Polasky, S., Aswani, S., Cramer, L.A., Stoms, D.M., Kennedy, C.J., Bael, D., Kappel, C.V., Perillo, G.M.E., Reed, D.J., 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. *Science* 319 (5861), 321–323. <https://doi.org/10.1126/science.1150349>.
- Barbier, E.B., Cox, M., 2003. Does economic development lead to mangrove loss? A cross-country analysis. *Contemp. Econ. Policy* 21 (4), 418–432. <https://doi.org/10.1093/cep/byg022>.
- BCRD, 2018. Importancia Y Evolución Del Turismo En La República Dominicana 2012–2017. BCRD. <https://cdn.bancentral.gov.do/documents/sala-de-prensa/document/s/bc20181017-palabras.pdf?v=1564704000125>.
- BCRD, 2024. Sector turismo. Banco Central de la República Dominicana (BCRD). Retrieved 14-05-2024 from. <https://www.bancentral.gov.do/a/d/2537-secto-r-turismo>.
- Beck, M.W., Heck, N., Narayan, S., Menéndez, P., Reguero, B.G., Bitterwolf, S., Torres-Ortega, S., Lange, G.-M., Pflieger, K., Pietsch McNulty, V., Losada, I.J., 2022. Return on investment for mangrove and reef flood protection. *Ecosyst. Serv.* 56, 101440. <https://doi.org/10.1016/j.ecoser.2022.101440>.
- Beeharry, Y., Bekaroo, G., Bussoopun, D., Bokhoree, C., Phillips, M.R., 2021. Perspectives of leisure operators and tourists on the environmental impacts of coastal tourism activities: a case study of Mauritius. *Environ. Dev. Sustain.* 23 (7), 10702–10726. <https://doi.org/10.1007/s10668-020-01080-7>.
- Brander, L.M., Van Beukering, P., Cesar, H.S.J., 2007. The recreational value of coral reefs: a meta-analysis. *Ecol. Econ.* 63 (1), 209–218. <https://doi.org/10.1016/j.ecolecon.2006.11.002>.
- Brathwaite, A., Pascal, N., Clua, E., 2021. When are payments for ecosystem services suitable for coral reef-derived coastal protection?: a review of scientific requirements. *Ecosyst. Serv.* 49, 101261. <https://doi.org/10.1016/j.ecoser.2021.101261>.
- Breitung, J., Brüggemann, R., Lütkepohl, H., 2004. Structural vector autoregressive modeling and impulse responses. In: Lütkepohl, H., Krätzig, M. (Eds.), *Applied Time Series Econometrics*. Cambridge University Press, pp. 159–196. <https://doi.org/10.1017/CBO9780511606885.005>.
- Coria, J., Sterner, T., 2011. Natural resource management: challenges and policy options. *Annu. Rev. Resour. Econ.* 3, 203–230. <https://doi.org/10.1146/annurev-resource-083110-120131>, 3, 2011.
- Dao, P.B., Staszewski, W.J., Klepka, A., 2017. Stationarity-based approach for the selection of lag length in cointegration analysis used for structural damage detection. *Comput. Aided Civ. Infrastruct. Eng.* 32 (2), 138–153. <https://doi.org/10.1111/mice.12238>.
- Davenport, J., Davenport, J.L., 2006. The impact of tourism and personal leisure transport on coastal environments: a review. *Estuar. Coast Shelf Sci.* 67 (1), 280–292. <https://doi.org/10.1016/j.ecss.2005.11.026>.
- Diaye, M.-A., Ho, S.-H., Oueghlissi, R., 2022. ESG performance and economic growth: a panel cointegration analysis. *Empirica* 49 (1), 99–122. <https://doi.org/10.1007/s10663-021-09508-7>.
- Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. *J. Am. Stat. Assoc.* 74 (366a), 427–431. <https://doi.org/10.1080/01621459.1979.10482531>.
- Duarte, C.M., Dennison, W.C., Orth, R.J.W., Carruthers, T.J.B., 2008. The charisma of coastal ecosystems: addressing the imbalance. *Estuaries Coasts* 31 (2), 233–238. <https://doi.org/10.1007/s12237-008-9038-7>.
