Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Assessing Risk and Economic Losses from Coconut Rhinoceros Beetle in the Americas

Sulav Paudel

sulav.paudel@agresearch.co.nz

AgResearch

Trevor A. Jackson

AgResearch

Jhony A. Benavides-Bolaños

Ilse A. Huerta-Arredondo

Universidad de Guanajuato

Wilson Vásquez-Castillo

John M. Kean

AgResearch

Research Article

Keywords: Americas, Mexico, biosecurity, human-mediated transport pathways, climatic and host suitability modelling, introduction and establishment probability

Posted Date: June 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10010670/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Assessing Risk and Economic Losses from Coconut Rhinoceros Beetle in the Americas

Sulav Paudel[1*], Trevor A. Jackson[1], Jhony A. Benavides-Bolaños[2], Ilse A. Huerta-Arredondo[3] Wilson Vásquez-Castillo [4] & John M. Kean[1]

[1] Bioeconomy Science Institute, Tuhiraki, 19 Ellesmere Junction Road, Lincoln 7608, New Zealand

[2] Universidad del Valle, Calle 13 No. 100-00, Cali, 760032, Colombia

[3]University of Guanajuato, Ex Hacienda El Copal k.m. 9; carretera Irapuato-Silao; C.P. 36500; Irapuato, Guanajuato, Mexico

[4] Universidad de Las Americas, Vía Nayon l Redondel del Ciclista Quito, PC 170137 Ecuador

** Corresponding author: sulav.paudel@agresearch.co.nz*

ORCID ID: 0000-0002-7562-2846

Author Contributions

SP initiated this study. Data analyses were performed by SP and TJ, JABB, IHA and JMK wrote the draft manuscript. All authors read and approved the final manuscript.

Acknowledgement

Thanks to Dr Laura Villamizar (Bioeconomy Science Institute, New Zealand) for reviewing initial drafts and providing valuable feedback and suggestions.

Funding Declaration

This research received no specific grant from any funding agency.

Abstract

The coconut rhinoceros beetle (*Oryctes rhinoceros,* CRB) is a destructive pest of coconut and oil palms resulting in major production losses in Asia and the Pacific regions. The beetle has been spreading across the islands of the Pacific, and an established population was reported for the first time in the Americas, at Puerto Vallarta, Mexico in 2025. This study presents the first spatial explicit risk assessment of CRB across the Americas, using data on human-mediated transport pathways combined with climatic and host (coconut and oil palm) suitability to estimate relative introduction and establishment probability. The analysis identifies high-risk areas and priority sites for surveillance and targeted interventions to support early detection and rapid response. If CRB spreads further and establishes in the Americas, the potential annual economic losses across the region are estimated between 3 billion USD (low) and 8 billion USD (high), consistent with extensive damage observed in the Pacific. These findings underscore the urgency of proactive biosecurity measures to protect emerging palm industries and regional livelihoods.

Keywords

Americas, Mexico, biosecurity, human-mediated transport pathways, climatic and host suitability modelling, introduction and establishment probability

Introduction

Coconut rhinoceros beetle (*Oryctes rhinoceros*, CRB) is a chronic pest of palms in its endemic region of South/Southeast Asia (Bedford 1980). Over the last 100 years CRB has been spreading from Asia into the Pacific islands where its impact can be devastating (Paudel et al. 2022, 2023a; Marshall et al. 2023; Jackson et al. 2025a). This includes damage to both coconuts (*Cocos nucifera*) and oil palm (*Elaeis guineensis*) (Fig 1). In the last 20 years, it has been reported from different regions of South and North Pacific and was recently reported to have been established for the first time in the Americas, at Puerto Vallarta, Mexico (Jackson et al. 2025b). If the CRB invasion is not contained, the beetle poses a threat to palm production in the American neotropics.



Figure 1: Symptoms of rhinoceros beetle damage in coconut and oil palm. (A) Coconut palm: the larger panel on the left shows a healthy, undamaged palm, while the images on the right depict palms exhibiting characteristic damage symptoms, with an inset at the top right showing the adult beetle, , which are approximately 3-5 cm in length.. (B) Oil palm: similar comparison showing a healthy palm (left) alongside multiple examples of damaged palms displaying varying degrees of feeding injury.

Several invasive insect pests native to South and Southeast Asia have already caused severe economic and ecological impacts in the Americas, illustrating the potential threat posed by the arrival and establishment of CRB. For instance, the disease known as Huanglongbing, caused by the bacteria *Candidatus Liberibacter asiaticus* (CLas) and spread by the Asian citrus psyllid (*Diaphorina citri*), has devastated citrus industries in Brazil destroying more than 50 million trees (Bassanezi et al. 2020) and causing annual loss of USD 3.6 billion in the United States of America (Ghosh et al. 2022). Similarly, invasion of brown marmorated stink bug (*Halyomorpha halys*) in the US has resulted in significant economic losses in the mid-Atlantic region of the US with reported loss of USD 37 million to the apple industry alone in 2010 (Leskey and Nielsen 2018). Red palm weevil (*Rhynchophorus ferrugineus*), another palm pest from Southeast Asia, has killed thousands of ornamental palms in Uruguay and triggered emergency responses (Associated Press 2025). These examples highlight how invasive pests native to South and Southeast Asia can significantly disrupt livelihoods and economies in the region.

