Conservation Gap Analysis of Select Native Asian Oaks

Kate Good, Joeri S. Strijk, Chai-Shian Kua, Nguyen Van Ngoc, Hoang Thi Binh, Amy Byrne, Silvia Alvarez-Clare

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This work was funded with support provided by
WALDER FOUNDATION.

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Recommended citation: Good, K., Strijk, J.S., Kua, C-S, Ngoc, N.V., Binh, H.T., Byrne, A., & Alvarez-Clare, S. (2026). Conservation Gap Analysis of Select Native Asian Oaks. Lisle, IL: The Morton Arboretum.

Cover photos
Front cover: *Quercus austrocochinchinensis* ia Vulnerable oak species from China, Lao People's Democratic Republic, Thailand, and Viet Nam (photo credit: Min Deng)
Back cover: *Quercus mangdenensis* a Critically Endangered oak species from Viet Nam (photo credit: Nguyen Van Ngoc)

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July 2026

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Phu Kradueng, Thailand (Queen Sirikit Botanic Garden)

ACKNOWLEDGEMENTS

We would like to thank everyone who shared *ex situ* accessions data, provided photos, reviewed occurrence maps, and contributed to *Species Profiles* and case studies. A successful conservation gap analysis relies on many different people from a variety of backgrounds generously sharing their time and expertise. For a full list of contributors, see Appendix A. We would also like to acknowledge the Science and Conservation Department and Leadership Team at The Morton Arboretum for their institutional support. This report was made possible by financial support from Walder Foundation.

ACRONYMS

AOO	Area of Occupancy
BGCI	Botanic Gardens Conservation International
BIEN	Botanical Information and Ecology Network
EOO	Extent of Occurrence
ERS	Ecological Representativeness Score
FCS	Final Conservation Score
GBIF	Global Biodiversity Information Facility
GCCO	Global Conservation Consortium for Oak
GRS	Geographical Representativeness Score
IOS	International Oak Society
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Area
NGO	Non-governmental Organization
SRS	Sampling Representativeness Score
SSC	Species Survival Commission
WDPA	World Database on Protected Areas

IUCN RED LIST THREAT CATEGORIES

CR	Critically Endangered
EN	Endangered
VU	Vulnerable
NT	Near Threatened
LC	Least Concern
DD	Data Deficient

Quercus tarokoensis (Roderick Cameron)

CONTENTS

Quercus quangtriensis (Queen Sirikit Botanic Garden)

EXECUTIVE SUMMARY

Southeast and East Asia are global biodiversity hotspots for oak (genus *Quercus*) biodiversity, with an estimated 172 species within this region. Despite this remarkable diversity, for many species little is known regarding population size, distribution, or threats. There is an urgent need to coordinate and prioritize conservation actions for both wild populations and living collections in botanic gardens. To this end, we conducted a conservation gap analysis of 54 threatened and Data Deficient species of Southeast and East Asian oaks. The study area includes Viet Nam, Lao People's Democratic Republic, Thailand, Cambodia, Myanmar, Brunei, Malaysia, Singapore, Indonesia, Philippines, Timor-Leste, Democratic People's Republic of Korea, Republic of Korea, Japan, and Taiwan. As part of this analysis we created a curated dataset of 1,272 *in situ* occurrence points, assessed the geographic and ecological representation of species in *ex situ* collections, identified priority conservation areas for oaks in the region, and determined conservation needs, with a particular focus on *ex situ* conservation. In addition to the main report, which summarizes results across species and subregions, we also created an in-depth profile for eight threatened species throughout our study region. These *Species Profiles* are stand-alone documents prepared and reviewed by taxonomic experts. Each highlights the most urgently needed conservation activities for that species, with the purpose of serving as a guiding tool for conservation practitioners, land managers, and researchers.

Viet Nam is the center of oak diversity in Southeast Asia, with 33 reported threatened or Data Deficient species occurring within this country. Of these, 15 species are endemic to Viet Nam. The Annamite Mountain range is an especially oak-rich region, with three out of the four identified oak biodiversity hotspots occurring within this area. The Annamites harbor highly diverse montane and evergreen forests that support rich Fagaceae communities (including species of *Quercus*, *Castanopsis* and *Lithocarpus*), making it a key region for oak and broader tree diversity in mainland Southeast Asia.

For each threatened species, we performed an extensive literature review and gathered information from global and regional Red List assessments to identify the most urgent threats. The most commonly reported threat was agriculture, including wood and pulp plantations, which was reported for 66% of species. This was followed by logging and wood harvesting (59% of species) and extremely small populations (37% of species). Overall, there is a need to expand both *in situ* and *ex situ* conservation for threatened oaks within Southeast and East Asia. We found that all of our target species have less than 40% of their inferred native range covered by protected areas, and 10 species have less than 10% protected area coverage. In addition, according to the results of our *ex situ* surveys, there are only 14 species of threatened or Data Deficient Southeast or East Asian oaks held in *ex situ* collections anywhere in the world. Of the 16 Critically Endangered species within the region, only one is in an *ex situ* collection. Of the species held in *ex situ* collections with wild provenance data, most are collected from a very narrow geographic range. Furthermore, 50% of species are represented by ten or fewer individuals in collections.

This gap analysis relies on methodology developed by The Morton Arboretum, in partnership with Botanic Gardens Conservation International-US (BGCI-US). The methodology is designed to be flexible and can be adapted to fit the needs of specific target taxa and geographic regions. In addition to incorporating well established gap analysis methodology, one novel aspect of this report is the use of the Human Footprint Index to quantify anthropogenic pressure within the native range of our target species. The results of this analysis can be used to further prioritize species for *in situ* and *ex situ* conservation, especially among those that are found outside of protected areas and are not currently held in botanic gardens or arboreta. We found that 46/54 of our target species had over 50% of their range classified as "Very High" or "High" human pressure in 2024. For a vast majority of species, this pressure has increased over time: 94% of our target species showed an increase in the area classified as "Very High" or "High" pressure from 2000 to 2024.

