Shiraz University

Iran Agricultural Research

Journal homepage: https://iar.shirazu.ac.ir/?lang=en

Research Article

Spatiotemporal analysis of pollinator bee biodiversity using artificial intelligence in Fars Province, Iran

Seyedeh Maryam Mousavi Motlaghian , Kambiz Minaei* , Maryam Aleosfoor

Department of Plant Protection, School of Agriculture, Shiraz University, Shiraz, I. R. Iran

ARTICLE INFO

Keywords:
Artificial intelligence
Biodiversity
Climate change
Pollinator bees
Smart monitoring

Received: 01 May 2026
Revised: 17 July 2026
Accepted: 21 July 2026

ABSTRACT- Given the key role of pollinator bees in enhancing the yield and quality of horticultural crops and the growing concerns regarding their population decline in recent years in Fars Province, precise monitoring of biodiversity trends in these insects has become essential. In this study, we integrated existing occurrence reports with satellite imagery analysis over a ten-year period (2013-2023) to investigate the changes in pollinator bee diversity across Fars Province. Analysis of biodiversity indices in the R software environment revealed a 36.8% reduction in documented species richness (from 38 to 24 species) and a 50% decline in the Shannon-Wiener diversity index (from 2.40 to 1.20). Processing of satellite imagery within the Google Earth Engine platform identified a 2.2 °C increase in mean annual temperature and a 30% decrease in the Normalized Difference Vegetation Index (NDVI) as critical environmental drivers. The application of the preliminary YOLOv8 (You Only Look Once) object detection model for automated identification of species from archival images detected a 40% decline in the relative abundance of the vulnerable dwarf honeybee (*Apis florea* Fabricius), with a per-class precision of 94% for this species. Furthermore, spatial hot spot analysis of population decline revealed that the western regions of the province (specifically Kazerun county) have experienced the most severe losses. Overall, this study underscores the urgent need for a revision of current environmental and agricultural policies to preserve pollinator biodiversity in Fars Province.

INTRODUCTION

Pollinator bees, particularly native species, play a fundamental role in sustaining agricultural ecosystems and enhancing orchard productivity in the Fars Province (Kiani Bakiani *et al*., 2016). These insects contribute substantially to the pollination of local horticultural crops, including citrus, pomegranate, and pistachio, and their presence is essential for maintaining plant genetic diversity and improving both the quantitative and qualitative attributes of the fruits (Goulson, 2019; Cheptou, 2021). Nevertheless, mounting evidence points to an alarming decline in pollinator populations at both regional and global scales (FAO, 2018). Climate change, particularly rising temperatures and habitat degradation, is widely recognized as the principal driver of this downward trend, with additional contributions from land-use change and pesticide intensification (Potts *et al*., 2016).

In this context, where conventional biodiversity monitoring methods are often costly, time-consuming, and limited in spatial coverage, the effective application of artificial intelligence (AI) and satellite remote sensing can open new avenues for the continuous surveillance of insect populations, more accurate identification of threatening factors, and prioritization of management interventions.

The combination of information from the field with satellite images using machine learning algorithms enables the investigation of temporal trends and spatial patterns of biodiversity loss with enhanced speed and precision. However, such approaches have rarely been applied to pollinator systems in arid and semi-arid regions, such as the Fars Province.

Despite recent advances in AI-based ecological monitoring, there remains a significant gap in the integration of long-term occurrence data with high-resolution satellite-derived environmental variables to assess the changes in pollinator biodiversity in a particular region. Moreover, the combined application of machine vision models and temporal deep learning frameworks for pollinator assessment remains largely unexplored (Van Klink *et al.*, 2024).

The primary objective of this study was to conduct a ten-year (2013-2023) analysis of species diversity trends among pollinator bees in Fars Province using intelligent systems, including the Google Earth Engine, machine vision models, and recurrent neural networks, integrated with the processing of climatic data, vegetation indices, and existing occurrence reports. The findings of this study are expected to support evidence-based decision-making, contribute to the development of targeted conservation strategies, and provide a scalable methodological framework applicable to other arid and semi-arid agroecosystems.