Neotropical America includes tropical and subtropical region from central Mexico through the Caribbean basin and the northern part of South America with large areas of coastal and lowlands that are suitable for CRB survival and establishment (Hao et al. 2022). These areas largely coincide with those where coconut palms are grown or are suitable for production (Descals et al. 2023), which play a major role in regional economies and food security. Oil palm plantations have been expanding rapidly in the Americas since the start of the 21st century with more than 1.7 million hectares under cultivation and gaining momentum, driven by rising global demand for palm oil and its economic benefits (Lesage et al. 2021; Feintrenie et al. 2025).

CRB is recognised as one of the major pests of coconut and oil palms through the Asia/Pacific region (Bedford 1980). In endemic and established regions, integrated pest management (IPM) reduce losses (Jackson et al. 2020) but can involve significant costs. In an uncontrolled scenario, especially in newly invaded areas, damage can be devastating. For coconuts, 50-70% palm death have been reported (Gressit 1953, Jackson et al. 2025a). In oil palm, CRB infestation can reduce oil palm fresh fruit bunch yield by up to 70-75%, with heavily infested palms producing only about one-quarter of the normal crop (Tarigan et al. 2026) and young palms may be heavily damaged or killed by beetle attack.

The arrival and establishment of CRB in Southern Mexico makes CRB a threat throughout Neotropical America, especially to those countries where coconut and oil palms have significant social and economic values and potential for development. Therefore, the aim of this study is to determine the risk of CRB spread within the Americas using a spatial model to identify high-risk areas and priority sites for surveillance and calculate potential economic losses should CRB spread uncontained.

Methods

CRB Risk model and predictor variables

Risks of biological invasion are typically assessed as a combination of transport networks, local climate suitability and host plant availability (Dupin et al. 2011; Cope et al. 2019). A

modified version of a spatial probability model (Paudel et al. 2026) was used to compute CRB risk scores. Risk was modelled at a 5 arcminute (~9.25 km) grid resolution by resampling or aggregating datasets to ensure spatial consistency across layers. For each grid cell, CRB invasion risk score *R* was estimated as the relative introduction pressure *I* and the local establishment potential *E*. These two components were multiplied to produce a raw CRB risk score, with scores forced to zero in areas where palm suitability was zero to avoid false positives in unsuitable habitat. The final CRB risk scores were used for mapping and to identify high-risk grid cells. By multiplying the scores, we assume that both introduction pressure and establishment potential are required for invasion. Since we are mapping invasion risk to identify high and low risk areas, relative scores are sufficient rather than precise estimates of probabilities.

The model estimates the likelihood of human-mediated introductions of CRB into uninfested areas from outside the Americas and its subsequent establishment and does not include natural dispersal (Paudel et al., 2026). It focuses on coconut and oil palm as primary hosts, assuming CRB cannot establish on less preferred palms or non-palm spillover hosts, which are only attacked when populations are very high.

Introduction Pressure (I)

The relative introduction pressure (*I*) was calculated as the sum of three pathways: *Port_Proximity*, *Road_Weight*, and *Human_Density. Port_Proximity and Human_Density* were treated as independent pathways because they can introduce CRB from distant regions to any areas regardless of land connectivity to the epicenter. However, road-based introduction is source-dependent (epicenter) and needs a continuous overland road network connecting to a source (e.g., southern United States, Central America). By adding *P*, *H* and *D*, we assume that either one can independently contribute to the relative introduction pressure.

$$\text{Relative Introduction Pressure (I)} = (\text{Port_Proximity } P + \text{Human_Density } H + \text{Road_Weight } D)$$

Port_Proximity P reflects the risk of introduction by passengers and cargo through seaports and airports (Liebhold et al. 2006; Kaluza et al. 2010; McNeill et al. 2011; Milián-García et al. 2025). Each grid cell was assigned a weight (0-1) based on both the type and proximity of the nearest port. The final score was calculated using an exponential decay function, where influence decreases with distance from the port. Locations of airports and seaports were obtained from Upply Open Data (https://opendata.upply.com/).

$$\text{Port_Proximity } P = \text{Base Score} \times \exp\left(-4.6 \frac{\text{Distance to Port}}{b}\right)$$

where the *base score* was 1.0 for large airports, 0.6 for medium airports, and 0.4 for small airports or seaports. *Distance to Port* is the straight-line distance from the cell to the nearest port, and *b* is the decay range parameter depending on port type (50 km for large, 30 km for medium, and 15 km for small). The decay parameters were chosen to reflect the assumed spatial influence, consistent with general distance-decay formulations in spatial interaction models (Fotheringham & O'Kelly, 1989).

Human_Density H represents invasion pathways associated with travel and mail. It also helps address the risks associated with isolated ornamental palms that are not captured by the *Palm_Cover C* factor below. Human population density data were log-transformed to normalize the distribution, then scaled to 0-1. Density data were obtained from the WorldPop Hub (WorldPop, and Bondarenko 2020).

$$\text{Human_Density } H = \frac{\log(\text{Population} + 1) - \min\big(\log(\text{Population} + 1)\big)}{\max\big(\log(\text{Population} + 1)\big) - \min\big(\log(\text{Population} + 1)\big)}$$

Road_Weight D represents risks associated with entry and subsequent transportation of commodities. *Road_Density Y* was weighted by Epicenter_Connectivity *E*, a distance decay function derived from the universal visitation law of human mobility (Schläpfer et al. 2021) As Road_Density is multiplied by Epicenter_Connectivity, Road_Weight will always contribute less or equal to Port_Proximity and Human_Density, while contribution from roads diminishing rapidly as the distance from epicenter increases, as expected of land spread. Therefore, the locations closer to Nayarit will experience disproportionately higher introduction pressure than distant locations. Road density data were extracted from 'OpenStreetMap' package. For each grid cell, total road lengths were summed, then normalized by dividing each grid's value by the country-specific maximum road length to create comparable weights (0-1). Road network data were downloaded from the Global Roads Inventory Project (GRIP) dataset (*www.globio.info*).