Recently, significant progress has been made in documenting and understanding the remarkable diversity of oaks globally. Despite this progress, critical knowledge gaps remain, and scientific findings have not consistently translated into effective conservation action. Strengthened coordination and collaboration across institutions and sectors will be essential to build on current momentum and curb ongoing biodiversity loss within Southeast and East Asia. This gap analysis provides a framework for identifying opportunities for partnership and setting clear conservation priorities. Our findings underscore the urgent need to expand survey work and exploration, increase protected area coverage for threatened species, and increase representation of oak species in *ex situ* collections, especially within their native range. With coordinated and targeted action, we can ensure no species of oak within the region go extinct.

INTRODUCTION AND OBJECTIVES

Quercus serrata (Atsushi Motohashi)

Southeast and East Asia (referred to throughout as SE-E Asia) together comprise a broad and biogeographically diverse region, including China, Japan, North and South Korea (East Asia), Viet Nam, Thailand, Laos, Cambodia, Myanmar, Malaysia, Indonesia, Brunei Darussalam, Singapore, the Philippines, and Timor-Leste (Southeast Asia). These regions span a wide range of climatic zones, from temperate to tropical, and collectively support exceptional biological diversity. Within this broader region, Southeast Asia is widely recognized as a center of plant biodiversity. Nearly 15% of the world's tropical forests are found within the 11 countries that make up this biogeographic region, as well as four globally recognized biodiversity hotspots (Stibig et al., 2014). Southeast Asia has approximately 50,000 native species of vascular plants, with an average of 364 new species being added every year (Raven et al., 2020). Relative to the world's other two major tropical regions (Latin America and tropical Africa), Southeast Asia is proportionately richest in plant diversity for its relatively small area. In addition, the region as a whole contains an extremely high level of endemism at both the species and higher taxonomic levels (Hughes, 2017).

Within Southeast Asia, the Annamite Mountains of Viet Nam and Laos stand out as a critical center of diversity for the Fagaceae family, particularly for oak (genus *Quercus*). This rugged mountain chain, spanning approximately 1,100 kilometers, acts as a refugium where varied topography and distinct microclimates have fostered the evolution of numerous oak species. Recent surveys continue to reveal new endemic oaks in these high elevation forests, such as the Critically Endangered (CR) *Quercus sontraensis* (Ngoc et al., 2022) and *Q. mangdenensis* (Ngoc & Binh, 2022). These discoveries position the Annamite Mountains as a global hotspot for oak speciation while simultaneously highlighting the urgent need for targeted conservation to protect these narrow-range endemics from habitat loss. The concentration of unique oak lineages in this narrow corridor underscores the importance of the area for understanding the evolutionary history of how these originally temperate trees are now found in a tropical landscape (Hipp, 2024).

Oaks in SE-E Asia are under intense anthropogenic pressure, with the forests of this region experiencing some of the highest rates of deforestation globally (Austin et al., 2017; World Resources Institute, 2025). Between 2001 and 2019, there was an estimated 61,000 km^2 of forest lost in Southeast Asia, of which 31% occurred in mountainous regions where oaks are typically found (Feng et al., 2021). Primary drivers of forest loss include land use change, infrastructure expansion, and logging, with climate change and invasive species identified as emerging threats (Struebig et al., 2025). Southeast Asia faces very high and rapidly increasing population pressures, with projected urban land expansion expected to drive even further habitat loss across the region (Simkin et al., 2022).

In addition to the urgent threats faced by SE-E Asian oaks, many species remain poorly understood in terms of their population sizes and trends, distribution, and ecology. This limited knowledge makes planning and implementing appropriate conservation actions extremely difficult. The recently published Red List of Oaks made crucial contributions to our understanding of the current status of oaks worldwide, including Asia (Carrero et al., 2020). Still, questions remain regarding how best to prioritize species and regions for conservation. One approach to identify and address these knowledge gaps is through a conservation gap analysis. A conservation gap analysis is a comprehensive evaluation of the successes and needs of both the *in situ* (wild, within native habitat) and *ex situ* (within living collections or seed banks) populations. Conservation gap analyses have been produced for oaks of the United States (Beckman et al., 2019) and Mesoamerica (Good et al., 2024). Despite its status as an oak biodiversity hotspot, this type of analysis has never been performed for oaks in SE-E Asia.

Institutions and individuals working to conserve threatened oaks face several challenges. First, oaks are recalcitrant species, meaning that acorns cannot survive the drying and freezing conditions typical of conventional seed banking. Oaks therefore need alternative methods such as tissue cryopreservation (Ross & Pence, 2023) or living *ex situ* collections. Although *in situ* conservation (i.e., conservation of species in their native habitat) is ideal, there is a growing recognition of the conservation value of high-quality living collections (Westwood et al., 2021). *Ex situ* conservation plays a vital and complementary role to *in situ* conservation by acting as an insurance policy against extinction in the wild. Effective *ex situ* conservation can also be used to support *in situ* conservation through restoration and recovery programs. The importance of *ex situ* conservation is recognized in The Global Strategy for Plant Conservation Action 4, which states the need to "promote programmes to ensure that threatened plant species are effectively conserved, managed, monitored and restored using *in situ* and *ex situ* methodologies, aiming to achieve adequate levels of genetic diversity and viable populations and, where appropriate, involving indigenous peoples and local communities" (Global Partnership for Plant Conservation, 2025). Second, hybridization is widespread within oaks of the same section (see Case Study 1). High morphological variation within a single species and original descriptions that lack sufficient information on this variation make species identification especially challenging in the field (Valencia-A, 2010). This leads to taxonomic uncertainty and controversy surrounding many scientific names (Ngoc & Binh, 2023). Collaboration among researchers focusing on topics such as population genetics, taxonomy, and phylogenetics is needed to better understand and protect this challenging genus. Third, in SE-E Asia, there is a lack of funding and support for *Quercus* conservation efforts, with more attention focused on other ecologically and economically important species such as those in the Dipterocarpaceae family. As a result, SE-E Asian oaks often remain underrepresented in research, conservation planning, and *ex situ* collections compared to these more prominently supported taxa. Finally, because oaks can be long-lived and large, they require a significant amount of physical space to grow. Metacollections involving multiple institutions working together are oftentimes needed in order to achieve an appropriate number of individuals in collections (Griffith et al., 2019). Addressing these challenges requires strong collaboration among stakeholders and the effective integration of *in situ* and *ex situ* conservation strategies.