*Corresponding Author: Professor, Department of Plant Protection, School of Agriculture, Shiraz University, Shiraz, I. R. Iran
E-mail address: kminaei@shirazu.ac.ir
DOI:10.22099/iar.2026.56048.1751

MATERIALS AND METHODS

Study area

This study was conducted in Fars Province, southwestern Iran, within the geographic boundaries of 27.03° to 31.70° N latitude and 50.50° to 55.60° E longitude. This geographic extent encompasses a pronounced climatic gradient and diverse vegetation. Based on the Köppen-Geiger climate classification, three main ecological zones were examined in this study.

Western zone (Kazerun and Mamasani counties): characterized by a Mediterranean climate with hot summers (Csa), featuring higher mean annual precipitation, and dominated by oak woodlands and species-rich rangelands.

Central zone (Shiraz and Marvdasht counties): characterized by a cold semi-arid climate (BSk), comprising a mosaic of irrigated croplands (wheat and maize) and steppe rangelands.

Eastern zone (Fasa and Darab counties): characterized by a hot desert climate (BWh), predominantly covered by citrus orchards, palm groves, and sparse shrublands.

These three zones were deliberately selected to capture a full ecological gradient from the more mesic western reaches to the arid eastern plains of Fars Province. This design enables the disaggregation of the effects of temperature change, NDVI-based vegetation decline, and agricultural intensification on the observed trend of pollinator bee biodiversity loss in the region.

Data collection

The present study is a retrospective investigation based exclusively on previously published data and existing official reports; no new field sampling was conducted. The four primary data sources are presented in Table 1.

Bee biodiversity data

To reconstruct the decadal trend of pollinator bee populations, 320 documented species occurrence reports covering the period from 2013 to 2023 (1392-1402 in the Persian calendar) were employed. These reports were primarily extracted from the annual monitoring records of the Fars Provincial Directorate of Environmental Protection (2023). In a few instances where supplementary data were required, scattered scientific documentation and, where accessible, citable records from international biodiversity databases were incorporated (GBIF.org, 2026). This monitoring has been conducted annually at a relatively stable network of stations; hence, there is no major inter-annual fluctuation in sampling effort.

Satellite imagery

To monitor changes in vegetation cover and land surface temperature, the USGS Landsat 8 Collection 2 Level 2 product (carrying the OLI and TIRS sensors) with a spatial resolution of 30 m was accessed and processed using the Google Earth Engine platform. A decadal time series of imagery with less than 10% cloud cover, restricted to the peak growing season of each year, was extracted for the analysis.

Meteorological data

Data on annual mean temperature (°C) and total annual precipitation (mm) for the period of 2013-2023 were obtained from 15 synoptic weather stations distributed across Fars Province (Fars Provincial Meteorological Office, 2023). To extrapolate these point-based measurements across the entire province and extract climate values corresponding to bee occurrence locations, the Inverse Distance Weighting (IDW) interpolation method was applied within the ArcGIS Pro 3.0 environment.

Validation data (land use)

To validate the results of the satellite-derived NDVI trend analysis, official statistics on rangeland cover change (Forest, Range and Watershed Management Organization of Iran, 2021) and the cultivated areas of pistachio and citrus orchards (Agricultural Research, Education and Extension Organization, Fars Province Directorate of Research, Education and Natural Resources, 2022) were utilized.

Satellite image time series analysis

The analysis of vegetation cover change and land surface temperature dynamics was conducted entirely within the Google Earth Engine platform, leveraging its cloud-based processing capabilities (Gorelick *et al*., 2017). The principal processing steps were as follows.

Data acquisition and preparation: The Landsat 8 Collection 2 Level-2 product (atmospherically corrected surface reflectance) was utilized for the period spanning 2013 to 2023.

Index calculation: For each image in the collection, NDVI and Land Surface Temperature (LST) were computed and stored as raster layers.