Epicenter_Connectivity E represents the degree of human mobility linkage between each location and the currently infested area in Nayarit, Mexico. Following the universal visitation law of human mobility (Schläpfer et al., 2021), Epicenter connectivity was calculated using the universal visitation law of human mobility that decreases as the inverse square of distance from the epicentre.

$$\text{Road_Weight } D = \text{Road Density R} \times \text{Epicenter Connectivity } E$$

$$\text{Road_Density } R = \frac{\text{Road Length in Cell}}{\text{Max Road Length in Country}}$$

$$\text{Epicenter_Connectivity } E = (\delta_0 / \Delta)^2$$

Where Δ is the Haversine distance (km) from each grid cell to the epicenter and δ_0 = 500 km is the reference distance at which connectivity is set to 1. Values were capped at 1 for any location within 500 km of the epicentre.

Establishment Potential (E)

The establishment score (*E)* was computed by multiplying the *Palm_Cover C* and the *Climate_Suitability S*. To avoid overestimating probabilities in areas unsuitable for CRB, grid cells with no palm cover were assigned to a final CRB score of zero.

$$\text{Establishment_Score (E)} = \text{Palm_Cover } C \times \text{Climate_Suitability } S$$

Palm_ Cover C represents the availability of host plants. The palm cover density score for each grid cell was computed by adding the log-transformed coconut and oil palm density values and normalizing the result to a 0–1 scale to generate a composite index. Coconut and oil palm density values were sourced from a global crop area dataset (IFPRI 2019).

Climate_Suitability *S* represents the climatic suitability for establishment and growth of CRB populations. The '*BIOCLIM*' model from the R package '*dismo*' (Hijmans et al. 2010) was used. Bioclimatic data (WorldClim v2.1 bioclimatic variables (BIO1–BIO19)) were downloaded and stacked to provide global climate predictors (Fick and Hijmans 2017). Confirmed CRB presence records were sourced from the Global Biodiversity Information Facility **(**GBIF) using '*rbif*' package (Chamberlain et al. 2012). The BIOCLIM algorithm was then fitted using the presence points to characterise the climatic suitability for CRB. The fitted model was projected across the global raster to generate a continuous suitability surface, which was normalised to a 0–1 scale.

Study areas

Model outputs were first mapped across the entire Americas to visualise the broad spatial distribution of predicted CRB risk. The analysis was then refined to six major coconut and oil palm producing countries to identify national-scale risk patterns and priority locations for surveillanceFor the top six countries, high-risk grid cells were identified for the top 10 grid cells with the highest CRB risk scores.

Economic loss estimation

Country-level coconut and oil palm production data for the Americas (2022/2023) were sourced from *Our World in Data* (https://ourworldindata.org). Copra and palm oil prices were obtained from *Selina Wamucii* (https://www.selinawamucii.com, accessed on 13 November 2025). These datasets were merged by country to allow calculation of the economic value of both commodities. Coconut production was first converted into copra-equivalent weight, assuming that 5 kg of coconut yields 1 kg of copra. The total value of copra and palm oil production was then estimated by multiplying production volumes (tonnes × 1,000 kg) by the respective market prices. The combined value for each country provided a baseline estimate of the economic importance of the two crops.

To estimate economic losses from CRB to palms, three damage scenarios were: 20% (low), 50% (medium), and 70% (high) reduction in production value. These scenarios reflect direct impacts on palm health and are consistent with impacts observed from historical and recent invasions in the Pacific (Gressitt 1953; Jackson et al. 2025a). Notably, these projected losses in the invasive range are significantly higher than those observed in CRB's native range – such as 10 % in countries like India and Indonesia on coconut palms and 25% for oil palm in Malaysia (Manjeri et al. 2014; Fauzana et al. 2018; Paudel et al. 2021). While these estimates summarize the broader fiscal impact, they represent primary crop losses that might be mitigated in the long term by IPM or crop diversification. Consequently, they do not account for other indirect shocks, such as impacts on local economies or to the considerable cultural value of coconuts to many societies (Bennett 2018). Economic losses (USD) under each scenario were calculated for each country in the study, and a regional total was added to summarise the broader economic impact.

Data processing and analysis

Data processing and analysis were done using the ‘dplyr’, ‘sf’, and ‘scales’ packages in Rstudio (R version 4.3.3) and visualized using ‘ggplot2’ package with the ‘viridis’ color scale (Wickham et al. 2007, 2011, 2014; Pebesma 2018). A complete set of outputs was generated to assess and visualize CRB risk across Americas. This included summary statistics for all key model components, and a series of spatial maps showing the distribution of each predictor variables and the final CRB score. In addition, high-risk grid cells were identified and visualized separately for the top 10 and 100 grid cells with the highest CRB risk scores.

