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Assessing Habitat Suitability for the Invasive Species *Lantana camara* on Bali Island: A Model Using the Biodiversity and Climate Change Virtual Laboratory (BCCVL)

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Abstract

Indonesia, known for its high biodiversity, is threatened due to alien plants that invade local plant species in forest areas. West Bali National Park is overgrown with invasive exotic plants, such as Lantana camara L.*, known locally as the kembang telek. The research aims to predict the distribution of L. camara using species distribution models* (*SDMs*) *and analysis variable contribution in the model featured in the biodiversity climate change virtual laboratory* (*BCCVL*) *application. L. camara distribution prediction model in Bali used the Bioclim data input by identifying areas of low, medium, and high habitat suitability. Central mountainous regions, including parts of Buleleng, Jembrana, Bangli, Karangasem, and Tabanan, show the highest suitability. Response curves demonstrated the correlation between climate variables and occurrence probability, highlighting the specific condition of rainfall and temperature ranges favoring Lantana's growth. The model showed a reliable AUC value of 0.89, indicating realibility. Potential improvements through additional environmental parameters were suggested. While L. camara has some potential benefits as a medicinal plant in Balinese culture, its invasive nature poses significant threats to native ecosystems. The predictive map offers valuable insights for authorities to implement initiative-taking strategies for preventing and controlling Lantanas spread in vulnerable areas of Bali.*

Keywords: *bioclim, distribution, prediction, invasive alien species, kembang telek*

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Introduction

Indonesia's remarkable flora diversity arises from its geographical location, variety of islands, and diverse ecosystems (Kusmana & Hikmat, 2015). Still, despite this potential, there are also threats to native plant ecosystems due to the presence of invasive plants that dominate (Tjitrosoedirdjo, 2005; Septiadi et al., 2018; Mukaromah & Imron, 2020). Refer to (Tjitrosoedirdjo, 2005) catalog of 75 plants as invasive alien species (IAS) that must be controlled. Invasive alien plants can grow and reproduce outside their natural habitat. They can disrupt the ecosystem and seriously challenge native plants (Srivastava et al., 2014). Understanding invasive plants' distribution and habitat suitability is crucial for effective control strategies. In addition, climate change has been proposed as one potential driver of invasive species spread and dominance, with warming potentially unevenly favoring invasive plants (Dukes et al., 2009; Taylor et al., 2012; Mungi et al., 2018). Note that foreign plant species and native plants under favorable conditions can become invasive, either directly or indirectly (Alpert et al., 2000).

Plant distribution patterns in nature, including invasive alien plants, can vary from random to uniform and clumped (Odum, 1994; Baddeley, 2010; Izadi & Keshtkar, 2020). Random distribution occurs in homogeneous environments, with individuals dispersed throughout the study area. Uniform distribution exhibits clustering within specific portions due to environmental heterogeneity and strong individual competition. Clumped distribution is a form of heterogeneous environment wherein close proximity points show pronounced interdependence (Izadi & Keshtkar, 2020; Nurlaila et al., 2020). A confluence of environmental factors, climate variables, geographic proximity, and the influence of human activities impacts the distribution of invasive alien species (Hsu et al., 2022; Waheed et al., 2023; Chen et al., 2023). Understanding these spatial patterns is important for control efforts. This study focuses on *Lantana camara* L., a globally widespread invader as an invasive alien plant (Mukherjee et al., 2022). It is nominated as one of the 100 worst invasive alien species and ranked 15th among terrestrial plants by the IUCN (Seid & Bekele, 2023; GISD, 2024).