Table 1. Data sources used in this study

No.	Data source	Description	Reference
1	Bee occurrence records	320 species occurrence reports (2013-2023) from Fars Province, used to calculate biodiversity indices	Fars Provincial Directorate of Environmental Protection (2023); GBIF.org (2026)
2	Landsat 8 satellite imagery	Surface reflectance and land surface temperature (30 m, 2013-2023, peak growing season, < 10% cloud)	Accessed via Google Earth Engine (Gorelick *et al*., 2017)
3	Synoptic weather station data	Annual mean temperature and total precipitation from 15 stations across Fars Province, interpolated via Inverse Distance Weighting (IDW)	Fars Provincial Meteorological Office (2023)
4	Official land use statistics	Rangeland cover change and cultivated area of pistachio & citrus orchards for validation of Normalized Difference Vegetation Index (NDVI) trends	Forest, Range and Watershed Management Organization (2021); Agricultural Research, Education and Extension Organization, Fars Province Directorate of Research, Education and Natural Resources (2022)

Annual composite generation: To minimize the influence of cloud cover and sensor noise, a single median composite was generated for each year using all available images acquired during the peak growing season, which coincides with the peak foraging activity of pollinators in the province.

Long-term trend extraction: Long-term trends in NDVI and LST were quantified by fitting an ordinary least squares linear regression to the annual time series of images on a per-pixel basis. The statistical significance of the trends was confirmed using the Mann-Kendall test and Theil-Sen slope estimator on the provincial mean annual time series ($P < 0.01$ for NDVI and $P < 0.001$ for LST). All images were filtered for clouds and shadows using the CFMask algorithm and were visually inspected prior to compositing. The slope of the regression line for each pixel represents the annual rate of change (increase or decrease). Finally, the derived index values were extracted at the 320 documented bee occurrence points and subsequently used in correlation analyses and predictive modeling.

Forecasting future biodiversity trends using LSTM neural networks

A Long Short-Term Memory (LSTM) recurrent neural network was employed to model temporal dynamics and forecast future biodiversity status.

Input data structure was a multivariate annual time series dataset constructed for the period of 2013-2023 (1392-1402 in the Persian calendar). The input features (predictors) included: (1) mean NDVI extracted at bee occurrence points, (2) mean LST, (3) interpolated mean air temperature, and (4) total annual precipitation. The target variables were the Shannon diversity index and species richness, asdocumented in the annual reports.

Data splitting and validation: Given the sequential nature of the time series data, a time-based split strategy was adopted. Data from 2013 to 2020 (the first 80% of the time series) were used for model training, whereas data from 2021 and 2022 (the final 20%) were reserved as an independent test set for evaluating forecast accuracy. No random shuffling of temporal order was performed.

Model architecture and implementation: The LSTM model was implemented using the TensorFlow/Keras library in Python programming language. The architecture consisted of a single LSTM layer with 50 units, followed by a dropout layer with a rate of 0.2 to mitigate overfitting. The trained model was then used to project the Shannon index and species richness for 2026 (1405 in the Persian calendar) under a business-as-usual scenario that assumes the continuation of current environmental and land-use trajectories. Given the short time series, this forecast is an exploratory extrapolation. For comparison, classical ARIMA and exponential smoothing (ETS) models were also fitted using walk-forward validation and showed a similar declining direction.

Spatial analysis of population decline patterns

To identify statistically significant bee population decline hotspots across the province, a Getis-Ord Gi hotspot analysis was conducted within the ArcGIS Pro 3.0 environment. This analysis was applied to the point layer of 320 documented bee occurrence locations, weighted by the percentage change in species abundance between the initial (2013) and final (2023) years of the study period. The results revealed statistically significant spatial clusters (at 95% and 99% confidence levels) of severe population decline, termed cold spots, which were predominantly concentrated in the western regions of the province. The spatial weights matrix was defined using inverse distance with a 35 km threshold (optimized via Moran's I), and the false discovery rate (FDR) correction was applied to account for multiple comparisons.

Image-based detection with YOLOv8

As an exploratory complement to the occurrence-based analysis, a YOLOv8n object detection model was trained on an archive of approximately 1,200 photographs collected at fixed monitoring stations. The images taken in 2013, 2016, 2019, and 2023 predominantly contained *Apis florea*, with occasional other flower-visiting insects. Two entomologists independently annotated a subset of the images (inter-annotator agreement, Cohen’s $\kappa = 0.76$). The labelled data were divided roughly in a ratio of 70:15:15 into training, validation, and test partitions, ensuring that images from each year were represented across all three subsets to mitigate temporal bias. With the default YOLOv8n settings and 80 training epochs, the model attained a per-class precision of 0.94 for *Apis florea*, yielding an overall precision of 0.78, recall of 0.72, and mAP@0.5 of 0.74. The per-class recall for *Apis florea* was 0.68 in the test set. A confidence threshold of 0.5 was applied to count the detections. The most frequent errors were occasional confusion between the non-Apis insect classes and false positives triggered by bright flower reflections. Given the modest size of the test set, these metrics were considered provisional estimates. Detection counts were obtained from the entire image archive and showed a declining trend consistent with the occurrence data.