Results

CRB Risk Maps

The CRB risk map shows clear spatial variation across the Americas, with highest predicted risk concentrated in humid tropical and subtropical regions. Areas of highest risk (of invasion and establishment) are predicted across Central America, the Caribbean, northern South America including large parts of Brazil (Fig. 2). The high-risk areas are particularly coastal and lowland regions with a high cover of palms and with human activity. Moderate risk is also evident in parts of southern Mexico and along the northern edge of South America. In contrast, temperate regions, including most of North America and the southern parts of South America, have little risk from CRB.

Spatial maps for key predictor variables (population density, port accessibility, road connectivity, palm cover density and climatic suitability) used in the current model are presented in Supplementary Fig. S1.

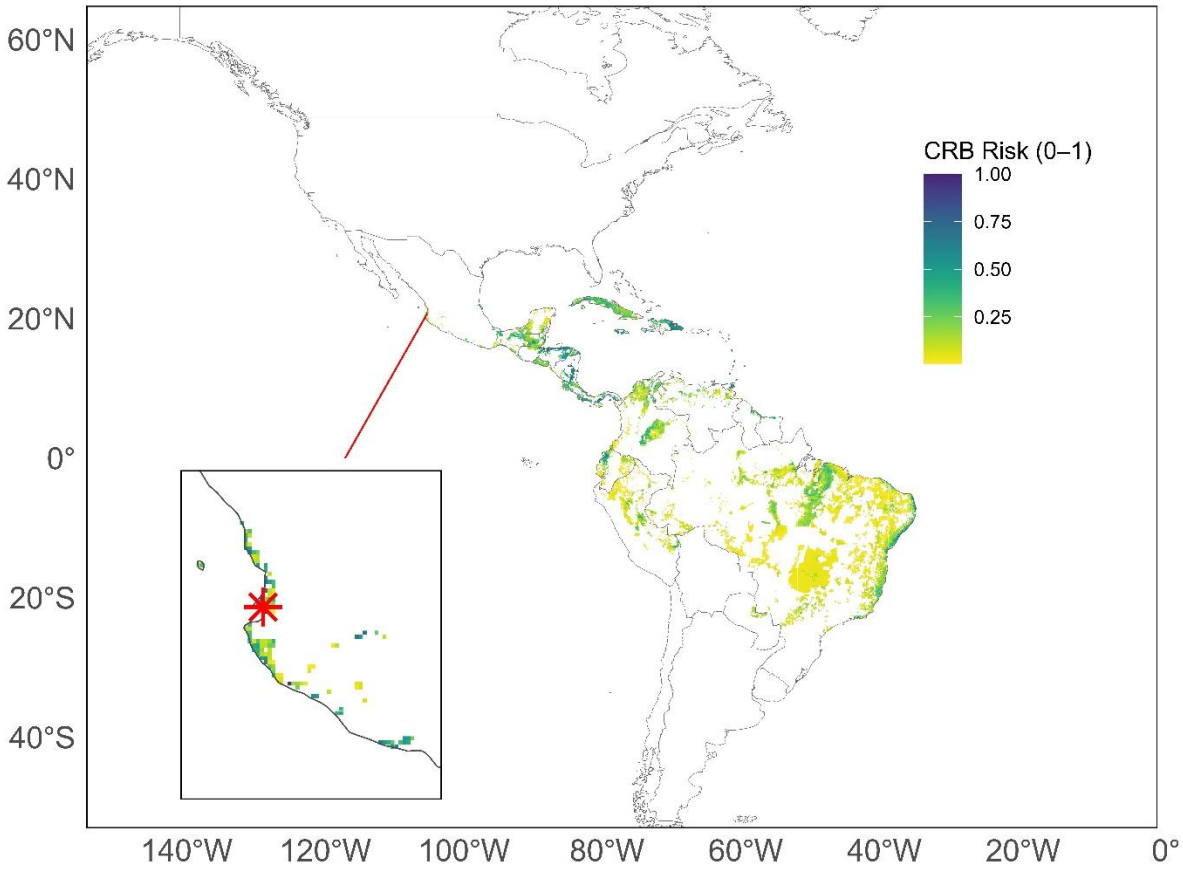


Figure 2. Spatial distribution of predicted Coconut Rhinoceros Beetle (CRB) invasion risk across the Americas. The map shows modelled CRB risk values scaled from 0 (low) to 1 (high), with areas shaded in yellow represent lower risk levels, while regions with green-blue indicate moderate to high risk. The red star marks the location of the first confirmed CRB detection in the Americas (Puerto Vallarta, Mexico). The lower-left inset shows a zoomed view of the Puerto Vallarta region to highlight local risk patterns, with a red arrow indicating its geographic position within the broader map.

The CRB risk maps for the six major coconut and oil palm producing countries in the Americas highlight distinct spatial patterns of vulnerability (Fig. 3). In Colombia and Ecuador, higher risk values are concentrated along coastal and lowland regions, with clusters of top-ranked high-risk sites occurring primarily in these areas. Brazil shows widespread low to moderate risk throughout the country, with higher risk patches and top-ranked sites mainly located in northern and gulf coast regions. In Mexico, elevated risk is largely confined to southern and southeastern regions, where all high-risk priority sites are concentrated. Honduras and Guatemala display comparatively broader areas of moderate to high risk, with multiple top-ranked sites distributed different regions.