Here, we present a comprehensive gap analysis of select native oaks in SE-E Asia, which we conducted to better understand the conservation needs and opportunities for all IUCN Red List threatened and Data Deficient category species in the region. For each of our target species, we characterized the following:

- Native distribution
- Protected area coverage
- Conservation value of *ex situ* collections based on geographic and ecological representation of wild populations
- Past, present, and future threats

Although we refer to East Asia throughout the report, we did not include oaks endemic to mainland China within our analyses. China is one of the most biodiverse countries in the world for oaks, with an estimated 115 species (BGCI, 2025a). Recent research from Chinese institutions has greatly advanced our understanding of *Quercus* diversity, phylogenetics, and biogeography (see Liang et al., 2022; Wang et al., 2022; Xiao et al., 2025). Currently, colleagues at Yunnan University are preparing a report on conservation priorities for oaks of China (Vyan, 2026). To avoid duplication of effort, oaks endemic to mainland China were excluded from our analysis. Together, the results of their study and ours will provide a comprehensive assessment of conservation needs for oaks across SE-E Asia.

In addition to a summary of results for all 54 target species, this gap analysis also includes in-depth *Species Profiles* for eight threatened species throughout the region that summarize distribution and threats, as well as *ex situ* and *in situ* conservation status and needs (Appendix E). These *Species Profiles* build on Red List assessments by providing the most up-to-date status for each species, as well as prioritizing conservation activities. This analysis relied on the input of species experts from throughout SE-E Asia who vetted occurrence points and provided input on the current threats and conservation needs of each species. Species experts represented a variety of sectors, including academia, government, botanic gardens, arboreta, herbariums, and NGOs, and are members of the Global Conservation Consortium for Oak (GCCO). Led by The Morton Arboretum in collaboration with Botanic Gardens Conservation International (BGCI), the GCCO brings together the world's oak experts, conservationists, and the botanic garden community to ensure that no wild species of oak becomes extinct. See Case Study 2 for more information on the GCCO and current projects in SE-E Asia.

CASE STUDY 1:
Hybridization: Implications for conservation gap analyses and Red List assessment

Authors: Chai-Shian Kua (The Morton Arboretum) and Charles H Cannon (Xishuangbanna Tropical Botanical Garden)

Hybridization, the interbreeding of closely related species, is widespread in trees and reflects their long lifespans, overlapping reproductive periods, and often incomplete reproductive barriers. The most probable outcome of hybridization is the introgression of small genomic fractions from one species to another through backcrossing, not the creation of a hybrid lineage. This process of interspecific gene flow both expands effective population sizes of species and provides an avenue for gaining adaptive alleles and traits.

Hybridization among tree species is a common biological process, particularly in species-rich and environmentally complex regions such as Southeast Asia. For conservation, hybridization presents both opportunities and challenges, particularly where species-level assessments are required.

Potential benefits for conservation and long-term resilience

Tree hybridization and subsequent introgression offer the potential to increase genetic and phenotypic diversity within forest populations (Janes & Hamilton, 2017; Brennan et al., 2020). In many contexts, this diversity enhances adaptive capacity, allowing populations to respond more effectively to environmental change, pests, and climatic extremes (Brennan et al., 2020; Karunarathne et al., 2024). Rather than being viewed solely as a breakdown of species boundaries, hybridization functions as a natural evolutionary mechanism that redistributes adaptive traits across landscapes, facilitating “evolutionary rescue” in the face of rapid degradation (Hamilton & Miller, 2016).

For example, introgression in *Populus* species has been shown to drive rapid adaptive evolution to warming climates (Hord et al., 2025), while hybrid zones in *Picea* provide novel genetic variation essential for niche expansion (Karunarathne et al., 2024). Furthermore, hybridization between *Juglans cinerea* and *Juglans ailantifolia* can offer improved tolerance to pathogen-driven diseases like Butternut Canker (Brennan et al., 2020). Recent conservation thinking argues that assisting phenotypic diversification through introgressive hybridization among "syngameons" is an effective proactive strategy to safeguard biodiversity through the current climate bottleneck (Cannon & Kua, 2025).

Challenges for species-based assessment frameworks

At the same time, hybridization poses real difficulties for conservation assessments that rely on clearly delimited species, such as the IUCN Red List. Hybridization can complicate species identification, monitoring, and enforcement. Where species boundaries are unclear, estimates of distribution, population size, and trends may be uncertain, increasing the risk of under- or over-estimating extinction threat. In some cases, extensive gene flow from widespread species may reduce the distinctiveness of rare or localized taxa, raising concerns about the long-term persistence of unique evolutionary lineages. This uncertainty can propagate into estimates of distribution, population size, and trends - core components of Red List evaluations. In extreme cases, extensive introgression with a widespread species may also threaten the persistence or recognizability of a narrow endemic lineage.

Taxonomic resolution and its consequences

In this report, several recently reclassified species are included to illustrate both the value and the complexity of resolving species boundaries. In Viet Nam, research led by Ngoc Nguyen and collaborators clarified elements of the *Quercus langbianensis* species complex, resulting in the recognition of multiple distinct species, including *Q. baolamensis*, *Q. bidoupensis*, and *Q. honbaensis* (Binh et al., 2018a), which were previously treated under broader concepts of *Q. langbianensis* in the region. Additionally, separate work described *Q. sontraensis* from Son Tra Nature Reserve as a new species (Ngoc et al., 2022); other recent publications have documented further new taxa such as *Q. ngochoaensis* from Ba Vi National Park (Binh et al., 2021) and *Q. xuanlienensis* from Xuan Lien Nature Reserve (Binh et al., 2018c).

This work revealed previously unrecognized endemism and, as a result, increased the number of oak species considered threatened. Similar discoveries are emerging in Laos, where Strijk and collaborating Laos botanists have identified two new species of *Quercus* restricted to small pockets of protected areas (Strijk et al., in prep). While these represent important advances in conservation accuracy, many of these newly recognized species are currently known from few collections or localities. Such data limitations can create short-term challenges for Red List assessments, including uncertainty in estimates of range size, population trends, and threat severity. At the same time, clearer species delimitation can catalyze targeted field surveys, strengthen local and regional capacity in species identification, and raise awareness of conservation priorities, particularly in habitats undergoing rapid land-use and climate-driven change, thereby supporting more effective and timely conservation action.