Statistical analyses and biodiversity modeling

All statistical analyses were performed using R software version 4.2.1 (R Core Team, 2022). Given the structure of the data, which comprised repeated annual measurements from various locations across the province, the chosen statistical methods were specifically designed to account for spatial and temporal dependencies.

Calculation of biodiversity indices

For each year, every occurrence report was treated as an independent incidence sample, yielding a species-by-sample incidence matrix for each year. The Shannon index was computed from incidence frequencies (i.e., the proportion of samples in which each species occurred) using the diversity function of the vegan package in R (Oksanen *et al*., 2020). This incidence-based approach reduces the sensitivity of the index to interannual variations in the total number of reports.

Correlation analysis between environmental variables and bee populations

The relationship between environmental variables, including annual mean temperature, annual NDVI, and area under orchard cultivation, and the abundance of key species (particularly *Apis florea*) was examined using the Pearson product-moment correlation coefficient. The assumptions of the test, including normality of distribution and linearity of the relationship, were verified prior to the analysis. A significance level of $\alpha = 0.05$ was adopted for all statistical tests.

Modeling drivers of biodiversity decline using linear mixed-effects models

Given the hierarchical structure of the data, in which annual observations within each ecological zone (Western, Central, and Eastern) are inherently correlated, linear mixed-effects models were employed. By incorporating a random effect for ecological zone, this approach accounts for within-zone correlations and avoids biased estimates of standard errors. For this analysis, biodiversity indices and environmental variables were aligned at the ecological zone level: annual NDVI, LST, temperature, and precipitation were first extracted at all occurrence points within each zone and then averaged to match the zone-level diversity indices. Models were fitted in R using the lme4 package (Bates *et al.*, 2015). Model fit was assessed using the conditional and marginal R^2 coefficients (Nakagawa & Schielzeth, 2013). The relative importance of each fixed effect was quantified by decomposing the marginal R^2 using the LMG (Lindeman, Merenda, and Gold) method (Grömping, 2006), with 95% confidence intervals obtained via bootstrap (1000 replicates). Variance inflation factors (VIF) were calculated to assess multicollinearity.

Temporal trend analysis and comparison of means

To statistically compare species richness and Shannon-Wiener diversity index ($H' = -\Sigma\, p_i \ln p_i$; Shannon, 1948) values between the initial (2013) and final (2023) years of the study period, a paired Student's t-test was employed. In this analysis, the corresponding values for each ecological zone in the two referenced years were treated as dependent pairs. The annual indices for each zone were derived from the 320 documented species occurrence reports accumulated throughout the entire study period.

RESULTS AND DISCUSSION

Trends in biodiversity indices

Over the ten-year period from 2013 to 2023 (1392-1402 in the Persian calendar), both biodiversity indices of pollinator bees in Fars Province exhibited a marked decline. Species richness decreased from 38 species in 2013 to 24 species in 2023, representing a 36.8% decline. Concurrently, the Shannon-Wiener diversity index (H') decreased from 2.40 to 1.20, indicating a 50% decline in both diversity and evenness of the bee community (Table 2). Statistical analysis using a paired t-test confirmed that these reductions were highly significant ($P < 0.001$) (Fig. 1).

Table 2. Comparison of pollinator bee biodiversity indices in Fars Province between 2013 and 2023

Year	Species richness (Mean ± SD)	Shannon–Wiener index, H' (Mean ± SD)
2013	38 ± 1.2^{a}	2.40 ± 0.30^{a}
2023	24 ± 1.1^{b}	1.20 ± 0.10^{b}

*Values are presented as mean ± standard deviation. Different superscript letters indicate a statistically significant difference between the two years based on a paired t-test ($P < 0.001$). The indices were calculated using 320 documented species occurrence reports accumulated over the study period.

