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GEOSPATIAL MAPPING OF MANGO ORCHARDS FOR FRUIT FLY PEST RISK ANALYSIS IN NEGROS OCCIDENTAL

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ABSTRACT

This study aims to develop a geospatial mapping approach for identifying and assessing fruit fly pest risks in mango orchards in Negros Occidental. By integrating uncrewed aerial vehicle (UAV) data, specifically drone imagery, with field survey observations, the research aims to delineate mango orchard distribution and evaluate spatial patterns associated with pest incidence. Aerial imagery from unmanned aerial vehicles (UAVs) was utilized to classify land use and accurately map mango-growing areas. At the same time, environmental variables such as temperature, humidity, elevation, vegetation cover, proximity to water sources, and other significant factors-including terrain characteristics (e.g., open fields, flat, rolling, and mountainous areas)-were incorporated to model pest suitability. The results demonstrate that geospatial methods can detect areas with increased fruit fly risk and locate mango orchards with high accuracy. Spatial analyses revealed that the fruit fly infestations are strongly correlated with specific environmental conditions, particularly warmer temperatures, moderate humidity, and areas with dense vegetation cover. Risk maps generated from the model identified several high-vulnerability clusters, thereby facilitating targeted monitoring and intervention. Validation using field data confirmed the reliability of the mapping outputs, demonstrating consistency between predicted and observed pest occurrences. The study concludes that geospatial mapping is a valuable tool for fruit fly pest risk analysis in mango production, providing a cost-effective and scalable approach for early detection, surveillance planning, and resource allocation. Furthermore, the integration of spatial data and environmental factors enhances the predictive capability of pest management strategies, thereby contributing to improved crop protection and reduced economic losses. Thus, the potential economic consequences can be effectively assessed by considering the direct and indirect effects of fruit fly pests, the probability of their spread within the province of Negros Occidental, the measures that may be applied, and the associated biological impacts. Future work should focus on

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incorporating temporal data for dynamic risk forecasting and expanding the model to include other pest species.

Keywords: Fruit fly, fruit fly incidence, geospatial mapping, mango orchard, pest risk analysis

INTRODUCTION

Agricultural lands set aside expressly for the commercial cultivation of mango trees (*Mangifera indica L.*) are known as mango orchards. The purpose of a mango orchard is to cultivate and produce mangoes for consumption and commerce. Mango trees are systematically cultivated to yield high-quality fruits that are marketed both in domestic and international markets. In the Philippines, mango is the third-most-exported crop, following banana and pineapple (Philippine Statistics Authority, as cited in the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development [PCAARRD], 2025). In Negros Occidental, where sugarcane cultivation is predominant, mangoes are also grown.

Mango orchards that prioritize food safety practices are essential, given the growing demand for premium produce and growing concerns about food safety. However, mango orchards are susceptible to pests and diseases, including fruit flies, scales, anthracnose, and powdery mildew, which can reduce yields and fruit quality. Integrated pest management (IPM) practices, including regular monitoring, biological controls, and judicious pesticide use, are considered important strategies for mitigating pest damage in mangoes (Afreen, 2024).

Fruit flies are among the most destructive pests affecting mango orchards worldwide, including the Philippines, causing significant economic losses due to fruit damage and quarantine restrictions on exports (Sevillano, 2024; Grechi, 2021; Reddy et al., 2018; Nankinga, 2014). There are different species of fruit flies, with *Bactrocera dorsalis* and *Bactrocera occipitalis* being the most commonly found in mango orchards (De Faveri et al., 2024; Susanto et al., 2022). Traditional monitoring methods for preventing fruit fly infestations are often reactive, localized, and insufficient for early detection and effective risk management. The Australian Center for International Agricultural Research (ACIAR) has proposed an Area-Wide Management (AWM) approach to reduce fruit fly infestations. AWM consists of several steps, including fruit fly identification; delineation of mango-growing areas where AWM will be applied; definition of AWM border zones; identification of stakeholders; mapping of the program area; identification of alternate host plants; conducting training sessions and meetings; monitoring adult fruit fly populations; applying male annihilation techniques; implementing a protein baiting program; maintaining good sanitation; monitoring fruit damage after the commencement of the program; managing hotspots and population spikes; and holding regular meetings with growers (De Faveri et al., 2024). According to the European and Mediterranean Plant Protection Organization (EPPO,

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2026), pest monitoring and the use of traps should be considered basic phytosanitary measures for fruit flies, particularly *Bactrocera dorsalis*.

