



Mapping and Monitoring Tree Species in Dense Forest Ecosystems for Apiculture in Greece Using AI and Satellite Imagery

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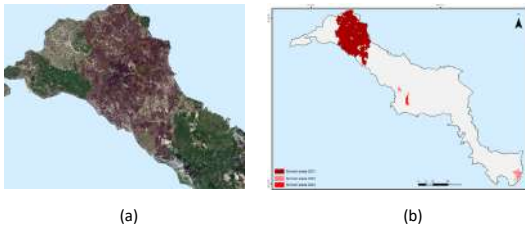
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Background of the Study

Apiculture in Evia, Greece depends on four melliferous tree habitats: pine (*Pinus spp.*), Greek fir (*Abies cephalonica*), oak (*Quercus spp.*), and chestnut (*Castanea sativa*). In our study, we mapped and monitored these habitats over five years (2020–2024) using Sentinel-2 monthly mosaics and species-level semantic segmentation based on a Vision Transformer (ViT) architecture. The 2021 mega-wildfires caused severe habitat loss and fragmentation, threatening honey production and ecosystem services, thus monitoring is of great importance.

Key Contributions

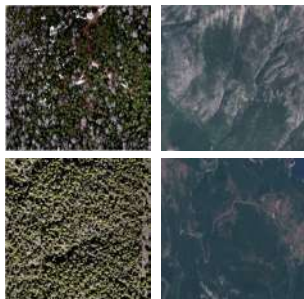
Our five-year (2020–2024) mapping initiative provides annual maps of Evia's four key honey-producing tree species. We developed a hierarchical methodology, integrating Sentinel-2 data, a ViT deep learning model, and rigorous ground truth validation. This approach accurately quantified the devastating 2021 wildfire impacts (30% pine, 11.5% oak loss), offering vital insights for sustainable apiculture and forest management.



Side by side comparison of Sentinel-2 monthly mosaic depicting the impact of the 2021 wildfire (a) and map of wildfires in Evia island and their impact on Apiculture (b).

Dataset Creation

Training data combined forestry polygons refined by expert photo-interpretation of Sentinel-2 monthly time series, constrained to single-species, medium–high density stands. A DJI Mavic 3 Multispectral campaign produced ultra-high-resolution orthomosaics for label verification. Inputs included annual monthly cloud-free Sentinel-2 mosaics (10 m) and a normalized DEM.



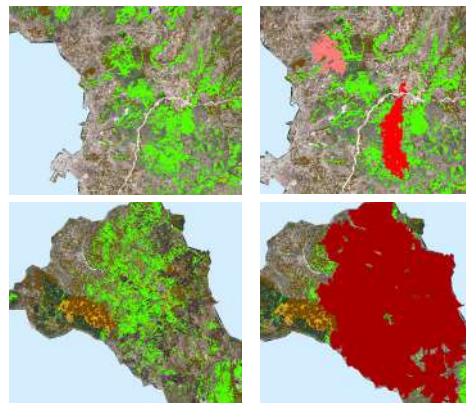
Methodology

We adopted a single-stage, end-to-end mapping pipeline with a ViT architecture for species classification over forested areas. Forest extent was first delineated using official maps to exclude non-forest pixels. For each forest tile, the ViT ingested a temporal stack of Sentinel-2 NDVI features across months plus a normalized DEM channel, learning phenology- and topography-aware representations to discriminate pine, fir, oak, and chestnut.

Training used tiled inputs, early stopping, class-balanced batches, and strong seasonal data augmentation; yearly outputs were temporally fused with the previous year's map to enhance stability and suppress spurious changes. We trained the ViT on expert-curated, single-species, medium–high density polygons validated by UAV multispectral orthomosaics, leveraging self-attention to capture long-range spatial context and cross-time relationships in heterogeneous Mediterranean forests. Post-processing applied confidence thresholding and small-patch smoothing to reduce mixed-stand noise, producing seamless 10 m annual four-species maps suitable for tracking wildfire impacts and guiding apiculture management.

Results and Discussion

In 2020, pine (~57k ha) and oak (~48.6k ha) dominated; fir (~10k ha) and chestnut (~8.5k ha) were more limited. The 2021 fires reduced pine to ~40k ha (~30%) and oak to ~43k ha (~11.5%), fragmenting habitats and constraining bee foraging. The ViT model accurately delineated species, with main errors in mixed stands and transition zones; NDVI+DEM proved sufficient and efficient. Annual temporal fusion improved map consistency year-to-year.



Conclusion

AI-enabled, Sentinel-2-based mapping provides robust, annual monitoring of melliferous tree habitats, critical for post-fire assessment and apiculture planning. Given pine honey's dependence on mature stands and *Marchalina hellenica*, production recovery will span decades without proactive restoration. The workflow is scalable, operationally relevant, and supports targeted conservation, restoration, and adaptive beekeeping in fire-prone Mediterranean forests.

Acknowledgements

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Apiculture plays a vital role in rural development and environmental sustainability by providing unique products while also enhancing biodiversity and crop production through pollination services. A large portion of Greek honey (over 65-70%) is derived from honeydew, primarily sourced from pine, fir, and oak forests. Identifying and mapping honeybee flora is essential for optimizing the deployment of honeybee colonies, improving honey production, and monitoring honeybee habitats. Bee habitats are vital indicators of environmental health and the impacts of climate change. The quality, availability, and diversity of these habitats reflect the state of ecosystems, as bees rely on specific flora and stable environmental conditions for survival. Changes in bee habitats, such as habitat loss, shifts in flowering patterns, or reduced biodiversity, often signal broader ecological imbalances caused by climate change, pollution, or human activity. Thus, accurate and temporal monitoring of these habitats can provide valuable insights into the resilience of ecosystems and the effects of environmental and climatic shifts. In this context, this study focuses on the region of Evia, Greece, and introduces a novel methodology for mapping major honeybee flora and tracking changes over time using Sentinel-2 satellite imagery and artificial intelligence (AI) models. Supporting this, a multi-year labeled dataset containing multiple hierarchical tree species is introduced to facilitate model training and evaluation. A Vision Transformer (ViT) architecture and a Transformer-based approach for time-series and spatial analysis are employed to classify honeybee flora, as well as to detect and quantify temporal changes. Experimental results for the Evia region demonstrate the effectiveness of the proposed methodology, achieving an overall classification accuracy exceeding 90%. A deeper understanding of the availability and density of honeybee flora is achieved through the spatial distribution maps generated by the above-mentioned approach, paving the way for beekeepers to identify optimal locations for colony deployment. The current study highlights the potential of combining Sentinel imagery with AI-driven classification frameworks to support sustainable apiculture practices, enhance honey production in Greece, and monitor honeybee habitats. The methodology can be further adapted for other regions, contributing to the broader goal of environmental sustainability and rural development.