- Duffy, L.N., Stone, G., Charles Chancellor, H., Kline, C.S., 2015. Tourism development in the Dominican Republic: an examination of the economic impact to coastal households. *Tourism Hospit. Res.* 16 (1), 35–49. <https://doi.org/10.1177/1467358415613118>.
- Durr, R.H., 1992. An essay on cointegration and error correction models. *Polit. Anal.* 4, 185–228. <https://doi.org/10.1093/pan/4.1.185>.
- Eastwood, E.K., Clary, D.G., Melnick, D.J., 2017. Coral reef health and management on the verge of a tourism boom: a case study from miches, Dominican Republic. *Ocean Coast Manag.* 138, 192–204. <https://doi.org/10.1016/j.ocecoaman.2017.01.023>.
- Ekpe, E.K., 2013. A review of economic instruments employed for biodiversity conservation. *Consilience* (9), 16–32. <http://www.jstor.org/stable/26476123>.
- Elgin, C., Elveren, A.Y., 2024. Unpacking the economic impact of tourism: a multidimensional approach to sustainable development. *J. Clean. Prod.* 478, 143947. <https://doi.org/10.1016/j.jclepro.2024.143947>.
- Elias, A., Dachito, A., Abdulbari, S., 2023. The effects of currency devaluation on Ethiopia's major export commodities: the case of coffee and khat: evidence from the vector error correction model and the Johansen cointegration test. *Cogent Economics Finance* 11 (1), 2184447. <https://doi.org/10.1080/23322039.2023.2184447>.
- Engle, R.F., Granger, C.W.J., 1987. Cointegration and error correction: representation, estimation, and testing. *Econometrica* 55 (2), 251–276. <https://doi.org/10.2307/1913236>.
- Ericsson, N.R., 1992. Cointegration, exogeneity, and policy analysis: an overview. *J. Pol. Model.* 14 (3), 251–280. [https://doi.org/10.1016/0161-8938\(92\)90001-S](https://doi.org/10.1016/0161-8938(92)90001-S).
- Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C. S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.* 35, 557–581. <https://doi.org/10.1146/annurev.ecolsys.35.021103.105711>, 35, 2004.
- Galaitis, S.E., Corbin, C., Cox, S.A., Joseph, G., McConney, P., Cashman, A., Springer, C., Keenan, J., Cummings, C.L., Trump, B.D., Linkov, I., 2024. Balancing climate resilience and adaptation for Caribbean Small Island Developing States (SIDS): building institutional capacity. *Integrated Environ. Assess. Manag.* 20 (5), 1237–1255. <https://doi.org/10.1002/ieam.4860>.
- Granger, C.W.J., 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* 37 (3), 424–438. <https://doi.org/10.2307/1912791>.
- Hagger, V., Worthington, T.A., Lovelock, C.E., Adame, M.F., Amano, T., Brown, B.M., Friess, D.A., Landis, E., Mumby, P.J., Morrison, T.H., O'Brien, K.R., Wilson, K.A.,

- Zganjar, C., Saunders, M.I., 2022. Drivers of global mangrove loss and gain in social-ecological systems. *Nat. Commun.* 13 (1), 6373. <https://doi.org/10.1038/s41467-022-33962-x>.
- Herr, D., von Unger, M., Laffoley, D., McGivern, A., 2017. Pathways for implementation of blue carbon initiatives. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 27 (S1), 116–129. <https://doi.org/10.1002/aqc.2793>.
- Herrera Estévez, Y., 2022. *Functional study of resistance and resilience in mangrove ecosystems in the Dominican Republic* Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). Turrialba, Costa Rica. <https://repositorio.catie.ac.cr/handle/11554/12090>.
- Inoue, A., Kilian, L., 2013. Inference on impulse response functions in structural VAR models. *J. Econom.* 177 (1), 1–13. <https://doi.org/10.1016/j.jeconom.2013.02.009>.
- Johansen, S., 1988. Statistical analysis of cointegration vectors. *J. Econ. Dynam. Control* 12 (2), 231–254. [https://doi.org/10.1016/0165-1889\(88\)90041-3](https://doi.org/10.1016/0165-1889(88)90041-3).