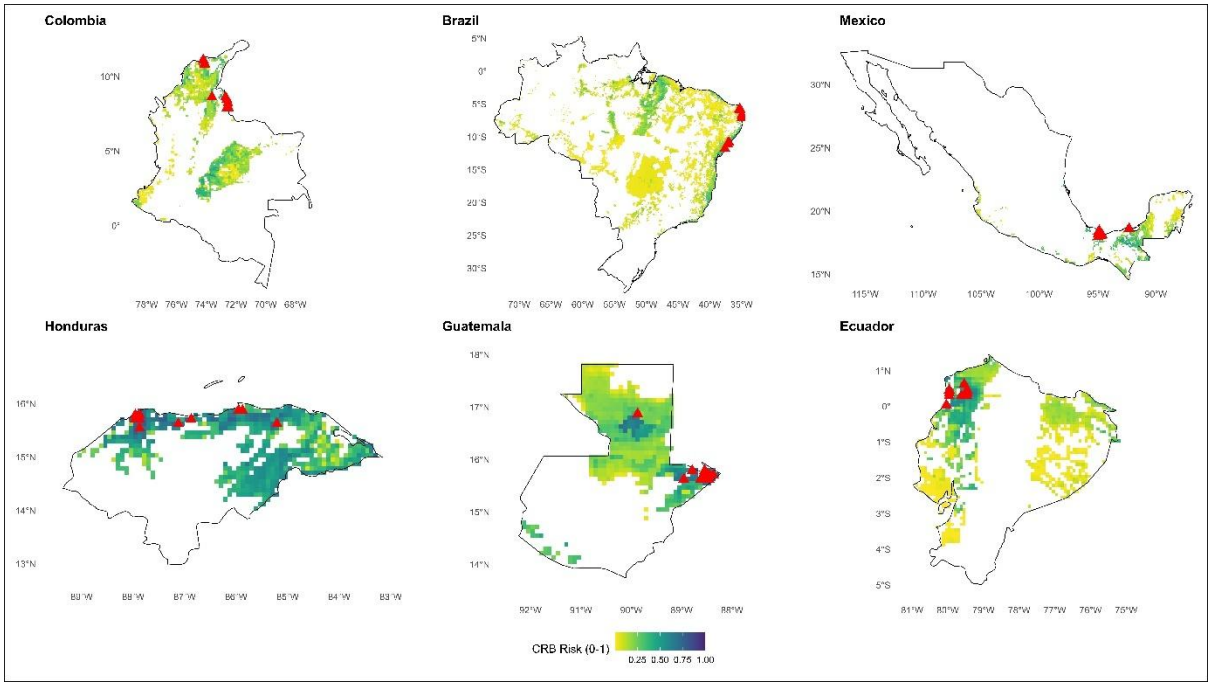


Figure 3. Spatial distribution of predicted Coconut Rhinoceros Beetle (CRB) risk six major coconut- and oil palm–producing countries in the Americas: Colombia, Brazil, Mexico, Honduras, Guatemala, and Ecuador. The map shows modelled CRB risk values scaled from 0 (low) to 1 (high), with areas shaded in yellow represent lower risk levels, while regions with green-blue indicate moderate to high risk. Red triangles indicate the top 10 highest-risk locations within each country based on CRB risk scores, suggesting priority areas where surveillance sites should be established.

Potential Economic Impacts

Coconut production is concentrated in Brazil (2.90 mt/yr) and Mexico (1.15 mt/yr), while palm oil production is highest in Colombia (1.77 mt/yr) followed by Guatemala (0.94 mt/yr), and Honduras (0.65 mt/yr) (Table S1). Copra prices vary widely; very high prices in Panama ($25.4) and Costa Rica ($8.0). Palm-oil prices are typically lower and more tightly clustered (generally ≤ ~USD 2 kg^{-1}), with notable highs in Guyana ($14.2) (Table S1).