Implications for gap analyses

For gap analyses, the key issue is balance. Accurate species delimitation and identification capacity are essential for credible Red List assessments and prioritization. At the same time, hybridization should not immediately be treated as a conservation failure or threat. In some systems, limited gene flow among related species seem to contribute to persistence rather than extinction risk. A pragmatic approach recognizes hybridization as part of the biological reality of many tree groups, while remaining clear about assessment units and transparent about uncertainty. This potential for adaptation is particularly relevant during the Anthropocene, when climate and land-use change are creating novel environments at an accelerated pace.

Key message

Effective tree conservation requires both taxonomic clarity and evolutionary realism. Clear species definitions are essential for accountability, regulation, and prioritization, but conservation strategies should also recognize hybridization and introgression as a natural process that may contribute to resilience under rapid environmental change. Gap analyses should support improved species identification and data collection – especially following taxonomic revisions – while also acknowledging that hybridization and introgression can, in some contexts, contribute to adaptive capacity. Framing hybridization neither as inherently good nor inherently bad allows conservation strategies to remain scientifically grounded, precautionary, and forward-looking.

Quercus kingiana (Min Deng)

Quercus bidoupensis (Nguyen Van Ngoc)

CONSERVATION GAP ANALYSIS METHODOLOGY

In 2016, The Morton Arboretum, in partnership with Botanic Gardens Conservation International-US (BGCI-US), began development of a conservation gap analysis methodology to identify gaps and provide recommendations for both *ex situ* and *in situ* conservation of woody plant species. Oaks native to the United States served as the pilot group for testing the methodology (Beckman et al., 2019), which incorporated methods developed by Khoury et al. (2020) to evaluate conservation priorities for crop wild relatives. Since its development, the methodology has been further refined and applied to additional taxa, resulting in a series of published gap analyses that build upon the original workflow. These include studies on *Acer* (Crowley, 2019); nine priority genera in the United States (American beech, hickories, Kentucky coffeetree, pines, selected laurels, walnuts, and yews; Beckman et al., 2021a); *Magnolia* (Linsky et al., 2022a; 2022b); ten fruit and nut tree crop wild relative genera in North America (Beckman Bruns et al., 2023a); and oaks of Mesoamerica (Good et al., 2024). The present gap analysis of SE-E Asian oaks represents the most recent application of this methodology. For detailed documentation and training materials, see Beckman Bruns (2023b).

STUDY REGION

The focus of this study is on threatened and Data Deficient oaks in Southeast Asia and select regions within East Asia. Our study region includes Viet Nam, Lao People's Democratic Republic (Laos), Thailand, Cambodia, Brunei Darussalam (Brunei), Myanmar, Malaysia, Singapore, Indonesia, the Philippines, Timor-Leste, Democratic People's Republic of Korea (North Korea), Republic of Korea (South Korea), Japan, and Taiwan. While we did not include species that are endemic to mainland China or South Asia, we did consider the full range of species that cross the border into these regions.

TARGET SPECIES

Throughout this report, we use the term "oak" to refer to species within the genus *Quercus* only. We first identified 108 SE-E Asian oak species within our study region and their synonyms based on the IUCN Red List (IUCN, 2025), BGCI GlobalTreeSearch (BGCI, 2025a), and discussions with regional species experts. For a full overview of all species in Asia, see www.asianfagaceae.com (Strijk, 2026a). We then refined our species list to include only those assessed by the IUCN Red List as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), or Data Deficient (DD; IUCN, 2025). We also included one species that is currently Not Evaluated (NE) on the Red List, based on conversations with regional species experts: *Quercus ngochoaensis*. *Quercus ngochoaensis* was recently identified from Ba Vi National Park, Viet Nam. Only 20 individuals of this species have been found, and it has been given a preliminary conservation assessment of CR (Binh et al., 2021). The Red List assessment for this species was submitted in 2026 and it is pending publication following a review by the IUCN Red Listing Unit.

It should be noted that there are several species of oak within our study region that are not well defined, and experts disagree on their taxonomic status. These species include *Q. xanthoclada*, *Q. quangtriensis*, *Q. lodicosa*, *Q. mespilifolia*, *Q. merrillii*, and *Q. percoriacea* (M. Deng and C. Cannon pers. comm. 2025). Although we have included these species in our study, we recognize that they deserve further taxonomic review. Our final target species list includes 41 threatened species and 13 Data Deficient species, for a total of 54 species (Table 1).

Table 1. List of 54 target species along with their IUCN Red List category, assessment criteria, and assessment year. Definitions of Red List criteria can be found at https://www.iucnredlist.org/resources/categories-and-criteria.
* Denotes species where an assessment has been submitted to the IUCN Red List, and is pending publication..