Originally, it is a native tropical American plant, and its distribution is now expanding widely throughout Africa, Australia, and Asia at an alarming rate, which poses a major obstacle to preserving native ecosystems (Sangita et al., 2020; Taneja et al., 2022). It can adapt quickly to various habitats, including areas with heavy rainfall and partially shaded environments (Carrión-Tacuri et al., 2011; Taylor et al., 2012). The distribution of *L. camara* is influenced by climate conditions, temperature, humidity, and rainfall; its development will be faster in areas with medium altitudes (Ndlovu & Shoko, 2023; Joshi et al., 2024). This plant can negatively impact native plants, outcompeting them for resources (food sources, space, light, and water) and better adapting to climate change, leading to their domination (Gooden et al., 2009; Taylor et al., 2012). The invasive plant *L. camara* suppresses the presence and diversity of other species, significantly impacting their distribution and composition, while its widespread proliferation can inhibit the regeneration of rainforests for up to three decades (Septiadi et al., 2018; Bayu et al., 2023).

L. camara is an invasive alien plant species with concerning distribution in Indonesia (Abywijaya et al., 2014; Septiadi et al., 2018; Sulistiyowati et al., 2021). The evergreen *L. camara* has high allelopathic properties and allelochemicals that can inhibit other plant growth. *L. camara* needs serious attention because of its high adaptability to various ecosystem conditions, threatening biodiversity, and allelopathy, which disrupts native flora and is supported by climate change (Kishore et al., 2024). For example, research shows that *L. camara* leaf extracts suppress weeds in tea plantations (Darana, 2006). Moreover, *Lantana* is ranked among the top three most severe weeds affecting Indonesian coffee production (Nanjappa et al., 2005). (Padmanaba et al., 2017) reported that it had invaded eight national parks: Baluran, Alas Purwo, Meru Betiri, Bromo Tengger Semeru, Merbabu, Merapi, Gede Pangrango, and Ujung Kulon. *L. camara's* wide distribution in Java indicates an invasion risk for neighboring Bali, exacerbated by observations of major *L. camara* clusters in West Bali National Park (TNBB) (Kundariati et al., 2021). Prior research has indicated the extensive presence of *L. camara* in vegetation around the Unda River Estuary in Klungkung Regency, with an importance value index (IVI) ranging from 12–32% (Wijaya et al., 2021). *L. camara* is also found in the Batukahu natural forest (Mukaromah & Imron, 2020). Additionally, lantadine toxins from *L. camara* ingestion by livestock has caused poisoning in bali cattle (Leestyawati, 2015). Hence, understanding the spatial patterns and prediction of *L. camara* in Bali, known locally as the *kembang telek*, is highly important to inform the local government for faster weed control management, protection of native plants, and to avoid further spread to other protected forest areas in Bali.

Climate change may enable the further spread of invasive plants like *L. camara* (Dukes et al., 2009; Taylor et al., 2012). To predict the potential spread of invasive alien plants like *L. camara* under changing climate conditions, species distribution models (SDMs) are a valuable projection tool (Sutomo & van Etten, 2017). SDMs help pinpoint areas susceptible to invasion by invasive alien species. By using SDMs, the potential range of invasive plants like *L. camara* can be predicted, thereby enabling the authorities to take proactive steps to prevent the spread of such species. However, research on SDMs for *L. camara*, is limited in the global scope (Taylor et al., 2012; Qin et al., 2016). Given the concerning invasiveness of *L. camara*, it is necessary to investigate the potential spread of this plant in Indonesia at the island level to achieve greater precision that aligns with the unique land geography.

This study aims to predict *L. camara*'s distribution areas using SDMs analysis and identify susceptible variables that contributed to the model by employing the BCCVL application. Findings aim to support local management in tackling this invasive threat to tropical ecosystems. Specifically, this study is expected to provide a prediction map of the distribution of the invasive alien plant *L. camara* in Bali, focusing on identifying its potential to dominate local habitats.

Methods

Study area This study covers Bali Province, situated at coordinates S08°03'40"–S08°50'48" latitude and E114°25'53"–E115°42'40" longitude, with a total provincial area of 5,636.66 km². Bali is a constituent of the Lesser Sunda Islands, measuring approximately 153 km in length and 112 km in width, and is located about 3.2 km from Java Island (Tarubali, 2023). The Bali region generally experiences a tropical climate influenced by seasonal winds. Bali experiences a clearly defined dry and wet season, interspersed with transitional periods. The average annual temperature in 2018–2022 is 27.7 °C, with an average humidity of 79%, air pressure of 1,008.90 mb, wind speed of 6 knots, annual rainfall of 1,477.70 mm, and 60% sunlight exposure (BMKG Bali, 2023).