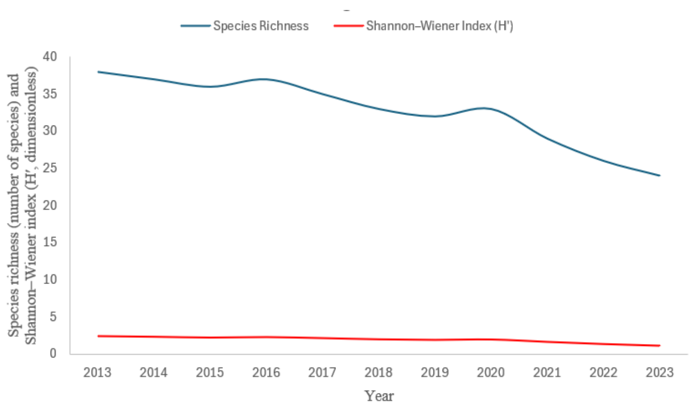

Fig. 1. Decadal trends in species richness (blue line) and the Shannon-Wiener index (H′; red line) in Fars Province (2013-2023). The lines depict the overall trajectory of decline over the study period.

Population trends of key species and sensitivity to the environmental factors

A separate examination of species occurrence reports over the study period revealed distinct response patterns to the environmental changes. The dwarf honeybee (*Apis florea* Fabricius) a small-bodied species reliant on moderate temperatures exhibited the most pronounced decline among the taxa investigated. The number of documented reports on this species decreased by approximately 40% between 2013 and 2023. A preliminary YOLOv8 image analysis of the same stations detected a similar declining trend for *Apis florea*, providing additional support for the occurrence-based trend (Rustia *et al*., 2019). Analysis of the relationship between population fluctuations of this species and climatic variables revealed a strong negative correlation with the rising trend in mean annual temperature across the province ($r = -0.82$, $n = 10$, and $P < 0.01$). In contrast, species such as the Eastern carpenter bee (*Xylocopa pubescens*), which possess larger body sizes and greater thermoregulatory capacity, experienced a much more gradual decline and showed no statistically significant correlation with increasing temperature. Smaller-bodied bee species, such as *Apis florea* are expected to exhibit higher thermal sensitivity due to their increased surface area-to-volume ratio, which accelerates water loss and constrains thermoregulatory efficiency under elevated temperatures (Fig. 2). In addition, rising ambient temperatures can shorten daily foraging windows and increase metabolic costs, thereby reducing net energy gain during critical resource acquisition periods. These physiological constraints are further compounded by climate-driven alterations in flowering phenology and nectar availability, leading to intensified resource limitation. Collectively, these interacting mechanisms provide a robust ecological explanation for the disproportionately stronger population declines observed in small-bodied thermally sensitive pollinators compared to larger and more heat-tolerant species, such as *Xylocopa pubescens*.

Geographic distribution of population decline

A Getis-Ord Gi* hotspot analysis applied to the 320 documented bee occurrence points revealed a spatially heterogeneous pattern in the severity of population decline across the province. The western region (Kazerun and Mamasani counties) emerged as a statistically significant cold spot at the 99% confidence level, exhibiting the highest rates of decline—up to approximately 60% relative to the baseline year. The eastern region (Fasa and Darab counties) showed a decline of approximately 40%, whereas the central region (Shiraz and Marvdasht counties) experienced the least pronounced reductions. This spatial pattern closely coincides with the provincial gradients of both vegetation cover change NDVI and LST increase (Fig. 3).

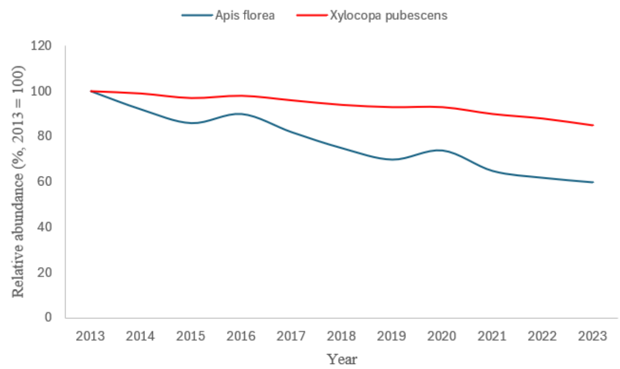

Fig. 2. Relative abundance of the dwarf honeybee (*Apis florea*; blue line) and the Eastern carpenter bee (*Xylocopa pubescens*; red line) in Fars Province (2013-2023). Abundance in 2013 is set as 100%. The 40% decline in *A. florea* in contrast to the 15% decline in *X. pubescens* reflects the higher sensitivity of small-bodied species to rising temperature ($r = -0.82$ and $P < 0.01$).