Species Name	IUCN Red List Category	IUCN Red List Criteria	Assessment Year
Quercus baniensis	Critically Endangered	D	2020
Quercus baolamensis	Critically Endangered	D	2020
Quercus bidoupensis	Critically Endangered	D	2020
Quercus blaoensis	Critically Endangered	D	2020
Quercus cambodiensis	Critically Endangered	B2ab(iii)	2020
Quercus camusiae	Critically Endangered	D	2020
Quercus dankiaensis	Critically Endangered (Possibly Extinct)	D	2020
Quercus dilacerata	Critically Endangered	D	2020
Quercus donnaiensis	Critically Endangered	D	2020
Quercus honbaensis	Critically Endangered	D	2020
Quercus mangdenensis	Critically Endangered	B1ab(iii)+2ab(iii); D	2024
*Quercus ngochoaensis**	Critically Endangered	D	2026
Quercus pseudoverticillata	Critically Endangered (Possibly Extinct)	B1ab(i,ii,iii)	2020
Quercus sontraensis	Critically Endangered	D	2024
Quercus trungkhanhensis	Critically Endangered	D	2020
Quercus xuanlienensis	Critically Endangered	D	2020
Quercus arbutifolia	Endangered	B2ab(ii,iii)	2020
Quercus asymmetrica	Endangered	B2ab(iii)	2020
Quercus bambusifolia	Endangered	B2ab(iii)	2020
Quercus chrysotricha	Endangered	B1ab(iii)+2ab(iii)	2019
Quercus disciformis	Endangered	B2ab(iii,iv,v); D	2019
Quercus edithiae	Endangered	B2ab(iii,iv,v)	2019
Quercus kinabaluensis	Endangered	B1ab(iii)+2ab(iii)	2020
Quercus kingiana	Endangered	B2ab(i,ii,iii,iv,v)	2019
Quercus lenticellata	Endangered	B1ab(iii)+2ab(iii)	2020
Quercus lodicosa	Endangered	B2ab(iii)	2019
Quercus nivea	Endangered	B2ab(i,ii,iii)	2020
Quercus percoriacea	Endangered	B2ab(iii)	2020
Quercus petelotii	Endangered	B2ab(iii)	2020
Quercus ramsbottomii	Endangered	B2ab(iii)	2020
Quercus rupestris	Endangered	B1ab(iii)+2ab(iii)	2020
Quercus steenisii	Endangered	B1ab(iii)+2ab(iii)	2020
Quercus xanthotricha	Endangered	B2ab(iii)	2020

Species Name	IUCN Red List Category	IUCN Red List Criteria	Assessment Year
Quercus austrocochinchinensis	Vulnerable	B2ab(iii)	2018
Quercus braianensis	Vulnerable	B2ab(ii,iii)	2020
Quercus gaharuensis	Vulnerable	B2ab(iii)	2020
Quercus hondae	Vulnerable	B1ab(iii,v)+2ab(iii,v)	2019
Quercus kerangasensis	Vulnerable	B2ab(iii)	2020
Quercus merrillii	Vulnerable	B2ab(iii)	2020
Quercus quangtriensis	Vulnerable	B2ab(iii)	2020
Quercus treubiana	Vulnerable	B2ab(iii)	2020
Quercus brevicalyx	Data Deficient	NA	2018
Quercus chapensis	Data Deficient	NA	2018
Quercus chevalieri	Data Deficient	NA	2020
Quercus chrysocalyx	Data Deficient	NA	2018
Quercus eumorpha	Data Deficient	NA	2020
Quercus liaoi	Data Deficient	NA	2020
Quercus mespilifolia	Data Deficient	NA	2020
Quercus platycalyx	Data Deficient	NA	2020
Quercus saravanensis	Data Deficient	NA	2018
Quercus tarokoensis	Data Deficient	NA	2020
Quercus tatakaensis	Data Deficient	NA	2020
Quercus thorelii	Data Deficient	NA	2018
Quercus xanthoclada	Data Deficient	NA	2018

Quercus mespilifolia (Queen Sirikit Botanic Garden)

Quercus variabilis (Arb Bergerette)

EX SITU COLLECTION DATA

Once per year between 2021 and 2025, *Quercus* accessions data, as well as associated wild provenance details, were requested from *ex situ* collections globally. We targeted institutions that reported holding native Asian oak species to the BGCI PlantSearch database (BGCI, 2025b), GCCO members, as well as our professional networks. All submitted accessions' data was compiled, standardized, and filtered in R (Version 4.2.0; R Core Team, 2022) using scripts adapted from Beckman Bruns et al. (2023b). We further refined our dataset to include species records only, excluding hybrids and cultivars. When coordinates were not provided, we manually geolocated points using the locality description. We did not attempt to geolocate points that included a general locality description at the province level or higher. When institutions did not report the number of individuals representing each accession, we assumed the accession consisted of a single individual. As such, the number of plants reported in *ex situ* collections is an estimate based on available data, and represents the minimum number of plants in *ex situ* collections.

We also included *ex situ* collections data from surveys conducted in 2017–2022 for previous gap analyses of oaks led by The Morton Arboretum, as these often included all *Quercus* level accession data at an institution and could have included one or more of our target species. See Appendix A for a detailed list of respondents for all survey years.

Collecting herbarium specimens and acorns in Gangwon-do, Korea (The Morton Arboretum)

IN SITU DATA SOURCES

To create a curated set of data points representing the known native distribution of each target species, we first compiled and standardized a variety of spatial point datasets in R. For herbaria that did not have their specimens digitized and freely available online, we visited the herbarium in person, photographed the vouchers, and manually transcribed the labels. Raw spatial point data sources for the 54 target species include:

- **Global Biodiversity Information Facility (GBIF)**; downloaded March 2025 (GBIF.org)
- **Herbaria consortiums**, downloaded March 2025 via SEINet Portal Network (https://symbiota.org/seinet/)
- **Symbiota portals** All Asia TCN (2025) and Northeastern Asian Flora (2025)
- **Herbaria,** including:
  - Andalas University (ANDA)
  - Bangkok Herbarium, Department of Agriculture (BK)
  - Dalat University Herbarium (DLU)
  - Central National Herbarium (CAL)
  - Chiang Mai University (CMU)
  - Forest Herbarium (BKF)
  - Forest Research Centre (SAN)
  - Forest Research Institute Malaysia (FRIM)
  - Harvard University (HUH)
  - Herbarium Bogoriense (BO)
  - Kew (K)

Quercus rex (Min Deng)

Quercus hondae (Toyoaki Osaki)

  - Muséum National d'Histoire Naturelle (P)
  - National Herbarium of Cambodia (RUPP)
  - National Herbarium of Laos (HNL)
  - National Taiwan University (TAI)
  - National University of Laos (FOF)
  - Naturalis (L)
  - New York Botanical Garden (NY)
  - Queen Sirikit Botanic Garden (QSBG)
  - Royal Botanical Garden Edinburgh (E)
  - Sarawak Herbarium (SAR)
  - Singapore Botanical Garden (SING)
  - Universiti Kebangsaan Malaysia (UKMB)
  - Universiti Malaya (KLU)
  - Vietnam Academy of Science and Technology (HN)
- **iDigBio Integrated Digitized Biocollections**; downloaded March 2025 (idigbio.org)
- **IUCN Red List**, downloaded March 2025 (https://www.iucnredlist.org/)
- **Botanical Information and Ecology Network (BIEN)**; downloaded January 2023 (https://bien.nceas.ucsb.edu/bien/)
- **Fagaceae of Vietnam**; by Ngoc & Binh (2023)
- **Communication with experts**, including records from collection trips and research projects
- **Flora of Cambodia, Laos and Vietnam - Fagaceae**; (draft manuscript), by Joeri Sergej Strijk and Norbert Holstein (Museum National d'Histoire Naturelle Paris & Royal Botanical Garden Edinburgh)
- **Published papers** (see the Biodiversity Heritage Library, https://www.biodiversitylibrary.org/)
- **Geolocated wild provenance localities** of the accessions from the 2017–2025 *ex situ* collections surveys