Occurrence and environmental data An open-source application (www.bccvl.org.au) was utilized for the habitat suitability modeling analysis (Hallgren et al., 2016). The source options of the species occurrence data were available in the BCCVL, which provides a link to import species occurrence data from the Global Biodiversity Information Facility (GBIF), an international open-source database (GBIF Secretariat, 2021). GBIF's database integrates data from diverse sources as a collaborative effort, including natural history collections, research observations, and citizen science efforts, ensuring free and open access to global biodiversity information rather than relying solely on field measurements.

This study utilized existing *L. camara* records for Bali from the GBIF database. Field sampling was not done due to resource constraints, but the thousands of GBIF records provided sufficient modeling data. The database contained approximately 68,094 records of *L. camara* occurrences, but not all of the data is complete with coordinate data, where only 59,524 records are recorded that are geographically referenced (GBIF, 2023). Therefore, these data, as coordinated data would be processed in the following model analysis.

The species occurrences in Bali were used as input in the BCCVL. Meanwhile, BCCVL also provides environmental data layers on its platform, with various lists of climate layers from climate databases. This study utilized environmental data from the Worldclim database (1950–2000) at a spatial resolution of 30 seconds (± 1 km) as predictor variables.

Distribution modeling This study utilized the Bioclim

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approach to model the spread of the invasive alien plant *L. camara*. Species occurrence data was integrated with environmental variables to produce a predicted distribution map for *L. camara* in Bali. Bioclim was selected for its niche modeling capabilities relating species occurrences to environmental factors, an established method for habitat suitability modeling (Booth et al., 2014). Bioclim creates a multidimensional environmental space for a species using occurrence data and predicts the probability of species occurrences at a given location by comparing the values of environmental variables to the percentile distribution from known locations (Phillips et al., 2006; Araújo & Peterson, 2012). The model incorporated climate variables, such as rainfall and temperature, encompassing temperature seasonality, annual rainfall, precipitation levels during the wettest and driest months, seasonal precipitation, and precipitation during the wettest, driest, warmest, and coldest quarters. The worldclim data for Indonesia show that several climate data has non-collinear to other variables, which are precipitation and temperature, especially Bio2, Bio3, Bio4, Bio15, Bio18, and Bio19. Even though precipitation has a lower correlation than temperature, which is reliable to use it beside other variable that have collinear with it (Pradhan & Setyawan, 2021).

The BCCVL analysis provides several results, including the variable response curves, which describe the response of *L. camara* to environmental parameters, the receiver operating characteristic (ROC) curve that evaluates the prediction model's sensitivity and specificity, and the species distribution model (SDM) map in TIFF format. The reliability of each location on the map was evaluated by measuring the area under curve (AUC) value, with higher values indicating more reliable models. The SDM map was further processed in the ArcGIS application (Phillips et al., 2006). Model performance was interpreted based on AUC scores, classified according to (Hosmer et al., 2013). The performance was determined to be outstanding (0.9–1.0), excellent (0.8–0.9), acceptable (0.7–0.8), poor (0.6–0.7), and no discrimination (<0.6).

Results and Discussion

The prediction map shows a habitat suitability index in gradient colors, referring to an area's capacity to provide necessary biological and ecological conditions to sustain a particular species (di Cola et al., 2017). The classes (Figure 1) range from green (low, 0–0.25) to orange (moderate, 0.25–0.50) to red (high, 0.50–0.75), based on temperature and rainfall variables. Low indicates an unsuitable habitat for invasive alien plants *L. camara*, medium denotes an appropriate habitat, and high indicates a very suitable habitat. The SDM analysis employed eight environmental variables related to climate, namely temperature and rainfall, as crucial factors influencing *L. camara* distribution (Taylor et al., 2012; Zhang et al., 2014).