Geospatial mapping (GM) is a broad term encompassing all operations involved in creating maps from geospatial data. It includes a range of processes such as data collection, spatial analysis, and the visualization of spatial features on maps. Geospatial mapping is a spatial visualization technique that enables the creation of customized maps tailored to specific needs. The purpose of GM is to represent features with geographic coordinates within a defined geographic context, thereby providing a model of the real world on a map. In analyzing geospatial and terrestrial data, various techniques, tools, and software are used within Geographic Information Systems (GIS). With advances in geospatial technologies such as GIS, remote sensing (RS), and GPS-based mapping, it has become possible to spatially analyze and visualize pest risk in mango orchards across larger landscapes.

Pest Risk Analysis (PRA) is the process of evaluating biological, scientific, and economic evidence to determine whether an organism should be classified as a pest, regulated, and the measures that were taken against it. The risk analysis process involves several stages, including initiation, pest risk assessment, and overall risk evaluation (Food and Agriculture Organization [FAO], n.d.; Sinha, 2020). Pest risk analysis is important for assessing threats to agricultural and horticultural crops and for identifying appropriate management options. Moreover, PRA enables the identification of economically important fruit fly species (FAO; International Atomic Energy Agency [IAEA], 2018).

Pest risk analysis has been used in previous studies to identify variables associated with fruit fly incidence (Broadley et al., 2024; Moreno et al., 2022; Bakka et al., 2019; Castrignano et al., 2012; De Lima, 2008). Spatial variables include proximity to water bodies, distance to roads and markets, orchard density and size, and previous infestations or hotspots. Non-spatial variables are typically categorized as biophysical or environmental factors, including temperature, relative humidity, rainfall, elevation, land use, soil type, and soil moisture.

Understanding pest incidence through pest risk analysis is important because it helps predict insect populations, improves our understanding of how insects interact with their habitats, supports monitoring changes in pest levels over time, and enables the mapping of the distribution of specific species. Furthermore, it can help detect new fruit fly species across different geographic areas.

OBJECTIVES OF THE STUDY

Generally, this study aims to develop a geospatial mapping framework to identify, monitor, and analyze mango orchards, and to assess and mitigate the risk of fruit fly infestations in Negros Occidental. Specifically, this study aims to map the spatial distribution of mango orchards using

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an unmanned aerial vehicle (UAV); assess the risk of fruit fly incidence through trap deployment; identify and geo-reference fruit fly infestation locations; and analyze factors influencing fruit fly incidence.

MATERIALS AND METHODS

Research Design

This study employed a descriptive–analytical geospatial research design integrating Geographic Information System (GIS), Unmanned Aerial Vehicle (UAV) technology, and spatial predictive analysis to map mango orchards and assess fruit fly pest risk in Negros Occidental. The design enabled the identification of spatial relationships among orchard distribution, environmental variables, landscape characteristics, and fruit fly incidence patterns.

To strengthen forecasting capability, GIS-based spatial modeling techniques such as hotspot analysis, weighted overlay analysis, and spatial interpolation were incorporated. In addition, machine learning approaches, particularly Random Forest classification, were considered to improve prediction accuracy of fruit fly occurrence and pest risk zones. The integration of geospatial and predictive techniques enhanced the reliability of the generated pest-risk maps.

Location of the Study

The study was conducted in the top six mango-producing cities or municipalities by land area. The list of major mango-producing cities or municipalities was obtained from the Provincial Agriculture Office of Negros Occidental.

Sampling Technique

A multi-stage sampling approach was employed to select mango orchards. Initially, the top six mango-producing cities or municipalities in Negros Occidental were identified. Subsequently, one mango orchard was selected from each city or municipality based on orchard size or total area. Each selected orchard was equipped with a fruit fly trap. The study was conducted over three months.

Research Instrument

Fruit fly incidence in mango orchards was assessed using traps containing a methyl eugenol lure to attract and capture fruit flies. UAVs (drones) were employed to map the orchards. Additionally, data were collected from orchard owners through a structured survey questionnaire, which gathered information on orchard location, grower or farmer name, area planted, total number of mango trees, number of fruit-bearing trees, tree classification (orchard, backyard, wild, seeded, or

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grafted), variety, age, observed pests, and a description of the surrounding area, including landform, proximity to water sources, and presence of other vegetation.

Data Collection Procedure

Fruit traps were used to gather data on fruit fly incidence in the selected orchards in Sipalay City, Bago City, San Carlos City, Calatrava, Sagay City, and Cadiz City. The traps were mounted by hanging them from tree branches at a height of 1.5 to 2 meters (approximately 5 to 6.5 feet) above the ground to ensure effective monitoring, with the traps suspended freely and not touching leaves or branches. The traps were labeled with unique trap numbers. Fruit traps were used in each orchard, 20 meters apart, following the standardized distance for fruit fly traps targeting *Bactrocera dorsalis* (Manasa and Bhagwan, 2025). Fruit flies trapped were manually counted on the 8th day after a 7-day exposure period for the first collection. The traps were retained on the mango trees for an additional 7-day exposure period, after which a second collection and counting were conducted, for a total of six counts over three months from January 2026 through March 2026. Data from each trap were recorded, and the total number of fruit flies was calculated. To count fruit fly incidence, the flies per trap per day (FTD) formula, FTD = [total number of fruit flies trapped/ (number of traps X number of days the traps were operational)] X 100. Moreover, the fruit fly species was identified.