- Johansen, S.R., 1991. Estimation and Hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica* 59 (6), 1551–1580. <https://doi.org/10.2307/2938278>.
- Jurgens, S.S., Mijts, E., Van Rompaey, A., 2024. Are there limits to the growth of tourism on the Caribbean islands? Case study Aruba [Original Research]. *Frontiers in Sustainable Tourism* 3. <https://doi.org/10.3389/frsut.2024.1292383>.
- Kanhai, L.D.K., Asmath, H., Gobin, J.F., 2022. The status of marine debris/litter and plastic pollution in the Caribbean Large Marine Ecosystem (CLME): 1980–2020. *Environ. Pollut.* 300, 118919. <https://doi.org/10.1016/j.envpol.2022.118919>.
- Kauffman, J.B., Heider, C., Norfolk, J., Payton, F., 2014. Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. *Ecol. Appl.* 24 (3), 518–527. <https://doi.org/10.1890/1360-0341.2013.0640.1>.
- Khan, A., Bibi, S., Li, H., Fubing, X., Jiang, S., Hussain, S., 2023. Does the tourism and travel industry really matter to economic growth and environmental degradation in the US: A sustainable policy development approach [Original Research]. *Front. Environ. Sci.* 11. <https://doi.org/10.3389/fenvs.2023.1147504>, 2023.
- Lamperti, F., Napoletano, M., Roventini, A., 2020. Green transitions and the prevention of environmental disasters: market-based vs. command-and-control policies. *Macroecon. Dyn.* 24 (7), 1861–1880. <https://doi.org/10.1017/S1365100518001001>.
- Landrigan, P.J., Stegeman, J.J., Fleming, L.E., Allemand, D., Anderson, D.M., Backer, L.C., Brucker-Davis, F., Chevalier, N., Corra, L., Czerucka, D., Bottein, M.Y.D., Demeneix, B., Depledge, M., Deheyn, D.D., Dorman, C.J., Fénichel, P., Fisher, S., Gaill, F., Galgani, F., Rampal, P., 2020. Human health and ocean pollution. *Ann. Glob. Health* 86 (1), 1–64. <https://doi.org/10.5334/aogh.2831>. Article 151.
- Leal, P.H., Marques, A.C., 2022. The evolution of the environmental kuznets curve hypothesis: a literature review from a critical analysis perspective. *Heliyon* 8 (11), e11521. <https://doi.org/10.1016/j.heliyon.2022.e11521>.
- Leotaud, N., Laidlow-Ferdinand, A., Clauzel, S., Vaughan, N., 2024. Towards sustainable blue tourism in the Caribbean: policy pathways to support community-based coastal and marine tourism. In: *Blue Tourism Initiative Diagnostic Study. CANARI: Port of Spain. The PDF*.
- Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J.R., Walker, B., 2013. Social-ecological systems as complex adaptive systems: modeling and policy implications. *Environ. Dev. Econ.* 18 (2), 111–132. <https://doi.org/10.1017/S1355770X12000460>.
- Ling, M., Xu, L., 2021. How and when financial incentives crowd out pro-environmental motivation: a longitudinal quasi-experimental study. *J. Environ. Psychol.* 78, 101715. <https://doi.org/10.1016/j.jenvp.2021.101715>.
- Lionetti, S., Gonzalez, O., 2012. On the relationship between tourism and growth in Latin America. *Tourism Hospit. Res.* 12 (1), 15–24. <https://doi.org/10.1177/1467358411429635>.
- Litzow, M.A., Hunsicker, M.E., 2016. Early warning signals, nonlinearity, and signs of hysteresis in real ecosystems. *Ecosphere* 7 (12), e01614. <https://doi.org/10.1002/ecs2.1614>.
- Liu, Z., Lan, J., Chien, F., Sadiq, M., Nawaz, M.A., 2022. Role of tourism development in environmental degradation: a step towards emission reduction. *J. Environ. Manag.* 303, 114078. <https://doi.org/10.1016/j.jenvman.2021.114078>.
- Lowitt, K., Ville, A.S., Lewis, P., Hickey, G.M., 2015. Environmental change and food security: the special case of small island developing states. *Reg. Environ. Change* 15 (7), 1293–1298. <https://doi.org/10.1007/s10113-015-0849-3>.