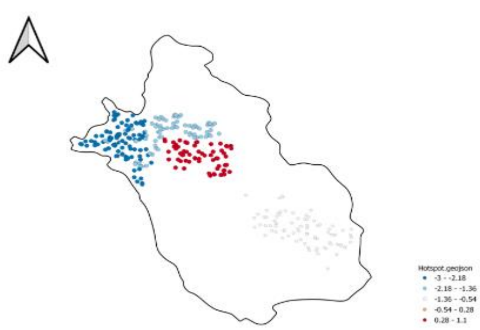

Fig. 3. Spatial pattern of pollinator bee population declines in Fars Province based on a Getis-Ord Gi* hot spot analysis of 320 documented occurrence points. Dark blue points (Z-score of -3.00 to -2.18) include statistically significant cold spots at the 99% confidence level, predominantly clustered in the western counties of Kazerun and Mamasani. Warmer tones transition eastward toward areas of non-significance (grey, white). This pattern closely coincides with the provincial gradients of Normalized Difference Vegetation Index (NDVI) decline and land surface temperature (LST) increase.

Environmental drivers of biodiversity decline

To estimate the relative contribution of environmental factors to the observed decline, a linear mixed-effects model was fitted, with ecological zone included as a random effect. The results indicated that three primary variables were significantly associated with a decrease in the Shannon diversity index. Based on the LMG decomposition of the marginal R^2, the relative contributions were as follows: increase in mean annual temperature 45% (95% bootstrap CI: 41-49%), decline in mean NDVI 30% (CI: 26-34%), and expansion of commercial orchard area 25% (CI: 21-29%). All variance inflation factors were below three, indicating no severe multicollinearity.

Future trend projection

The exploratory LSTM-based projection suggests that if current environmental and land-use trends continue, the Shannon diversity index could decline further by 2026.

Interpretation of key findings in the context of environmental change

The 36.8% decline in documented species richness and the 50% reduction in the Shannon diversity index observed in Fars Province over a single decade are consistent with the alarming global trends in pollinator decline (Potts *et al*., 2016). These figures underscore the urgent need for fundamental revisions to regional management strategies. The integration of satellite, climatic, and biological data through machine learning models provides a disaggregated picture of the roles played by different environmental drivers.

1. Rising Temperature: The strong negative correlation between mean annual temperature and the abundance of the dwarf honeybee ($r = -0.82$) indicates that small-bodied and specialized species have been disproportionately affected by regional warming. The documented temperature increase recorded at provincial synoptic stations (Fars Provincial Meteorological Office, 2023) may exert cascading effects on the entire pollination network through reduced nectar availability and increased physiological stress on the host plants.

2. Decline in Native Vegetation Cover: Analysis of Landsat imagery revealed a substantial decrease in NDVI across the province's rangelands. This decline, officially estimated at approximately 30% by the Forest, Range, and Watershed Management Organization (2021), has severely constrained bee access to both forage resources and nesting habitats. The spatial overlap between population declines hot spots and areas exhibiting the most pronounced NDVI loss further reinforces this association.

3. Agricultural Intensification and Landscape Homogenization: The expansion of commercial pistachio and citrus orchards, particularly in the eastern counties of Fasa and Darab, has coincided with a marked decline in bee biodiversity (Agricultural Research, Education and Extension Organization, Fars Province Directorate of Research, Education and Natural Resources, 2022). These extensive monocultures drastically reduce landscape-level plant diversity and are typically associated with high pesticide inputs, which exert detrimental effects on pollinator populations. Notably, our models indicate that while rising temperature has been the dominant driver of decline in the western region (Kazerun), land-use change has played a more prominent role in the eastern part of the province.

