

Iranian oak habitats and space: a combined gap analysis to inform effective protected areas expansion

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Keywords: fragmentation, climate change, species distribution model (SDM), zonation

Quercus brantii Lindl. and *Q. macranthera* Fisch. & C.A.Mey. ex Hohen. are the dominant oaks in the Zagros and Hyrcanian forests in Iran, respectively. *Q. brantii* is experiencing declines due to drought, fire, and land-use changes, while *Q. macranthera* is increasingly vulnerable in the Hyrcanian and Arasbaran regions. Yet, the combined effects of historical and future climate change, habitat fragmentation, and the coverage of current protected areas on their distributions remain largely unquantified. This study aimed to (1) reconstruct potential distributions of both oak species under past, present, and projected future climates; (2) identify stable refugia and habitats likely to remain suitable over time; (3) assess how well current protected areas overlap with these suitable habitats; and (4) highlight priority regions for conservation expansion and management. To achieve this, we employed Maxent for species distribution modeling, paired with morphological spatial pattern analysis to delineate habitat patches and assess structural connectivity over time. The Zonation and Venn diagram algorithms were then used to evaluate the effectiveness of the existing protected-area network and to identify priority areas for conservation action. Key findings reveal that both species are expected to encounter increased habitat fragmentation and connectivity loss, particularly *Q. macranthera*. Over 70% of climatically suitable habitats are projected to fall outside current protected areas. *Q. brantii* is projected to lose substantial habitat in the central Zagros; however, stable climatic refugia persist in the northwestern Zagros, which have remained suitable since the Last Glacial Maximum. Priority conservation areas include the central Zagros and adjacent northern and southern patches. *Q. macranthera* faces more dramatic range contraction, upslope shifts, and fragmentation within the Hyrcanian forests. Key habitats for conservation are concentrated in the central and eastern Hyrcanian forests, while long-term climatic stability is strongest in the eastern Hyrcanian and western Alborz Mountains, extending toward the South Caucasus. Our results highlight the importance of distinguishing long-term climatic refugia from future conservation priorities, ensuring that management strategies focus both on regions with enduring ecological resilience and areas that will remain suitable under climate change. These findings provide actionable guidance for expanding and optimizing protected areas for Iranian oak habitats.