Figure 1 depicts the areas with the highest suitability predictions, such as Buleleng, Jembrana, Bangli, Karangasem, and Tabanan. The prediction for this species is that it is highest in the central area of the island of Bali. This location is a protected and conservation forest area whose topography is generally mountainous and characterized by

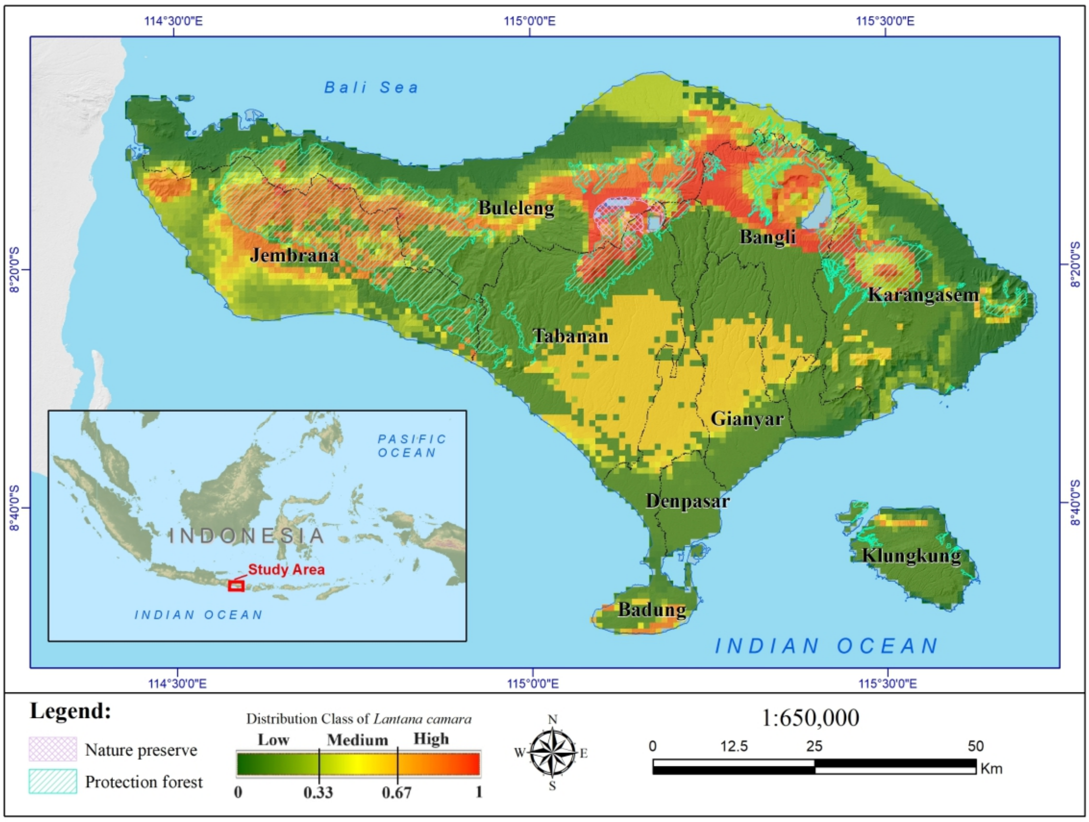


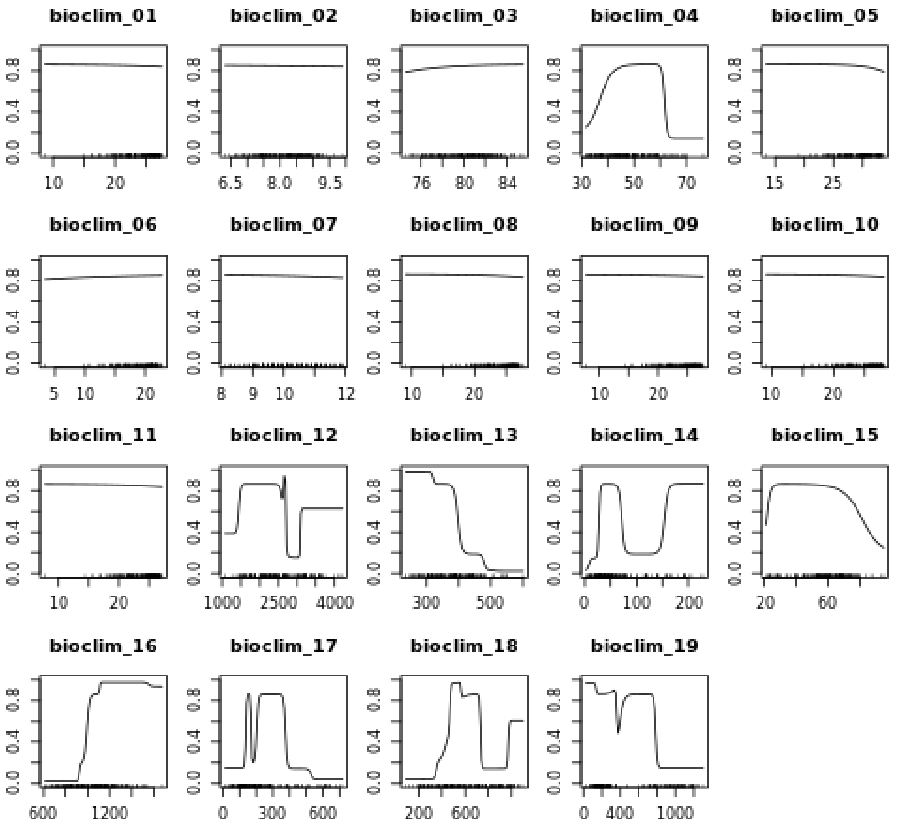
Figure 1 Distribution prediction map of *Lantana camara* in Bali Island using the Bioclim method in BCCVL.

cool temperatures with less humidity than the area below. This condition is of particular concern considering that this species has invasive potential, which can disrupt the continuity of diversity in a forest community, and the more the area experiences disturbance, which results in a more open area, the more potential this species has to develop.

The distribution of *L. camara* in the medium class is mostly found in the middle to lower elevation of Bali Island, namely in Tabanan, Badung, and Gianyar (Figure 1). This type of distribution is also almost not found in coastal areas characterized by hotter environmental temperatures. Coastal regions show low suitability partly due to *L. camara's* limited tolerance for saline soils (Nanjappa et al., 2005; Sharma et al., 2005). *L. camara* can withstand humid and dry heat conditions but is vulnerable to frost and low temperatures (Nanjappa et al., 2005; Sharma et al., 2005).