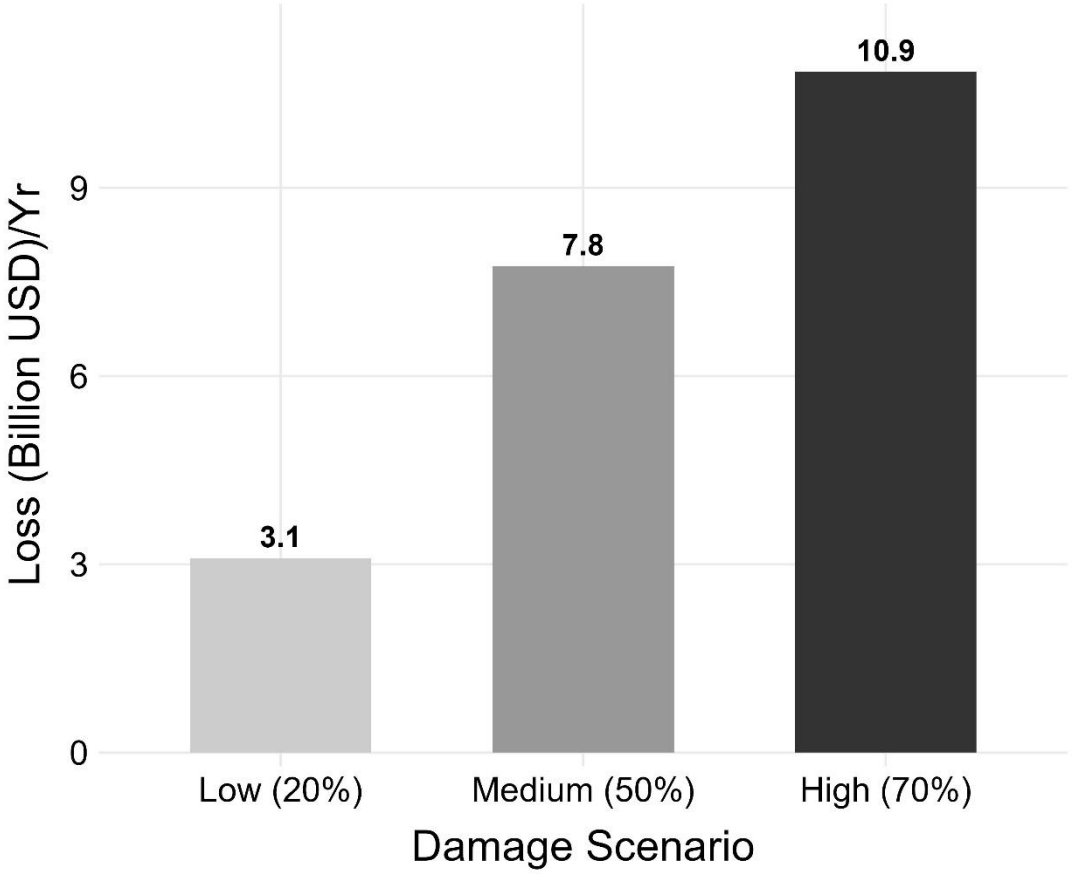


Figure 4: Estimated Regional Economic Impact of Coconut Rhinoceros Beetle (CRB) Infestation. Bars represent total losses in Billion USD per year across three damage scenarios and values above each bar indicate exact projected losses.

Under a low-damage scenario (20%), estimated losses reach approximately USD 3.1 billion, reflecting limited spread and moderate crop damage (Fig 4). A medium-damage scenario (50%) escalates losses to USD 7.8 billion, indicating significant disruption to coconut and oil palm production systems. In the high-damage scenario (70%), losses surge to over USD 10.9 billion, representing severe infestation levels comparable to worst-case outbreaks in the Pacific region.

Discussion

This study presents the first spatially explicit risk assessment of CRB across the Americas. By integrating human-mediated introduction risk factors with establishment potential based on host crop availability and climatic suitability, the analysis provides a continent-wide view of areas most vulnerable to CRB introduction and establishment. This is timely given the recent report of CRB from Mexico and the potential for substantial economic losses in the region (USD 3–10 billion), highlighting the importance of proactive surveillance, early detection, and preparedness in one of the major palm-producing regions. Once locally established, the high value of potentially impacted industries justifies investment to eradicate

(if possible), contain or slow the spread to other areas, similar to the spongy moth strategy in the US (Mayo et al. 2003).

The confirmation of CRB in southern Mexico has important implications for both national and regional biosecurity (Jackson et al. 2025b). Mexico is a major trade and transport hub in the Americas with high volumes of movement and trade that increases the likelihood of human-mediated spread of CRB to other parts of the country and to neighbouring regions. Due the proximity to the current invasion epicenter and trade connectivity, countries such as Honduras, Guatemala, and Ecuador face relatively higher CRB risk levels, making them particularly vulnerable to incursion and establishment. Therefore, Mexican biosecurity authorities (e.g., SENASICA: Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria) in coordination with stakeholders should immediately establish high-density pheromone traps in and around the Bahía de Banderas region (epicentre) and also along port perimeters(Paudel et al. 2023b). Additionally, a strict quarantine system should be established of all 'hitchhiker' pathways such as sea containers and plant/organic matter shipments originating from infested zones like Nayarit (Hoffmann et al. 2024). Aggressive sanitation of dead palms and organic heaps are required, as they serve as breeding sites, together with the application of entomopathogenic fungi (*Metarhizium majus*) will be critical to prevent further expansion and eradication efforts in already infested areas (Bedford 1980; Paudel et al. 2022). Frequent monitoring and surveillance using pheromone traps and photographic surveys of palms at high-risk sites identified (within Mexico and Americas) from the current study will be essential to ensure an early detection and rapid response. Regularly reviewing global biodiversity platforms such as the Global Biodiversity Information Facility (GBIF) and iNaturalist across the Americas is essential for detecting new CRB reports, as these datasets enabled early detection of the Mexico incursion (Jackson et al. 2022; González-Moreno et al. 2025). Coordination and information sharing at both national and regional levels including rapid reporting of new detections, data exchange on high-risk areas and commodities, and harmonized response protocols will be key to reducing the risk of onward spread and mitigating the broader economic and social impacts of CRB in the Americas.

Oil palm cultivation is gaining momentum in the Americas driven by rising global demand for palm oil and its economic benefits (Lesage et al. 2021; Feintrenie et al. 2025). Expansion plans often target tropical lowland regions that overlap with areas identified as moderate to high CRB risk in current analysis. While this growth presents significant economic opportunities, it also increases vulnerability to invasive pests such as CRB. If CRB establishes in the tropical Americas, it could severely damage young and mature palms, reduce yields and substantially increase replanting and management costs. It would be another hard hit to the oil palm industry which has been ravaged by bud rot (BR) with a significant reduction in production (Valdez-Torres et al. 2012; Sundram and Intan-Nur 2017). CRB may also exacerbate the damage by multiplying on the decaying fibres of the dead palms and possibly vectoring BR to uninfested palms. Experiences from the Pacific show that CRB infestations can lead to long-term production declines and multi-million-dollar losses (Marshall et al. 2023; Paudel et al. 2023a; Jackson et al. 2025a), which, if replicated in the Americas, could undermine the viability of the emerging oil palm industry and disrupt livelihoods.