CURATION OF OCCURRENCE DATA

All datasets were combined, and occurrence data for the target species were mapped using R statistical software and the *leaflet* package (Graul, 2016). Points were initially flagged for further review using the R package *CoordinateCleaner* (Zizka et al., 2019) and, if necessary, removed from the dataset based on the following conditions: 1) records within 500 m of a country or state centroid, 2) records within 100 m of biodiversity institutions, 3) records outside of the species native range as reported by the IUCN Red List and GlobalTreeSearch (BGCI, 2025a), and/or 4) records in countries reported in the IUCN Red List as part of the species "introduced" range. We also removed spatial duplicates by rounding the latitude and longitude to four digits after the decimal point. Each species' occurrence map was reviewed either in person or virtually by a minimum of two regional *Quercus* taxonomic experts to further curate the dataset. For species that cross the border into China, we compared our occurrence maps to those generated by Vyan (2026) and removed inconsistent points following conversations with the author. Our final, curated dataset contained 1,272 records.

Quercus acorns collected from Viet Nam by Dalat University staff (The Morton Arboretum)

SPATIAL ANALYSES

We estimated geographic coverage of ex *situ* collections by dividing the total buffer area around ex *situ* wild provenance collection points by the total buffer area around all *in situ* points. The results of this analysis are used as an indicator of how well the ex *situ* collections represent the geographical range of the native population. Ecological coverage was calculated by dividing the total number of ecoregions under the ex *situ* buffer area by the total number of ecoregions under the *in situ* buffer area. The results of this analysis are used as an indicator of how well ex *situ* collections represent the ecological range of the native population.

Ecoregions were defined using the Holdridge life zone classification system. Originally developed by Leslie Holdridge in 1967 for application in tropical regions, this ecosystem classification framework has since been broadly applied worldwide (Khatun et al., 2013; Missanjo et al., 2019; Derguy et al., 2022). The Holdridge system delineates land areas according to five variables: mean annual precipitation, biotemperature, potential evapotranspiration ratio, latitude, and longitude. Life zones are intended to provide generalized ecological classifications based on these predictor variables and are not meant to replace the finer-scale micro environments or specific ecosystems in which species occur. Globally, the system recognizes 38 potential life zones, spanning environments from polar deserts to tropical rainforests. Holdridge life zones for the study region were mapped using WorldClim Version 2.1 bioclimatic data (1970–2000) at 30 arc-second spatial resolution (approximately 1 km²; Fick & Hijmans, 2017). To calculate Holdridge life zones, we used an R script developed by Isabel Trejo and Angela Cuervo of the Universidad Nacional Autónoma de México, Mexico City (Trejo and Cuervo, 2016). Maps were generated in QGIS (Version 3.28.3-Firenze).

Quercus tarokoensis (Roderick Cameron)

SPECIES RICHNESS AT THREE SPATIAL RESOLUTIONS

We analyzed species richness at three different spatial resolutions: 1) country level, 2) province level, and 3) a 50 x 50 km grid. Data on the native country for all species of SE-E Asian oaks was obtained from GlobalTreeSearch (BGCI, 2025a). We also generated heat maps at the province level for our target species only. We mapped target species occurrence data, counted the number of species within each province, and created a heat map based on those values. To achieve a finer resolution, we overlaid occurrence data with a grid of 50 km x 50 km placed over the entire study region, counted the number of species within each grid cell, and created a heat map in QGIS. Finally, we added an outline of the Annamite Range Moist Forest to the heat map, which is a World Wildlife Fund Global 200 (terrestrial) ecoregion (Olson et al., 2001). The Annamite Range Moist Forest is made up of two terrestrial ecoregions: Southern Annamites montane rain forests and Northern Annamites rain forests. This ecoregion is known for high levels of biodiversity, including oaks, with relatively intact moist forest (WWF, 2017). WWF Ecoregion maps were downloaded from Data Basin (Conservation Biology Institute, 2026) and shapefiles created in QGIS.

KEY BIODIVERSITY AREAS

Key Biodiversity Areas (KBAs) are sites identified as making significant contributions to the persistence of global biodiversity across taxonomic groups and ecosystems. Adopted by the IUCN in 2016, the KBA framework provides a standardized, science-based approach for identifying the most important terrestrial, marine, and freshwater sites for conservation worldwide (IUCN, 2016). KBAs help direct limited conservation resources to the places where action will have the greatest impact in preventing extinctions and maintaining ecosystem health. To date, more than 16,600 KBAs have been mapped globally. The resulting spatial data are used to guide the expansion of protected area networks, support the implementation and monitoring of international environmental agreements, prioritize conservation actions in areas with the greatest potential impact, and inform private-sector project planning, design, and development.

Quercus serrata, Sorak San Valley, South Korea (Joke Ossaer)

To qualify as a KBA, a site must meet specific criteria within one of five categories that capture biodiversity at the genetic, species, and ecosystem levels: 1) threatened biodiversity, 2) geographically restricted biodiversity, 3) ecological integrity, 4) biological processes, or 5) irreplaceability. These criteria are primarily based on the presence of one or more "trigger species" which identify a site as a KBA by meeting thresholds under the threatened biodiversity or irreplaceability criteria. For instance, a site may qualify as a KBA if it supports more than 0.5% of the global population size and more than five reproductive units (RU) of a CR or EN species (IUCN, 2016). Vulnerable species may also trigger KBA designation when a site contains more than 1% of the global population size and more than 10 RU of the species.