Methodological strengths and limitations strength

The combined use of cloud-based remote sensing (Google Earth Engine), machine vision models (YOLOv8), and LSTM recurrent neural networks provides an innovative framework for biodiversity monitoring in regions where systematic field data are scarce. The principal advantage of this approach lies in its ability to integrate heterogeneous data sources—satellite imagery, scattered biological records, and climatic variables—within a unified analytical platform, thereby revealing hidden patterns at the provincial scale. For instance, the YOLOv8 model detected *Apis florea* with a per-class precision of 94% in preliminary tests, illustrating the potential of such tools to assist with automated identification in future monitoring programs.

Limitations

Despite these strengths, the interpretation of the findings should be tempered by the following considerations.

Secondary Data Limitations: The analysis relies on dispersed and non-standardized biological records. Variations in sampling effort or identification accuracy across years may have influenced population decline estimates. Consequently, the reported figures should be viewed as conservative trend estimates rather than absolute population measures. A worst-case sensitivity analysis, assuming that half of the species missing in 2023 were undetected due to the imperfect detection, still yielded a > 18% decline in species richness and a > 35% decline in the Shannon index, confirming the robustness of the downward trend. Sensitivity analyses confirmed that the results are insensitive to the choice of point-aggregation method (mean vs. median) and interpolation technique (IDW vs. kriging). The YOLOv8 analysis was a preliminary assessment based on a modest image archive; its quantitative metrics are provisional and should be treated as initial estimates rather than definitive performance measures.

Causal Inference Constraints: Strong statistical correlations (e.g., $r = -0.82$ with temperature) do not necessarily imply causation. Unmeasured confounding factors such as pesticide application rates or competition with managed honeybees may also have influenced the observed patterns.

Limited Temporal Scale: A ten-year period is relatively short for disentangling long-term climatic trends from short-term natural fluctuations (e.g., drought cycles). Continued monitoring in the coming years will be essential to confirm the persistence of these trends.

Generalizability of predictive models: The LSTM-based forecast for 2026 assumes the continuation of past trajectories and does not account for unforeseen events, such as abrupt policy shifts or extreme climatic episodes, and simpler baseline models (ARIMA, ETS) confirmed the same trend, although prediction intervals are wide due to the short series.

CONCLUSION

By employing an artificial intelligence-based analytical framework and integrating remote sensing, climatic, and biological data, this study provides a well-documented yet concerning picture of the declining trend in pollinator bee biodiversity across Fars Province over a single decade (2013-2023). The 36.8% reduction in species richness and 50% decline in the Shannon diversity index, together with the identification of critical hotspots in the western parts of the province where declines reached approximately 60%, represent a serious threat to the sustainability of pollination services and, consequently, to regional food security and agroecosystem health (Kevan & Viana, 2003; Smith *et al*., 2015). The findings indicate that the synergistic pressures of rising temperatures, loss of native vegetation cover, and expansion of monoculture farming have placed escalating stress on bee communities, rendering small-bodied and specialized species, such as *Apis florea* particularly vulnerable. Consequently, conservation strategies in Fars Province must move beyond generic, one-size-fits-all approaches and shift toward site-specific, evidence-based interventions.

Despite the contributions of this study to the intelligent monitoring of biodiversity, the inherent limitations of secondary data and the ten-year time frame underscore the urgent need for standardized, continuous field monitoring. Future research should prioritize the ground-truth validation of predictive models and the direct measurement of factors such as pesticide impacts and competition with managed honeybees. An essential next step is the development of an integrated monitoring system that combines satellite-derived data with standardized field reports, thereby enabling the adaptive management of this unfolding crisis.

FUNDING

This research was funded by Shiraz University.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Methodology: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Software: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Investigation: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Data curation: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Writing-original draft: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Preparation: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Writing—review and editing: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Supervision: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor; Project administration: Seyedeh Maryam Mousavi Motlaghian, Kambiz Minaei, and Maryam Aleosfoor.

DECLARATION OF COMPETING INTEREST

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

ETHICAL STATEMENT

Not applicable.

DATA AVAILABILITY

The aggregated (county-level) species incidence matrix and core R and Python scripts used in this study are available from the corresponding author upon reasonable request. The YOLOv8 model configuration and corresponding Python inference script are available from the corresponding author upon reasonable request. The trained weights are not publicly released because of the preliminary nature of the analysis and the presence of sensitive location metadata in the original images. Raw occurrence point data are provided only in an aggregated form to protect sensitive species locations.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the Research Council of Shiraz University for their support in this work. We are grateful to the two anonymous reviewers for their constructive comments.