The projected regional economic losses to palm products under CRB damage scenarios reveal substantial potential impacts. It is important to note that these estimates only account for production losses; additional economic impacts on tourism, landscaping, and other industries reliant on palms are not included, meaning the true cost could be considerably higher. For example, many coastal regions in the Caribbean basin and tropical Americas have resorts, golf courses and other attractions where palms are iconic and contribute significantly to the state's aesthetic value and tourism economy, making them vulnerable assets if CRB establishes.

This study highlights CRB risk across Neotropical America and provides guidance for identifying priority surveillance sites and targeted interventions. If no action is taken to prevent the spread and establishment of CRB, significant economic losses could occur consistent with experiences from the Pacific. Proactive biosecurity, early detection, eradication and containment measures are therefore critical to safeguard the emerging oil palm industry and protect livelihoods in the region.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information.

References

Associated Press (2025) Uruguay confronts a powerful new threat to its palm trees: A tiny red bug. Retrived from: https://apnews.com/article/uruguay-red-palm-weevil-parasite-south-america-agriculture-94b5f102bb49076e23247303c75aace3 23 September 2025

Bassanezi RB, Lopes SA, De Miranda MP, et al (2020) Overview of citrus huanglongbing spread and management strategies in Brazil. Trop Plant Pathol 45:251–264. https://doi.org/10.1007/s40858-020-00343-y

Bedford GO (1980) Biology, ecology, and control of palm rhinoceros beetles. Annu Rev Entomol 25:309–39. https://doi.org/10.1146/annurev.en.25.010180.001521

Bennett JA (2018) Pacific Coconut: Comestible, Comfort and Commodity. J Pac Hist 53:353–374. https://doi.org/10.1080/00223344.2018.1523705

Chamberlain S, Oldoni D, Waller J (2012) rgbif: Interface to the Global Biodiversity Information Facility API. 3.8.4

Cope RC, Ross JV, Wittmann TA, et al (2019) Predicting the Risk of Biological Invasions Using Environmental Similarity and Transport Network Connectedness. Risk Anal 39:35–53. https://doi.org/10.1111/risa.12870

Descals A, Wich S, Szantoi Z, et al (2023) High-resolution global map of closed-canopy coconut palm. Earth Syst Sci Data 15:3991–4010. https://doi.org/10.5194/essd-15-3991-2023

Dupin M, Brunel S, Baker R, et al (2011) A comparison of methods for combining maps in pest risk assessment: application to *Diabrotica virgifera virgifera*. EPPO Bull 41:217–225. https://doi.org/10.1111/j.1365-2338.2011.02466.x

Fauzana H, Sutikno A, Salbiah D (2018) Population fluctuations Oryctes rhinoceros L. beetle in plant oil palm (Elaeis guineensis Jacq.) given mulching oil palm empty bunch. Crop-J Plant Prot 1:42–47

Feintrenie L, Vázquez Navarrete CJ, Lagunes Espinoza LDC (2025) Americas, new world for a more sustainable palm oil. Cah Agric 34:11. https://doi.org/10.1051/cagri/2025009

Fick SE, Hijmans RJ (2017) WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. Int J Climatol 37:4302–4315. https://doi.org/10.1002/joc.5086

Ghosh D, Kokane S, Savita BK, et al (2022) Huanglongbing Pandemic: Current Challenges and Emerging Management Strategies. Plants 12:160. https://doi.org/10.3390/plants12010160

González-Moreno P, Anđelković AA, Adriaens T, et al (2025) Citizen science platforms can effectively support early detection of invasive alien species according to species traits. People Nat 7:278–294. https://doi.org/10.1002/pan3.10767

Gressitt JL (1953) The coconut rhinoceros beetle (Oryctes rhinoceros) with particular reference to the Palau Islands. Bernice P Bishop Museum Bulletin 212:1–157

Hao M, Aidoo OF, Qian Y, et al (2022) Global Potential Distribution of Oryctes rhinoceros, as predicted by Boosted Regression Tree Model. Glob Ecol Conserv e02175

421 Hijmans RJ, Phillips S, Leathwick J, Elith J (2010) dismo: Species Distribution Modeling. 1.3-16

422 Hoffmann B, Tay W, Blas A (2024) Biosecurity interceptions of coconut rhinoceros beetle
423 Oryctes rhinoceros. Management of Biological Invasions 15 (3): 437–443

424 IFPRI (2019) Global Spatially-Disaggregated Crop Production Statistics Data for 2010 Version
425 2.0: Spatial Production Allocation Model (SPAM) 2010

426 Jackson T, Kemoi M, Asigau B, et al (2025a) Coconut rhinoceros beetle, *Oryctes rhinoceros*
427 (Coleoptera: Scarabaeidae), continues to devastate coconut palms around Port
428 Moresby, Papua New Guinea. EPPO Bull 55:151–157. https://doi.org/10.1111/epp.13062

429 Jackson TA, Nájera-Rincón M, Paudel S, et al (2025b) Coconut rhinoceros beetle *Oryctes*
430 *rhinoceros* (Coleoptera: Scarabaeidae) confirmed in the Americas. EPPO Bull
431 epp.70014. https://doi.org/10.1111/epp.70014

432 Jackson TA, Rincón MN, Villamizar LF, Paudel S (2022) Social media posts suggest that coconut
433 rhinoceros beetle has established in the Western hemisphere. J Appl Entomol 147:19–
434 22. https://doi.org/10.1111/jen.13083