The orchard geospatial map was determined using a drone. The UAV image processing workflow involved several key steps to convert raw drone images into useful data and maps for analysis. The process began with flight planning, in which a flight plan was created by defining the area of interest. The UAV hovered over the orchard at the planned altitude and speed to capture imagery. The images were then pre-processed, photogrammetrically processed, analyzed, and visualized in Adobe Lightroom.

Furthermore, a face-to-face survey was conducted among mango growers using a structured questionnaire. Data on other vegetation were collected through direct observation of the areas surrounding the mango orchards.

Ethical consideration

The researcher ensured that the study was conducted ethically. Used traps were discarded with household waste, as they are not classified as hazardous materials. For the survey, consent was obtained from the mango growers, who were informed about the study's purpose and nature before participating.

Data Analysis

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Analysis of Variance (ANOVA) was used to determine whether fruit fly captures differed significantly between cities and municipalities. Risk classification was based on trap counts, and areas were grouped into different risk levels. Low risk indicates minimal fruit fly captures, medium risk reflects a moderate number of captures, and high risk represents high population density or clustering of fruit flies. Fruit fly numbers serve as a determinant of pest risk because population levels directly indicate the likelihood of pest entry, establishment, and spread in an area. The likelihood of a pest's movement depends on the pathways and the frequency and number of pests associated with them. In assessing establishment potential, several factors are considered: host availability, abundance, and distribution; climatic suitability; the pest's potential to adapt; and methods of pest survival. Moreover, the probability of spread after establishment refers to the expansion of a pest's geographical distribution within an area (Food and Agriculture Organization [FAO], 2021). High trap counts indicate a well-established, expanding population capable of causing significant crop damage.

In categorizing risk levels, the percent fruit fly incidence was used as the primary basis. An incidence of 0–10% indicates very few positive traps and a limited population, representing low risk. An incidence of 11–30% indicates moderate detection: the population is established but controlled, and the risk is moderate. An incidence greater than 30% indicates high population pressure, and the resulting risk is classified as high. In categorizing risk levels, the percent fruit fly incidence was used as the primary basis. If the incidence is 0–10%, it means very few traps are positive, and the population is limited; therefore, the risk is low. An incidence of 11–30% indicates moderate detection and suggests that the population is established but controlled; thus, the risk is moderate. If the incidence exceeds 30%, it indicates high population pressure, and the resulting risk is classified as high.

Estimating the overall risk for each identified fruit fly pest: combine the likelihood of introduction and the overall consequences of introduction (= Cumulative Scores (Establishment Potential + Natural Spread Potential + Economic Impact).

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Table 1: Determination of the consequence of the introduction, with an assessment of environmental impact

Cumulative Scores (Establishment potential + Natural Spread + Environmental Impact)	Rating for Consequence	Numerical Score
0-10%	Low	1
11-30%	Moderate	2
>31%	High	3

Table 2: Determination of the consequences of the introduction without assessment of the environmental impact

Cumulative Scores (Establishment potential + Natural Spread + Economic Impact)	Rating for Consequence	Numerical Score
0-10%	Low	1
11-30%	Moderate	2
>31%	High	3

In Table 1, the determination of the consequences of introduction incorporates an assessment of environmental impact, including establishment potential and natural spread. This approach is ecologically focused, recognizing that introduced species can significantly alter ecosystem functions. Frameworks such as those described by David M. Richardson et al. (2000) emphasize that environmental consequences are critical in evaluating biological invasions, particularly in biodiversity-rich regions. Similarly, Mark A. McGeoch et al. (2016) highlight those environmental impacts, such as changes in ecosystem function, are central to global assessments of invasive species. By incorporating environmental impacts, this approach aligns with international risk analysis guidelines, such as those of the International Plant Protection Convention, which emphasize the importance of ecological consequences in pest risk analysis.

Table 2 replaces environmental impact in Table 1 with economic impact, focusing on consequences such as crop losses, management costs, and trade restrictions. This approach is commonly used in agricultural and trade-related risk assessments. Gordon H. Copp et al. (2005) discuss how economic considerations are often prioritized in risk screening tools, particularly when invasive

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species threaten fisheries or agriculture. Similarly, Jeffrey A. Lockwood et al. (2013) note that economic damage is a primary driver of policy decisions regarding invasive species management. Both tables use identical scoring thresholds (0–10%, 11–30%, and >31%), which standardize interpretation and allow comparability across assessments. Assigning numerical scores (1–3) simplifies integration into broader risk models and enables semi-quantitative analysis.