- Mancini, M.S., Galli, A., Niccolucci, V., Lin, D., Hanscom, L., Wackernagel, M., Bastianoni, S., Marchettini, N., 2017. Stocks and flows of natural capital: implications for ecological footprint. *Ecol. Indic.* 77, 123–128. <https://doi.org/10.1016/j.ecolind.2017.01.033>.
- Marena, U.A.S.D., Pnuma, 2010. Informe GEO República Dominicana 2010. Estado Y Perspectiva Del Medio Ambiente. <https://bvearmb.do/handle/123456789/4519>.
- Matias, T.P., Leonel, J., Imperador, A.M., 2022. A systemic environmental impact assessment on tourism in island and coastal ecosystems. *Environ. Dev.* 44, 100765. <https://doi.org/10.1016/j.envdev.2022.100765>.
- McGlathery, K.J., Reidenbach, M.A., D'Olorico, P., Fagherazzi, S., Pace, M.L., Porter, J. H., 2013. Nonlinear dynamics and alternative stable states in shallow coastal systems. *Oceanography (Wash. D. C.)* 26 (3), 220–231. <http://www.jstor.org/stable/24862085>.
- Menéndez, P., Losada, I.J., Beck, M.W., Torres-Ortega, S., Espejo, A., Narayan, S., Díaz-Simal, P., Lange, G.-M., 2018. Valuing the protection services of mangroves at national scale: the Philippines. *Ecosyst. Serv.* 34, 24–36. <https://doi.org/10.1016/j.ecoser.2018.09.005>.
- Meyer, C.A., 2020. Tourism and Economic Growth in the Dominican Republic: 1985–2018. *GMU Working papers in Economics Issue*. G. M. University. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3538902.
- MMARN/ORPALC/PNUMA, 2025. Informe GEO-2024 República Dominicana. <https://bvearmb.do/handle/123456789/>.
- Mullahy, John, Norton, Edward C., 2023. Why TransformY? The Pitfalls of Transformed Regressions with a Mass at Zero*. *Oxford Bulletin of Economics and Statistics* 86 (2), 417–447. <https://doi.org/10.1111/obes.12583>. <https://onlinelibrary.wiley.com/doi/10.1111/obes.12583>. (Accessed 14 November 2023).
- Nadler, S., Kros, J.F., 2007. Forecasting with excel: suggestions for managers. *Spreadsheets Educ.* 2 (2). <https://sie.scholasticahq.com/article/4545.pdf>.
- ONE, 2023. Boletín Censal X Censo Nacional De Población Y Vivienda 2022. ONE. <https://www.one.gob.do/media/Uhqd0F5b/boletin-censal-26.pdf>.
- Ouerfelli, C., 2008. Cointegration analysis of quarterly European tourism demand in Tunisia. *Tour. Manag.* 29 (1), 127–137. <https://doi.org/10.1016/j.tourman.2007.03.022>.
- Papana, A., Kyrtous, C., Kuejuntzis, D., Diks, C., 2023. Identification of causal relationships in non-stationary time series with an information measure: evidence for simulated and financial data. *Empir. Econ.* 64 (3), 1399–1420. <https://doi.org/10.1007/s00181-022-02275-9>.
- Papadimitis, E., Politis, D.N., 2018. The asymptotic size and power of the augmented dickey–fuller test for a unit root. *Econ. Rev.* 37 (9), 955–973. <https://doi.org/10.1080/00927872.2016.1178887>.
- Peralta Quesada, L., 2021. *Tourism in Central America and the Dominican Republic in the Face of Digital Technologies: Challenges and Opportunities for Msme's*.
- Peterson, R.R., 2023. Over the Caribbean top: community well-being and over-tourism in small island tourism economies. *International Journal of Community Well-Being* 6 (2), 89–126. <https://doi.org/10.1007/s42413-020-00094-3>.
- Pirró, M., Pereira, S., Gentile, C., Magalhães, F., Cunha, A., 2025. Damage detection under environmental and operational variability using the cointegration technique. *Eng. Struct.* 328, 119700. <https://doi.org/10.1016/j.engstruct.2025.119700>.