There are currently 1,524 KBAs within our study region, with 15,656 trigger species used to designate these KBAs (KBA Partnership, 2025). Of these, only 773 (5%) are plants, none of which are oaks. We mapped the wild occurrence points of all threatened oak species in SE-E Asia, overlaid with a map of KBAs to identify species that could potentially be added as triggers to existing KBAs, as well as species that could be used to designate new KBAs. Identifying KBAs using multiple taxonomic groups provides a more robust and representative basis for prioritizing conservation areas than reliance on a single taxon.

THREATS

We conducted a literature review for each of our 41 threatened species to identify primary threats, drawing from IUCN Red List assessment and the Vietnam Red List of Threatened Species (Vietnam Academy of Science and Technology, 2024). Due to the limited data available for the Data Deficient species, our threat analysis focused on those currently assessed as threatened. We classified threats into one of 10 categories based on the Threats Classification Scheme Version 3.3 (IUCN, 2022) and the Conservation Gap Analysis of Native U.S. Oaks (Beckman et al., 2019):

- Logging and wood harvesting
- Agriculture, wood and pulp plantations
- Residential/commercial development, mining, roads
- Tourism and recreation
- Fire and fire suppression
- Invasive species competition/disturbance
- Climate change and severe weather
- Genetic material loss
- Pests/pathogens
- Extremely small populations

The category "extremely small populations" was identified as a threat for all species classified as threatened under Criterion D in the IUCN Red List. A taxon qualifies for Criterion D if the number of mature individuals in the population is under a threshold set for each category: <50 for CR, <250 for EN, and <1,000 for VU.

Quercus blaoensis (Nguyen Van Ngoc)

HUMAN FOOTPRINT INDEX

Human Footprint refers to the pressure that human activities place on ecological processes and natural landscapes. Measuring how the Human Footprint of a region changes over time is one way to quantify the temporal variability of human influence on habitats and biodiversity. Mu et al. (2022; 2025) analyzed the Human Footprint globally at 1 km resolution from 2000–2024 using eight variables that reflect various aspects of human pressure on the environment: built environments, population density, nighttime light, croplands, pasture lands, roadways, railways, and navigable waterways. Each 1 km^2 grid cell is assigned a score of 0–50 based on the aggregate score of the eight aforementioned pressure variables. A Human Footprint score of 0 indicates no pressure, 1–2 is low pressure, 3–5 is moderate pressure, 6–11 is high pressure, and 12–50 is very high pressure (Venter et al., 2016).

Global Human Footprint data for the year 2000 were downloaded from a figshare repository, freely available at https://doi.org/10.6084/m9.figshare.16571064 (Li et al., 2020; Mu et al., 2025), and GEOTIFF files were converted to Shapefiles in QGIS. The dataset includes scores ranging from 0–50 for each 1 km^2 grid cell. For each target species, the total area of each Human Footprint score within a 50 km buffer was calculated. Values were categorized as no, low, moderate, high, or very high pressure, and the percent of each category within the 50 km buffer was calculated. In order to quantify change in Human Footprint over time, this process was repeated using 2024 data, the most recent year data was available.

Quercus glauca - Lushan, China (Joke Ossaer)

Quercus myrsinifolia (Arb Bergerette)

CONSERVATION ACTION SCORE

The Conservation Action Score was originally developed by Khoury et al. (2020) as a way to prioritize species for conservation based on protected area coverage (*in situ* conservation) and geographic/ecological representation in botanic gardens and arboreta (*ex situ* conservation). With so many species in need of conservation action and in the face of limited time and resources, calculating a Conservation Action Score is one way to prioritize species based on the most urgent need. For each target species, we calculated a Conservation Action Score to prioritize species for *ex situ* and *in situ* conservation efforts by adapting methods outlined in Khoury et al. (2020). Scores were divided into two categories: those related to *in situ* populations and those related to ex *situ* populations. *In situ* scores provide geographic and ecological measurements of the proportion of a species' range that is conserved in protected areas. *Ex situ* scores provide geographic and ecological measurements of the proportion of a species' range that is conserved in *ex situ* collections. All scores range from 0–100, with a score of 100 indicating robust conservation, and a score of 0 indicating extremely poor conservation. A combined final conservation score was then calculated by taking the average of the final conservation score *in situ* and the final conservation score ex *situ* for each species.

For our *in situ* analyses, we used protected area layers from the World Database on Protected Areas (UNEP-WCMC & IUCN, 2025). While our primary focus was on threatened speices in specific SE-E Asian countries, we assessed each species across their full range, which in some cases included China and India. Due to data restrictions in China and India, complete protected area datasets are not fully accessible through the Protected Planet website. The protected area layers for India were accessed through the India Biodiversity Portal (World Database on Protected Areas, ENVIS Centre on Wildlife & Protected Areas [Wildlife Institute of India, WII], 2019). This database includes protected areas from WDPA that have been updated using layers available from the Wildlife Institute of India. Protected areas for China were accessed through the Data Resources of Nature Reserves in China Repository (National Specimen Information Infrastructure, 2020). Descriptions of all *in situ* and *ex situ* scores are below:

In Situ Scores

- **Sampling Representativeness Score *In Situ* (SRS *In Situ*)**: The number of occurrence points that fall within protected areas divided by the total number of occurrence points.
- **Geographical Representativeness Score *In Situ* (GRS *In Situ*)**: The area of a species' inferred native range that is covered by protected areas divided by the total area of a species' inferred native range.

Quercus saravanensis (Queen Sirikit Botanic Garden)

- **Ecological Representativeness Score *In Situ* (ERS *In Situ*)**: The number of Holdridge life zones within a species' inferred native range that are located inside protected areas divided by the number of Holdridge life zones within the species' inferred native range.
- **Final Conservation Score *In Situ* (FCS *In Situ*)**: The mean of all *In Situ* scores.