Assessing Entry Potential, Establishment Potential, and Probability of Spread

Bactrocera dorsalis females lay eggs in the pulp of developing or ripening mangoes. They prefer yellowing, ripe fruit, although they can infest immature fruits, particularly when populations are high. Eggs hatch into larvae within 1–2 days. The maggots develop through three instars, feeding on the fruit pulp for 6–35 days, causing internal rot. Mature (third instar) larvae exit the fruit and drop to the ground to pupate in the soil (upper 4 cm). Mangoes provide a highly favorable environment for *B. dorsalis* larvae, particularly due to their high carbohydrate content, which enhances progeny survival. The presence of other fruits, such as guava, citrus, and banana, in and around mango orchards enables *B. dorsalis* to survive outside the mango season, maintaining high populations year-round. In terms of probability of spread, *B. dorsalis*is is strongly attracted to the aroma and softer texture of ripening mangoes, which allows easier piercing by the female's ovipositor. Lack of sanitation, such as failing to destroy fallen, infested fruit (which serves as a reservoir for maggots), accelerates population growth (Grechi et al., 2022).

Bactrocera umbrosa specifically targets breadfruit and jackfruit, making areas where these crops are cultivated highly vulnerable. The pest thrives in tropical climates and has demonstrated the ability to colonize areas with varying ecological conditions. It is especially abundant in areas with high host availability, such as cultivated jackfruit, and becomes particularly active during monsoonal rains. In terms of the probability of spread, larvae live inside the fruit. If infested fruit is transported and discarded, the larvae emerge to pupate in the soil, allowing the species to establish in new areas. Additionally, as *B. umbrosa* larvae drop from fruit to pupate in the soil, the movement of soil, compost, or potting media containing pupae can facilitate the pest's dispersal (Susanto et al., 2022).

Bactrocera occipitalis is a pest of several major commercial crops, including mango, guava, citrus, papaya, and banana, which allows it to adapt to diverse agricultural environments. The primary pathway for entry is international trade and travel, specifically through the movement of infested host fruits. As a member of the *Bactrocera* genus, it has a short life cycle, allowing for multiple generations per year (up to 10), which can lead to rapid population expansion once introduced. In terms of establishment potential, as a tropical species, *B. occipitalis* thrives in warm climates, suggesting it could establish in subtropical regions. While specific climate modeling for *B. occipitalis* is limited compared to *B. dorsalis*, its native range suggests it could establish in similar

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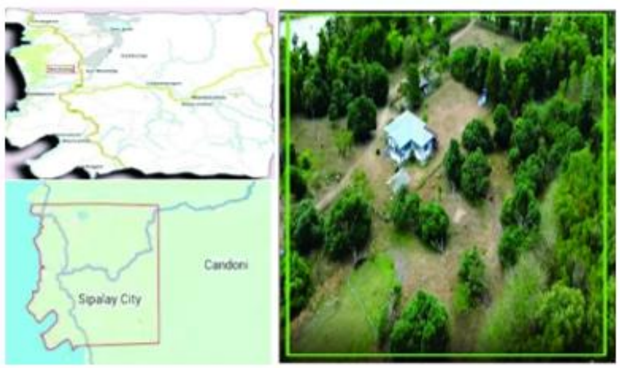
warm regions globally. Increasing global temperatures and changes in land use further facilitate its introduction and potential establishment in new areas.

Regarding the probability of spread, while long-distance dispersal (50–100 km) is often anecdotal, *B. occipitalis* can fly short distances, typically up to 2 km, to colonize nearby areas. Its short life cycle and capacity to reach up to 10 generations per year allow populations to grow rapidly and spread effectively (Vargas et al., 2015).

RESULTS AND DISCUSSION

Spatial Distribution of Mango Orchards



a. Geographical location of the study area in Brgy. Nauhang, Sipalay City (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

b. Geographical location of the study area in Brgy. Dulao, Bago City (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

c. Geographical location of the study area in Brgy. Old Sagay, Sagay City (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

d. Geographical location of the study area in Brgy. Luna, Cadiz City (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

e. Geographical location of the study area in Brgy. Rizal, San Carlos City (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

f. Geographical location of the study area in Brgy. Lemery, Calatrava (**Left**): regional context, with the orchard's location marked in a red box (**Right**): aerial image of orchard outlined by a green boundary.