- Portella-Carbó, F., Pérez-Montiel, J., Ozelebi, O., 2023. Tourism-led economic growth across the business cycle: evidence from Europe (1995–2021). *Econ. Anal. Pol.* 78, 1241–1253. <https://doi.org/10.1016/j.eap.2023.05.011>.
- Pásková, M., Štekerová, K., Zanker, M., Lasisi, T.T., Zelenka, J., 2024. Water pollution generated by tourism: review of system dynamics models. *Heliyon* 10 (1), e23824. <https://doi.org/10.1016/j.heliyon.2023.e23824>.
- Rajapaksa, D., Gifford, R., Torgler, B., Garcia-Valinas, M., Athukorala, W., Managi, S., Wilson, C., 2019. Do monetary and non-monetary incentives influence environmental attitudes and behavior? Evidence from an experimental analysis. *Resour. Conserv. Recycl.* 149, 168–176. <https://doi.org/10.1016/j.resconrec.2019.05.034>.
- Rodríguez-Espíndola, O., Cuevas-Romo, A., Chowdhury, S., Díaz-Acevedo, N., Albore, P., Despoudi, S., Malesios, C., Dey, P., 2022. The role of circular economy principles and sustainability-oriented innovation in enhancing social, economic, and environmental performance: evidence from Mexican SMEs. *Int. J. Prod. Econ.* 248, 108495. <https://doi.org/10.1016/j.ijpe.2022.108495>.
- Roig-Munar, F.X., Martín-Prieto, J.Á., Rodríguez-Perea, A., Batista, Ó.O., 2018. Environmental analysis and classification of coastal sandy systems of the Dominican Republic. In: Botero, C.M., Cervantes, O., Finkl, C.W. (Eds.), *Beach Management Tools - Concepts, Methodologies and Case Studies*. Springer International Publishing, pp. 59–74. https://doi.org/10.1007/978-3-319-58304-4_4.
- Ruiz de Gauna, I., Greño, F., Torres, X., Galarra, L., 2024. *Economic Valuation of Ecosystem Services Provided by Blue Economy Ecosystems in the Dominican Republic*.
- Sarkodie, S.A., Strezov, V., 2019. A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. *Sci. Total Environ.* 649, 128–145. <https://doi.org/10.1016/j.scitotenv.2018.08.276>.
- Schubert, S.F., 2010. Coping with externalities in tourism: a dynamic optimal taxation approach. *Tour. Econ.* 16 (2), 321–343. <https://doi.org/10.5367/000000010791305626>.
- Selkoe, K.A., Blenckner, T., Caldwell, M.R., Crowder, L.B., Erickson, A.L., Essington, T.E., Estes, J.A., Fujita, R.M., Halpern, B.S., Hunsicker, M.E., Kappel, C.V., Kelly, R.P., Kittinger, J.N., Levin, P.S., Lynham, J.M., Mach, M.E., Martone, R.G., Mease, L.A., Salomon, A.K., Zedler, J., 2015. Principles for managing marine ecosystems prone to tipping points. *Ecosys. Health Sustain.* 1 (5), 1–18. <https://doi.org/10.1890/EHS14-0024.1>.
- Sherman, B.H., 2017. Multiple marine ecological disturbance assessments for large marine ecosystems in Latin America and the Caribbean. *Environ. Dev.* 22, 129–142. <https://doi.org/10.1016/j.envdev.2017.02.003>.
- Sherman, R.E., Fahey, T.J., Martinez, P., 2003. Spatial patterns of biomass and aboveground net primary productivity in a mangrove ecosystem in the Dominican Republic. *Ecosystems* 6 (4), 384–398. <http://www.jstor.org/stable/3659037>.
- Shortridge, J.E., Bukvic, A., Mitchell, M., Goldstein, J., Allen, T., 2024. Characterizing climatic socio-environmental tipping points in coastal communities: a conceptual framework for research and practice. *Earths Future* 12 (7). <https://doi.org/10.1029/2023EF004123>. e2023EF004123.