REFERENCES

Agricultural Research, Education and Extension Organization, Fars Province Directorate of Research, Education and Natural Resources. (2022). *Status report on pollinator bees and plant diversity in orchards of Fars Province* [Unpublished internal report]. Fars Agricultural Jihad Organization. Retrived from: https://fars.areeo.ac.ir/

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67* (1), 1-48. https://doi.org/10.18637/jss.v067.i01

Cheptou, P. O. (2021). Pollination strategies in the face of pollinator decline. *Botany Letters*, *168*(3), 316-323. https://doi.org/10.1080/23818107.2021.1884900

FAO (Food and Agriculture Organization of the United Nations). (2018). The state of the world's biodiversity for food and agriculture. Retrieved from: http://www.fao.org/3/CA3129EN/CA3129EN.pdf

Fars Provincial Directorate of Environmental Protection. (2023). *Annual report on the status of biodiversity and distribution of pollinator species in Fars Province* [Unpublished internal report]. Department of Environment, Shiraz. Retrived from: https://fars.doe.ir

Fars Provincial Meteorological Office. (2023). *Annual report of average precipitation and temperature of Fars Province (2013–2023)* [Unpublished internal report]. Iran Meteorological Organization. Retrived from: https://www.irimo.ir

Forest, Range and Watershed Management Organization of Iran. (2021). *Land use and vegetation cover maps of*

Fars Province. Tehran: Natural Resources Research Center.

GBIF.org. (2026). *GBIF Home Page* Retrived from: https://www.gbif.org/

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, *202*, 18-27. http://dx.doi.org/10.1016/j.rse.2017.06.031

Goulson, D. (2019). The insect apocalypse, and why it matters. *Current Biology*, *29*(19), R967-R971.

Grömping, U. (2006). Relative importance for linear regression in R: The package relaimpo. *Journal of Statistical Software*, *17*, 1-27.

Kevan, P. G., & Viana, B. F. (2003). The global decline of pollination services. *Biodiversity*, *4*(4), 3-8.

Kiani Bakiani, S., Monfared, A., Hajiqanbar, H., & Azhari, S. (2016). A survey on Apoidea bees (Insecta: Hymenoptera) and their associated mites in Fars Province, Iran. *Journal of Insect Biodiversity and Systematics*, *2*(*2*), 285-299. SID. Retrived from: https://sid.ir/paper/262385/en

Nakagawa, S., & Schielzeth, H. (2013). A general and simple method for obtaining R^2 from generalized linear mixed-effects models. *Methods in Ecology and Evolution*, *4*(2), 133-142.

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2020). *vegan: Community Ecology Package* (Version 2.5-7) [R package]. Retrived from: https://CRAN.Rproject.org/package=vegan

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Aizen, M. A., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., Garibaldi, L. A., Hill, R., Settele, J., & Vanbergen, A. J. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, 540, 220–229. https://doi.org/10.1038/nature20588

Potts, S. G., Ngo, H. T., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., Garibaldi, L. A., Hill, R., Settele, J., & Vanbergen, A. (2016). *The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production*. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

R Core Team. (2022). *R: A language and environment for statistical computing* (Version 4.2.1) [Computer software]. R Foundation for Statistical Computing. Retrieved from: https://www.R-project.org/

Rustia, D. J. A., Chao, J. J., Chung, J. Y., & Lin, T. T. (2019). An online unsupervised deep learning approach for an automated pest insect monitoring system. In *2019 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, *27*(3), 379-423.

Smith, M. R., Singh, G. M., Mozaffarian, D., & Myers, S. S. (2015). Effects of decreases of animal pollinators on human nutrition and global health: a modelling analysis. *The Lancet*, *386*(10007), 1964-1972. http://dx.doi.org/10.1016/ S0140-6736(15)61085-6

Van Klink, R., Sheard, J. K., Høye, T. T., Roslin, T., Do Nascimento, L. A., & Bauer, S. (2024). Towards a toolkit for global insect biodiversity monitoring. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *379*(1904), 20230101. https://doi.org/ 10.1098/rstb.2023.0101