Figure 1: Geospatial mapping of mango orchards across study sites

Figure 1 shows the geospatial mapping of mango orchards across the study sites using an Unmanned Aerial Vehicle (UAV). The geospatial analysis revealed distinct spatial patterns in the distribution of mango orchards across Sipalay City, Bago City, San Carlos City, Calatrava, Sagay City, and Cadiz City in Negros Occidental. Aerial imagery indicated that orchards are predominantly concentrated in lowland municipalities, particularly in areas with accessible road

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networks and favorable climatic conditions. These locations provide optimal environments for mango production but also increase exposure to fruit fly infestation due to higher human activity.

In Sipalay City, a flat mango orchard covering three hectares contains sixty-five Philippine mango trees planted at 20-meter intervals. The orchard is surrounded by mixed vegetation, including grassland and dense trees, and is generally distant from densely populated residential areas, although there is one nearby house. The mango trees are widely spaced despite the even terrain. In Bago City, the orchard spans three hectares and contains eighteen Carabao mango trees planted at 10-meter intervals. It is surrounded by agricultural vegetation, particularly sugarcane fields, and is located near a road. The trees are moderately dense and arranged in rows.

The mango orchard in San Carlos City is situated in a mountainous area and spans eight hectares, with approximately 1,000 Carabao mango trees planted. It is located close to settlements and near roads and transport routes. The surrounding vegetation includes papaya crops. In Calatrava, the orchard covers four hectares and includes 105 mango trees comprising Carabao, apple, and Indian mango varieties. The trees are planted at appropriate distances of about 10 meters apart. The orchard is surrounded by coconut trees and continuous vegetation, with nearby residential zones and water bodies.

Sagay City has a flat mango orchard covering 1.5 hectares, containing 105 Carabao mango trees. A road runs through the middle of the orchard. It is surrounded by agricultural vegetation, mainly sugarcane fields, and is located near residential zones. In Cadiz City, the flat mango orchard spans six hectares and has 90 Carabao mango trees. The area is dominated by sugarcane fields with year-round vegetation. The orchard has a moderately dense planting pattern and is located near a residential house.

Spatial modeling results indicated that the fruit fly pest risk is not uniformly distributed across populations, as reflected in population dynamics. However, all study sites were identified as high-risk zones characterized by moderate-to-high temperatures, elevated humidity, and dense vegetation. These environmental conditions are conducive to fruit fly breeding and survival. In contrast, upland areas with lower temperatures and reduced orchard density exhibited relatively low pest risk. The proximity of orchards to water bodies and residential zones also significantly increased the likelihood of infestation, suggesting that anthropogenic and ecological factors jointly influence pest dynamics.

Hotspot analysis further highlighted clusters of high vulnerability, particularly in intensively cultivated mango-producing municipalities. These clusters represent priority areas for pest surveillance and control interventions. The integration of multiple variables through weighted overlay analysis enhanced the precision of risk classification, allowing identification of gradients ranging from low to very high risk.

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Field validation confirmed the geospatial model's reliability, with observed infestation patterns closely matching predicted high-risk zones. This alignment supports the methodology's robustness and underscores the importance of combining remote sensing with ground-truth data.

Spatial modeling results indicated that fruit fly pest risk is not uniformly distributed, given fruit fly population dynamics. All studies were conducted in high-risk zones characterized by moderate-to-high temperatures, elevated humidity, and dense vegetation. These environmental conditions are conducive to the breeding and survival of fruit flies. In contrast, upland areas with lower temperatures and reduced orchard density exhibited relatively low pest risk. The proximity of orchards to water bodies and residential zones also significantly increased the likelihood of infestation, suggesting that anthropogenic and ecological factors jointly influence pest dynamics.

Hotspot analysis further highlighted clusters of high vulnerability, particularly in intensively cultivated mango-producing municipalities. These clusters represent priority areas for pest surveillance and control interventions. The integration of multiple variables through weighted overlay analysis enhanced the precision of risk classification, allowing the identification of gradients ranging from low to very high risk.

Field validation confirmed the geospatial model's reliability, with observed infestation patterns closely matching predicted high-risk zones. This alignment supports the methodology's robustness and underscores the importance of combining remote sensing with ground-truth data.

The findings indicate that geospatial mapping serves as an effective decision-support tool for pest risk management. This approach enables agricultural stakeholders to implement targeted control strategies, optimize monitoring efforts, and minimize economic losses. The results underscore the importance of continuous data updates and the integration of temporal variables to enhance predictive accuracy and support long-term pest management planning.