435 Kaluza P, Kölzsch A, Gastner MT, Blasius B (2010) The complex network of global cargo ship
436 movements. J R Soc Interface 7:1093–1103. https://doi.org/10.1098/rsif.2009.0495

437 Lesage C, Cifuentes-Espinosa J, Feintrenie L (2021) Oil palm cultivation in the Americas: review
438 of the social, economic and environmental conditions of its expansion. Cah Agric 30:27.
439 https://doi.org/10.1051/cagri/2021015

440 Leskey TC, Nielsen AL (2018) Impact of the Invasive Brown Marmorated Stink Bug in North
441 America and Europe: History, Biology, Ecology, and Management. Annu Rev Entomol
442 63:599–618. https://doi.org/10.1146/annurev-ento-020117-043226

443 Liebhold AM, Work TT, McCullough DG, Cavey JF (2006) Airline Baggage as a Pathway for Alien
444 Insect Species Invading the United States. Am Entomol 52:48–54.
445 https://doi.org/10.1093/ae/52.1.48

446 Manjeri G, Muhamad R, Tan SG (2014) Oryctes rhinoceros beetles, an oil pest in Malaysia. Annu
447 Res Rev Biol 4:3429–3439

448 Marshall SDG, Paudel S, Mansfield S, et al (2023) Coconut rhinoceros beetle in Solomon
449 Islands: a tale of two invasions. Biol Invasions 1–20

450 Mayo JH, Straka TJ, Leonard DS (2003) The Cost of Slowing the Spread of the Gypsy Moth
451 (Lepidoptera: Lymantriidae). J Econ Entomol 96:1448–1454.
452 https://doi.org/10.1093/jee/96.5.1448

453 McNeill M, Phillips C, Young S, et al (2011) Transportation of nonindigenous species via soil on
454 international aircraft passengers' footwear. Biol Invasions 13:2799–2815.
455 https://doi.org/10.1007/s10530-011-9964-3

456 Milián-García Y, Pyne C, Chen A, et al (2025) Uncovering the hidden within shipping containers:
457 molecular biosurveillance confirms a pathway for introducing multiple regulated and
458 invasive species. Biol Invasions 27:91. https://doi.org/10.1007/s10530-025-03549-w

Paudel S, Jackson TA, Boulekouran S, et al (2023a) The coconut rhinoceros beetle (Oryctes rhinoceros) outbreak is well established on Efate, Vanuatu. EPPO Bull 53:404–410. https://doi.org/10.1111/epp.12930

Paudel S, Jackson TA, Mansfield S, et al (2023b) Use of pheromones for monitoring and control strategies of coconut rhinoceros beetle (Oryctes rhinoceros): A review. Crop Prot 174:. https://doi.org/10.1016/j.cropro.2023.106400

Paudel S, Kean JM, Phillips CB, et al (2026) A Spatial Probability Model for the Arrival and Establishment of Coconut Rhinoceros Beetle

Paudel S, Mansfield S, Villamizar LF, et al (2021) Can biological control overcome the threat from newly invasive coconut rhinoceros beetle populations (Coleoptera: Scarabaeidae)? A review. Ann Entomol Soc Am 114:247–256. https://doi.org/10.1093/aesa/saab015

Paudel S, Marshall SD, Richards NK, et al (2022) Coconut Rhinoceros Beetle in Samoa: Review of a Century-Old Invasion and Prospects for Control in a Changing Future. Insects 13:. https://doi.org/10.3390/insects13050487

Pebesma E (2018) Simple Features for R: Standardized Support for Spatial Vector Data. R J 10:439. https://doi.org/10.32614/RJ-2018-009

Schläpfer M, Dong L, O'Keeffe K, et al (2021) The universal visitation law of human mobility. Nature 593:522–527. https://doi.org/10.1038/s41586-021-03480-9

Sundram S, Intan-Nur AMA (2017) South American Bud rot: A biosecurity threat to South East Asian oil palm. Crop Prot 101:58–67. https://doi.org/10.1016/j.cropro.2017.07.010

Tarigan AA, Tarigan Z, Tiarman FA, et al (2026) Relationship Between the Population of Oryctes rhinoceros and the Extent of Frond Damage and Fresh Fruit Bunch Yield in Oil Palm (Elaeis guineensis Jacq.). In: Afrianti S, Pratomo B (eds) Proceedings of the 1st International Conference of Technology, Innovation, Design & Enterprise (ICTIDE 2025). Atlantis Press International BV, Dordrecht, pp 161–169

Valdez-Torres JB, Soto-Landeros F, Osuna-Enciso T, Báez-Sañudo MA (2012) Phenological prediction models for white corn (*Zea mays* L.) and fall armyworm (*Spodoptera frugiperda* J.E. Smith). Agrociencia 46:399–410

Wickham H, Chang W, Henry L, et al (2007) ggplot2: Create Elegant Data Visualisations Using the Grammar of Graphics. 4.0.1

Wickham H, François R, Henry L, et al (2014) dplyr: A Grammar of Data Manipulation. 1.1.4

Wickham H, Pedersen TL, Seidel D (2011) scales: Scale Functions for Visualization. 1.4.0

WorldPop,, Bondarenko M (2020) Individual Countries 1km UN Adjusted Population Density (2000-2020)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- supplementaryinfo12062026.docx