L. camara can invade a broad range of habitats due to its ability to withstand diverse environmental conditions. However, it favors disturbed areas and rarely thrives under a dense canopy because it requires direct sunlight for optimal growth. Such suitable habitats include wastelands, pastures, cultivated areas, forest edges, recently burned sites, and cleared logging areas (Sharma et al., 2005; Samarajeewa, 2017).

Response curves in Figure 2 depict the relationship between *L. camara* occurrence probability and specific environmental factors. The condition precipitation parameters, especially rainfall in the wettest month, rainfall in the driest month, rainfall of seasonality, rainfall coldest, and rainfall warmest, showed the strongest correlations with habitat suitability according to the curves. Response curves are frequently used in SDM to explore the correlation



Where:
bioclim_01 = Annual Mean Temperature
bioclim_02 = Mean Diurnal Range
bioclim_03 = Isothermality
bioclim_04 = Temperature Seasonality
bioclim_05 = Max Temperature of Warmest Month
bioclim_06 = Min Temperature of Coldest Month
bioclim_07 = Temperature Annual Range (BIO5-BIO6)
bioclim_08 = Mean Temperature of Wettest Quarter
bioclim_09 = Mean Temperature of Driest Quarter
bioclim_10 = Mean Temperature of Warmest Quarter
bioclim_11 = Mean Temperature of Coldest Quarter
bioclim_12 = Annual Precipitation
bioclim_13 = Precipitation of Wettest Month
bioclim_14 = Precipitation of Driest Month
bioclim_15 = Precipitation Seasonality
bioclim_16 = Precipitation of Wettest Quarter
bioclim_17 = Precipitation of Driest Quarter
bioclim_18 = Precipitation of Warmest Quarter
bioclim_19 = Precipitation of Coldest Quarter

Figure 2 Response curve from variables used (red square having high respon) in the model of *Lantana camara* distribution in Bali using the Bioclim method in BCCVL.