- Siggiridou, E., Kugiumtzis, D., 2016. Granger causality in multivariate time series using a time-ordered restricted vector autoregressive model. *IEEE Trans. Signal Process.* 64 (7), 1759–1773. <https://doi.org/10.1109/TSP.2015.2500893>.
- Spalding, M., Burke, L., Wood, S.A., Ashpole, J., Hutchison, J., zu Ermgassen, P., 2017. Mapping the global value and distribution of coral reef tourism. *Mar. Pol.* 82, 104–113. <https://doi.org/10.1016/j.marpol.2017.05.014>.
- Spencer, A., 2019. Climate change and the sustainable development of tourism within the Caribbean. In: Spencer, A. (Ed.), *Travel and Tourism in the Caribbean: Challenges and Opportunities for Small Island Developing States*. Springer International Publishing, pp. 27–46. https://doi.org/10.1007/978-3-319-69581-5_2.
- Steneck, R.S., Torres, R., 2023. Trends in Dominican Republic Coral Reef Biodiversity 2015–2022. *Diversity* 15 (3).

- Uchiyama, K., 2016. Environmental kuznets curve Hypothesis. In: Uchiyama, K. (Ed.), *Environmental Kuznets Curve Hypothesis and Carbon Dioxide Emissions*. Springer, Japan, pp. 11–29. https://doi.org/10.1007/978-4-431-55921-4_2.
- Wang, H., Zheng, Q., Li, S., Yang, X., 2021. The Closer, the Better? Modeling Spatial Spillover Effects of Ecological Externalities in Coastal Mangroves [Original Research]. *Front. Mar. Sci.* 8. <https://doi.org/10.3389/fmars.2021.708772>.
- Wielgus, J., Cooper, E., Torres, R., Burke, L., 2010. *Coastal capital: dominican Republic. Case Studies on the Economic Value of Coastal Ecosystems in the Dominican Republic*. Washington DC, USA. World Resources Institute.
- Williams, J.W., Cook, N.M., 2016. Econometrics as evidence? Examining the 'causal' connections between financial speculation and commodity prices. *Soc. Stud. Sci.* 46 (5), 701–724. <https://doi.org/10.1177/0306312716658980>.
- Winarno, S., Usman, M., Warsono, Kurniasari, D., Widiarti, 2021. Application of Vector Error Correction Model (VECM) and impulse response function for daily stock prices. *J. Phys. Conf.* 1751 (1), 012016. <https://doi.org/10.1088/1742-6596/1751/1/012016>.
- Wolf, F., Moncada, S., Surroop, D., Shah, K.U., Raghoo, P., Scherle, N., Reiser, D., Telesford, J.N., Roberts, S., Havea, P.H., Naidu, R., Nguyen, L., 2024. Small island developing states, tourism, and climate change. *J. Sustain. Tourism* 32 (9), 1965–1983. <https://doi.org/10.1080/09669582.2022.2112203>.
- Xu, C., Qin, B., Rawlings, D., 2022. Motivational crowding effects of monetary and nonmonetary incentives: evidence from a common-pool resources experiment in China. *Ecol. Econ.* 202, 107597. <https://doi.org/10.1016/j.ecolecon.2022.107597>.
- Xu, X., Fu, D., Su, F., Lyne, V., Yu, H., Tang, J., Hong, X., Wang, J., 2024. Global distribution and decline of mangrove coastal protection extends far beyond area loss. *Nat. Commun.* 15 (1), 10267. <https://doi.org/10.1038/s41467-024-54349-0>.
- Yamamoto, Y., 2023. Living under ecosystem degradation: evidence from the mangrove–fishery linkage in Indonesia. *J. Environ. Econ. Manag.* 118, 102788. <https://doi.org/10.1016/j.jeem.2023.102788>.
- Zivot, E., Andrews, D.W.K., 2002. Further evidence on the great crash, the oil-price shock, and the unit-root Hypothesis. *J. Bus. Econ. Stat.* 20 (1), 25–44. <https://doi.org/10.1198/073500102753410372>.
- Zou, X., 2018. VECM model analysis of carbon emissions, GDP, and international crude oil prices. *Discrete Dynam Nat. Soc.* 2018 (1), 5350308. <https://doi.org/10.1155/2018/5350308>.