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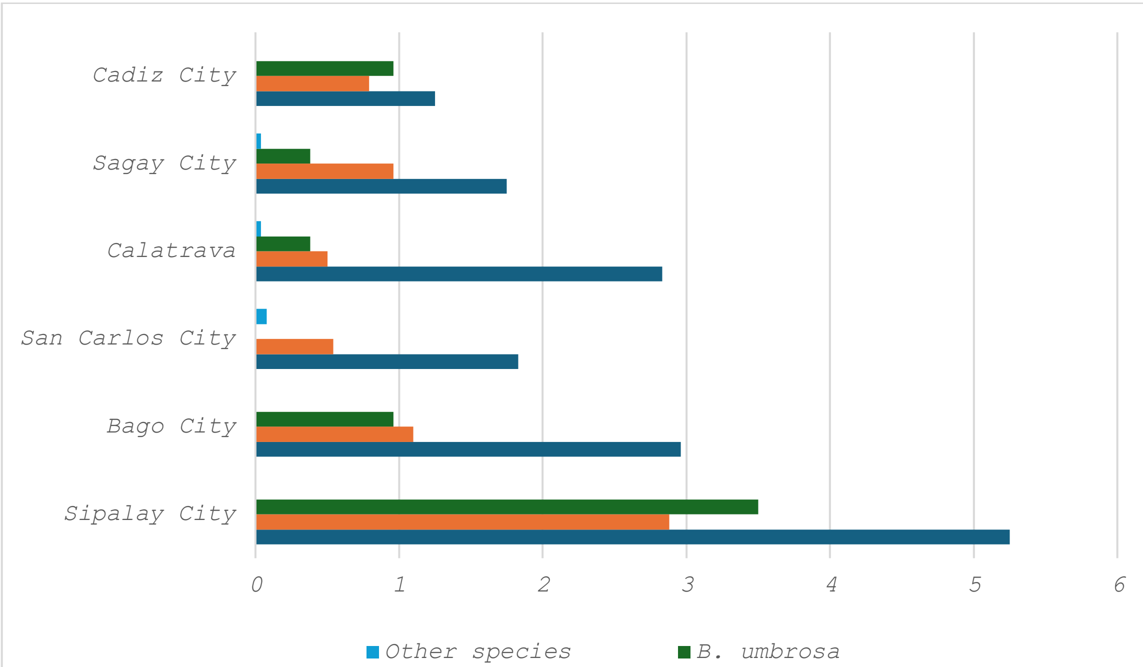

Fig. 2: Fruit fly incidence across study sites

The figure shows the mean number of fruit flies collected in the selected cities and municipalities. *Bactrocera dorsalis recorded* the highest number of fruit flies across all study areas. *Bactrocera umbrosa* followed *B. dorsalis* in Sipalay City, while *Bactrocera occipitalis* had the lowest count. In Bago City, *B. occipitalis* was more abundant than *B. umbrosa*. In San Carlos City, *B. occipitalis* ranked second after *B. dorsalis*, and an additional species was also observed. In Calatrava and Sagay City, *B. dorsalis*, *B. occipitalis*, *B. umbrosa*, and other species were all present. Meanwhile, in Cadiz City, *B. umbrosa* was more abundant than *B. occipitalis*.

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a. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 1 is installed in Bago City.

b. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 2 is installed in Sipalay City.

c. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 4 is installed in San Carlos City.

d. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 4 is installed in Calatrava.

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e. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 3 is installed in Sagay City.

f. The geo-referenced location of the highest fruit fly infestation, marked in a red box where Trap No. 4 is installed in Cadiz City.

Figure 3 shows the georeferenced locations of fruit fly incidence, using traps to detect fruit flies and record their exact geographic locations. Most of the traps installed along pathways and near other vegetation recorded the highest infestation levels. This is likely due to frequent human movement in and out of these areas, as well as the availability of host fruits, which can facilitate fruit fly establishment, especially when people introduce different types of fruits.

Risk Level of Fruit Fly Incidence

Table 3: Fruit fly incidence per trapping period

Study Areas	Number of fruit flies trapped						Fruit fly incidence (%)	Risk level (%)
	Trapping Period 1	Trapping Period 2	Trapping Period 3	Trapping Period 4	Trapping Period 5	Trapping Period 6		
Sipalay City	26	70	46	41	48	80	185	High
Bago City	16	29	14	16	19	28	73	High
San Carlos City	4	7	9	10	14	16	36	High
Calatrava	5	9	11	10	12	9	33	High
Sagay City	4	13	7	11	18	29	49	High
Cadiz City	9	11	12	23	15	33	61	High

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Table 3 presents the fruit fly incidence for each trapping period, along with the corresponding risk level. The findings indicate that Sipalay recorded the highest fruit fly incidence (185%). Regarding risk classification, all study sites were categorized as high risk because their fruit fly incidences exceeded 30%. These results emphasize the need for effective mitigation strategies to reduce the likelihood of economic losses in mango orchards.