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between a species and its environment, helping to determine essential factors influencing species distribution and predicting potential impacts of environmental changes.

The Bioclim variable thrives optimally at B04 and then B12 to B19 from the nineteen Bioclim variables. The curves indicate that *L. camara* thrives optimally in temperature seasonality (B04) in a range of 40–60. The B04 calculation indicated the standard deviation value of the average temperature for each month of the year. The resulting range of values is 40-60, indicating conditions of variation in the medium class, meaning that seasonality allows this type to survive environmental temperature without changes too extreme (Figure 2). Data for B04 has resulted from a standard deviation of seasonal temperature. Furthermore, *Lantana*'s invasiveness is highly associated with high rainfall, as shown by the annual rainfall response curve, indicating high suitability at 1,500–2,500 mm year^{-1} (Figure 2). Understanding the wettest and driest months (B13 and B14) is crucial for determining potential *L. camara* invasion periods. Bali's wettest month is October (544.13 mm), and the driest month is July (17.43 mm) (BPS Bali, 2023). The response curves show an optimum range of 300–400 mm for the wettest month and 30–70 mm for the driest month of rainfall. This result indicates *L. camara*'s reliance on water availability for photosynthesis and food production. Then, the response of the model with the AUC value of invasive alien species (IAS), *L. camara* has 0.89 (Figure 3) indicating reliability. Rainfall conditions in the dry season quarters on the island of Bali (tropical area) still indicate quite high amounts of rain in the response display from B17–B18 (Figure 2). This condition means that regions of Bali are suggested to have suitable habitats for *L. camara* to develop.

L. camara is significantly affected by various environmental conditions in its non-native environments, and these effects have substantial consequences for native ecosystem conservation. Temperature and precipitation are significant ecological elements that might limit *L. camara*'s optimal growth, and understanding these constraints is critical to effectively controlling this invasive alien species. This information from our study can be used to identify and prioritize places where *L. camara* is more likely to thrive and spread in managing this invasive species.

Although *L. camara* only invades several areas in Bali such as the Unda River estuary and Batukahu natural forest (Mukaromah & Imron, 2020; Wijaya et al., 2021), it has the potential to spread further to other areas in Bali. Based on this prediction map, appropriate and rapid action is needed to prevent worse impacts from the invasion of the *L. camara* species and protect the biodiversity on Bali Island. Without control, the *L. camara* population will continue to increase and the invasion area will be wider. This will threaten the survival of native species and disrupt the balance of the forest ecosystem. *L. camara* control in targeted habitats is expected to increase program effectiveness (Tarugara et al., 2022). Conservationists and land managers can more effectively eradicate or restrict its spread by concentrating control efforts in areas with favorable temperature and precipitation conditions for its growth. Furthermore, boosting awareness about *L. camara*'s environmental restrictions can assist in guiding land use and restoration efforts that take these aspects into account, ultimately contributing to the conservation of native ecosystems by limiting the advance of this invasive alien plant. Therefore, understanding the complex interactions between *L. camara* and environmental factors is crucial for developing effective conservation strategies, as it emphasizes the importance of controlling and managing this invasive species to preserve the integrity of native ecosystems in Bali and elsewhere in Indonesia.

L. camara is an invasive plant with some potential benefits, one of which is as a medicinal plant. Balinese people called *L. camara*, *krasi*, which has medicinal properties and this is written in the *lontar taru* Pramana. *Krasi* is used in traditional medicine to relieve hangovers, rheumatism, constipation, and bronchitis (Suryadarma, 2005; Claria et al., 2023). Traditional knowledge about the efficacy of *L. camara* plants is an opportunity to develop natural medicines that have added value for the Balinese community using *L. camara*. The Balinese community can obtain economic benefits from using medicinal plants through the cultivation, processing, and marketing of these natural medicinal products. Other potentials of *L. camara* include natural insecticides (Routray et al., 2021), ornamental plants (Patel et al., 2018), natural dyes (Datta et al., 2023), and wood preservatives (Musli et al., 2019). The use of *L. camara* must be carried out wisely and by considering the environmental impact and safety of its use, such as its lantadine poison content which has a negative impact in the form of poisoning in livestock (Leestyawati, 2015).

The model's constraints encompass the absence of soil and land use parameters, which may also influence the suitability of the *L. camara* habitat. Additionally, model validation with an independent dataset for Bali would further verify accuracy higher than the current AUC score of 0.89. Despite those limitations, the model's results offer valuable

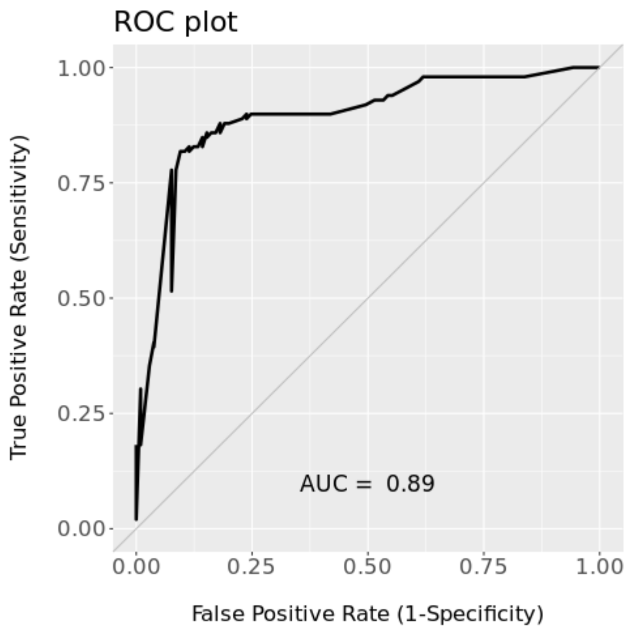

Figure 3 Receiver operating characteristic (ROC) with AUC value of invasive alien species (IAS), *Lantana camara,* in Bali using the Bioclim method in BCCVL.

information for preventing and controlling *L. camara* by focusing on predicted areas with the highest suitability, such as Buleleng, Jembrana, Bangli, Karangasem, and Tabanan. Prevention efforts can involve identifying invasive and native species, monitoring and controlling their introduction and re-invasion, and educating the public about the disadvantages of invasive foreign plants. Control strategies can include risk assessment of weeds for control planning, followed by eradication and ecosystem restoration through planting fast-growing native plants to suppress the invasive species (Sitepu, 2020). Efforts to prevent the invasion of *L. camara* species are substantial to maintain the diversity of native species (Shiri et al., 2023).

Conclusion

The suitable habitat for *L. camara* is the mountainous area in central Bali, such as Buleleng, Jembrana, Bangli, Karangasem and Tabanan. Those areas have cool air temperatures, quite high rainfall ranging from 1,500–2,500 mm and lower humidity compared to the areas below. Response curves demonstrated the correlation between climate variables and occurrence probability, highlighting *Lantana*'s growth's specific rainfall condition and temperature. Although the model achieved an acceptable AUC value of 0.89, indicating reliability, potential improvements through additional environmental parameters were suggested. The predictive map offers valuable insights for authorities to implement proactive strategies for preventing and controlling *Lantana*'s spread in vulnerable areas. Despite limitations in considering other environmental factors, this study represents a crucial step toward understanding *Lantana*'s potential to dominate local habitats. It informs management decisions to protect Indonesia's rich biodiversity from invasive alien species.

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