January to March is a critical phase that marks the transition from flower induction to fruit development. Major flower-induction activities typically occur between November and February, setting the stage for harvesting, which usually begins toward the end of this period, typically in March (Ravishankar H. Kulkarni, 2004; Ravindra Kumar Singh et al., 2012). Major flower-induction activities typically occur between November and February, setting the stage for harvesting, which usually begins toward the end of this period, typically in March (Ravishankar H. Kulkarni, 2004; Ravindra Kumar Singh et al., 2012). However, due to constraints such as the aftermath of a typhoon, many mango growers first assessed their trees' condition before proceeding with spraying. The January to March period is also crucial for protecting developing fruits from pests and diseases, including cecid fly and anthracnose. Producers are navigating climatic pressures, including potential water scarcity, which may affect both the quality and quantity of the harvest. All study sites experienced a typhoon, which is why growers had not yet initiated flower induction.

Table 4: Overall Risk Assessment of fruit flies across study areas

Study Areas	CUMULATIVE SCORES (Establishment potential + Natural Spread + Environmental Impact)	Rating for Consequence	Numerical Score
Sipalay City	85%	High	3
Bago City	65%	High	3
San Carlos City	35%	High	3
Calatrava	40%	High	3
Sagay City	50%	High	3
Cadiz City	60%	High	3

Population pressure is high across the six study areas, although the percentages vary. The establishment potential, natural spread, and environmental impact were assessed using all factors contributing to fruit fly population dynamics (Table 4). Sipalay City has the highest risk level (85%), indicating favorable conditions for fruit fly infestations.

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Differences in Fruit Fly Incidence Across Study Sites

Table 5: Analysis of Variance (ANOVA) for the Differences in Fruit Fly Incidence Across Study Sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7646.889	5	1529.378	14.717	.000
Within Groups	3117.667	30	103.922		
Total	10764.556	35			

As shown in Table 5, fruit fly incidence varies significantly across the study sites (p = 0.000), suggesting that incidence differs among Sipalay, Bago City, Sagay City, Cadiz City, San Carlos City, and Calatrava, likely due to location-specific factors.

Table 6: Multiple comparisons for fruit fly incidence across study sites

(I) Municipality /City	(J) Municipality /City	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Sipalay City	Bago City	31.500*	5.886	.000	13.60	49.40
	Sagay City	41.833*	5.886	.000	23.93	59.74
	Cadiz City	42.500*	5.886	.000	24.60	60.40
	San Carlos City	38.167*	5.886	.000	20.26	56.07
	Calatrava	34.667*	5.886	.000	16.76	52.57
Bago City	Sipalay	-31.500*	5.886	.000	-49.40	-13.60
	Sagay City	10.333	5.886	.508	-7.57	28.24
	Cadiz City	11.000	5.886	.440	-6.90	28.90
	San Carlos City	6.667	5.886	.864	-11.24	24.57
	Calatrava	3.167	5.886	.994	-14.74	21.07
Sagay City	Sipalay	-41.833*	5.886	.000	-59.74	-23.93
	Bago City	-10.333	5.886	.508	-28.24	7.57
	Cadiz City	.667	5.886	1.000	-17.24	18.57

	San Carlos City	-3.667	5.886	.988	-21.57	14.24
	Calatrava	-7.167	5.886	.825	-25.07	10.74
	Sipalay	-42.500*	5.886	.000	-60.40	-24.60
	Bago City	-11.000	5.886	.440	-28.90	6.90
Cadiz City	Sagay City	-.667	5.886	1.000	-18.57	17.24
	San Carlos City	-4.333	5.886	.976	-22.24	13.57
	Calatrava	-7.833	5.886	.766	-25.74	10.07
	Sipalay	-38.167*	5.886	.000	-56.07	-20.26
	Bago City	-6.667	5.886	.864	-24.57	11.24
San Carlos City	Sagay City	3.667	5.886	.988	-14.24	21.57
	Cadiz City	4.333	5.886	.976	-13.57	22.24
	Calatrava	Sipalay	5.886	.991	-21.40	14.40
	Sipalay	Bago City	5.886	.000	-52.57	-16.76
	Bago City	Sagay City	5.886	.994	-21.07	14.74
Calatrava	Sagay City	San Carlos City	5.886	.825	-10.74	25.07
	Cadiz City	Calatrava	5.886	.766	-10.07	25.74
	San Carlos	3.500	5.886	.991	-14.40	21.40

Fruit fly incidence varied significantly among the study sites. In particular, the incidence in Sipalay differed from that in Bago City, Sagay City, Cadiz City, San Carlos City, and Calatrava, with Sipalay showing the highest incidence. This variation was highly significant ($p = 0.000$).

Conversely, among the other sites (excluding Sipalay), there was no significant difference in fruit fly incidence. This pattern may be explained by geographical proximity: Bago City, Sagay City, Cadiz City, San Carlos City, and Calatrava are relatively close to one another, whereas Sipalay is located farther from these sites. Additionally, Sipalay orchards are near coastal areas, which may increase fruit fly infestation due to higher humidity levels (Table 6).

Factors Influencing Fruit Fly Incidence

A combination of environmental, biological, and human-related factors shapes fruit fly incidence. Environmental conditions strongly affect fruit fly survival, reproduction, and spread. For example, warm temperatures (around 20–30°C) accelerate the life cycle, leading to rapid population growth, while extremely high or low temperatures reduce survival. High humidity favors egg survival and larval development, particularly during hot months like March. Moderate rainfall can increase host fruit availability, whereas heavy rain may wash away eggs. Fruit fly populations often peak during fruiting seasons and decline during off-seasons.

Host availability also plays a critical role. Crop diversity, including multiple host plants such as papaya and coconut, enables fruit flies to reproduce and sustain themselves continuously. Biological factors, such as species-specific characteristics, influence host preference and infestation patterns. Farm management practices, such as dense crop spacing and limited pruning, create humid, shaded microclimates that favor fruit fly survival. Lack of monitoring and control further increases the risk of outbreaks. Landscape and surroundings, including nearby infested farms, waste disposal practices, and human activities like the movement of infested fruit, can contribute to the spread of fruit flies.

Sipalay City has several contributing factors to fruit fly infestation. Its tropical climate, characterized by warm temperatures and seasonal rainfall, provides ideal conditions for fruit flies. The city experiences hot months (especially March–May) and periodic rainfall. The proximity of orchards to water resources, dense surrounding vegetation, and human activities, such as improper waste disposal and the movement of infested fruits, further accelerates infestation. These environmental, agricultural, and human-related conditions strongly favor the survival, reproduction, and spread of fruit flies, making Sipalay City more vulnerable to infestation than other areas.

Limitations of the Study

The study has potential limitations and should be acknowledged. The study covered only six representative orchards and was conducted over a three-month period, which may not fully capture seasonal variability in fruit fly populations. Limited access to historical infestation data and real-time weather information also constrained predictive analysis.

Additionally, UAV imagery resolution and environmental variability may have influenced spatial classification accuracy. Future studies should incorporate long-term monitoring, larger sample sizes, and real-time climatic datasets to improve forecasting reliability.

CONCLUSION AND RECOMMENDATION

Conclusion

The study demonstrated that geospatial mapping is an effective approach for identifying mango orchard distribution and assessing fruit fly pest risk in Negros Occidental. This was achieved by integrating Global Positioning System (GPS) data with field validation to verify the accuracy of UAV-derived classification and spatial analysis results. Ground-truth data were collected through field surveys at selected mango orchard sites. The research successfully generated spatially explicit risk maps that reflect actual pest occurrence patterns. The results confirmed that fruit fly infestation is associated with environmental factors, including temperature, humidity, orchard density, and proximity to human settlements and water sources. High-risk areas were predominantly located in flat, intensively cultivated zones surrounded by other plants and vegetation, where conditions favor pest survival and reproduction.

The consistency between predicted risk zones and field observations validates the geospatial model's reliability. This indicates that spatial analysis can serve as a valuable decision-support tool for agricultural planning and pest management. Overall, the study contributes to improved early detection, targeted intervention, and efficient resource allocation in mango production systems. Furthermore, the integration of GIS-based analysis, hotspot mapping, and predictive modeling improved the reliability of pest risk assessment and provided valuable decision-support information for agricultural management. Findings also confirmed that fruit fly incidence varies significantly across municipalities due to differences in environmental and landscape conditions.

Overall, the study highlights the importance of integrating geospatial technologies, predictive analytics, and field validation in sustainable pest management programs.

Recommendations

Based on the findings of this study, it is recommended that local government units (LGUs) and agricultural agencies in Negros Occidental adopt geospatial mapping as part of their regular pest surveillance and management programs, particularly in areas with dense populations and high levels of transport activity. The identified high-risk areas should be prioritized for monitoring, installation of additional fruit fly traps, and timely implementation of control measures. Neighboring or adjacent farms should also be considered in the analysis and included in the study context as part of the surrounding environment, since pest dynamics, such as fruit fly movement, are not confined to a single orchard. Their presence may influence infestation levels in the target mango orchards.

Future studies should incorporate temporal data, such as seasonal and climatic variations, to enhance the predictive capability of pest risk models. The integration of real-time weather data and advanced spatial analysis techniques is also encouraged to improve accuracy. Moreover, integrate real-time weather data and temporal analysis for improved forecasting, expand sampling to include more orchards and diverse management systems, apply advanced machine learning and spatial predictive models, develop mobile-based or web-based early warning systems, extend the methodology to other crops and agricultural pests such as banana, rice, citrus, and coconut systems.

Agricultural agencies and local government units are encouraged to adopt GIS-based pest monitoring systems to improve surveillance efficiency, reduce economic losses, and support sustainable mango production in Negros Occidental.

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