Ex Situ Scores

- **Sampling Representativeness Score *Ex Situ* (SRS *Ex Situ*)**: The number of *ex situ* institutions that hold at least one accession of wild provenance of the target species, up to a maximum of 10. Final SRS *Ex Situ* scores were multiplied by 10 to achieve a scale of 0–100.
- **Geographical Representativeness Score *Ex Situ* (GRS *Ex Situ*)**: The area of the buffer surrounding all *ex situ* points divided by the area of the species' inferred native range.
- **Ecological Representativeness Score *Ex Situ* (ERS *Ex Situ*)**: The number of Holdridge life zones in the buffer surrounding all *ex situ* points divided by the number of Holdridge life zones in the species' inferred native range.
- **Final Conservation Score *Ex Situ* (FCS *Ex Situ*)**: The mean of all *Ex Situ* scores.

To calculate geographic and ecological coverage, a circular buffer was placed around each *ex situ* point in order to estimate the native distribution represented in *ex situ* collections. Previous gap analyses have used different buffer sizes depending on their taxon of interest and habitat specificity, typically either 20 km (Good et al., 2024), 50 km (Beckman et al., 2019) or 100 km (Beckman et al., 2021b). Recently, Koontz et al. (2026) calculated the correlation between ecological, geographic, and genetic coverage over a wide range of buffer sizes for 10 species in North America and Eurasia. They found that, in general, narrowly ranged species required smaller buffer sizes in order for geographic coverages to match genetic coverages, while wide-ranging species required larger buffer sizes. However, there was not one consistent calculation to identify optimal buffer size across multiple taxa. Based on their results, they recommend that gap analyses calculate ecological and geographic coverage at multiple buffer sizes in order to determine how this affects prioritization action scores. To test this, we calculated a Conservation Action Score for each species using three different buffer sizes (20 km, 50 km, and 100 km) and compared the results using Kendall's W, a non-parametric statistic for rank correlation.

CASE STUDY 2:
The GCCO: An innovative network to promote oak conservation in Southeast Asia

Author: Amy Byrne (The Morton Arboretum)

Above: Participants from Southeast Asia, China, and India posing for a photo following a tour of the arboretum at Viet Nam National University of Forestry, hosted by Dr. Hoang Van Sam. This tour came after the completion of a Red List training workshop that the GCCO coordinated.

The Global Conservation Consortium for Oak (GCCO) is a network dedicated to the preservation and protection of oaks worldwide, currently led by The Morton Arboretum, in partnership with Botanic Gardens Conservation International (BGCI). This Consortium is made up of scientists, conservation experts, and oak enthusiasts. The GCCO works closely with governments, non-governmental organizations, and local communities to promote research, living collections curation, restoration, habitat protection, and education about the ecological and cultural importance of oaks. Its main objective is to address the challenges that threaten these valuable tree species, such as deforestation, climate change, pests and pathogens, and soil degradation, by implementing innovative and sustainable strategies.

The GCCO is a collaborative initiative that seeks to protect and preserve oak species and forests, recognized as keystone species in the habitats they are distributed throughout, providing benefits and services to humans and wildlife. This initiative is necessary due to the accelerated loss of oaks in recent years. The GCCO is currently working in the oak biodiversity hotspots around the world, including: Mexico and Central America, China, Southeast and East Asia, United States of America, Europe, West Asia, and North Africa.

Southeast Asia is an oak biodiverse region with more than 90 species distributed in multiple habitats, and including around 40 threatened and 11 Data Deficient species in the wild, according to GlobalTreeSearch (BGCI, 2025a). The GCCO, in collaboration with local partners, coordinates efforts on priority, threatened, and data-deficient species in this region.

More specifically, the GCCO and local partners have focused on the following objectives: 1) surveying wild populations to better understand species native ranges, threats and phenology to inform future conservation and research projects, 2) recruitment of Consortium members throughout the region across multiple disciplinary sectors, 3) hosting capacity-building workshops such as propagation training and conservation action planning to engage and leverage local expertise in threatened oak species conservation work, and 4) propagation of different species of oak, for restoring wild populations and contributing to the formation of a metacollection so as to increase the representation of living conservation collections in regional botanical gardens. The GCCO partners in this region play a critical role in the ongoing conservation and research of oaks. As the network continues to expand within this center of diversity, these efforts will only grow stronger and contribute to a more sustainable future for oaks.

Quercus helferiana (Queen Sirikit Botanic Garden)

Forest with *Quercus crispula* and *Quercus serata* (Atsushi Motohashi)

SPECIES RICHNESS

According to GlobalTreeSearch (BGCI, 2025a), there are 108 species of *Quercus* within our study region. Viet Nam has the most *Quercus* species at 55, followed by Thailand (34), Myanmar (27), Laos (24), Malaysia (19), Taiwan (17), Indonesia (15), Japan (15), South Korea (12), North Korea (7), Brunei (4), Cambodia (2), Singapore (1), and The Philippines (1). North Korea, South Korea, and Singapore do not have any threatened or DD *Quercus* species, and are thus excluded from the remainder of the analyses. However, special attention should be given to South Korea in particular. Rapid urbanization and industrialization on the Korean peninsula is a major threat to the flora and fauna of this region, resulting in an estimated decrease in forested area of 2.1% within the past two decades (Convention on Biological Diversity, 2026). Forest fires also pose a significant threat, with 2025 having an unusually high number of fire alerts for the region (Global Forest Watch, 2026). As threats to oak species in South Korea become more clear, their Red List assessments should be revisited. See Case Study 3 for more information on the oaks of South Korea and their threats.

Viet Nam has the greatest number of target species (threatened and DD) at 33. Fifteen of these species are endemic to Viet Nam: *Q. baniensis*, *Q. baolamensis*, *Q. bidoupensis*, *Q. blaoensis*, *Q. dankiaensis*, *Q. dilacerata*, *Q. donnaiensis*, *Q. honbaensis*, *Q. mangdenensis*, *Q. ngochoaensis*, *Q. petelotii*, *Q. rupestris*, *Q. sontraensis*, *Q. trungkhanhensis*, and *Q. xuanlienensis*. It is possible that with additional survey work, several of these species may also be found in neighboring countries.

The province with the greatest number of target oak species in Viet Nam is Lam Dong (13), followed by Ha Tinh and Kon Tum with seven each (Figure 1A). The only other country with a province of seven or more target species is Sarawak in Malaysia with eight species (Figure 1B). See Appendix C for a list of target species by province for each country.

Quercus hypophea, Taiwan (The Morton Arboretum)

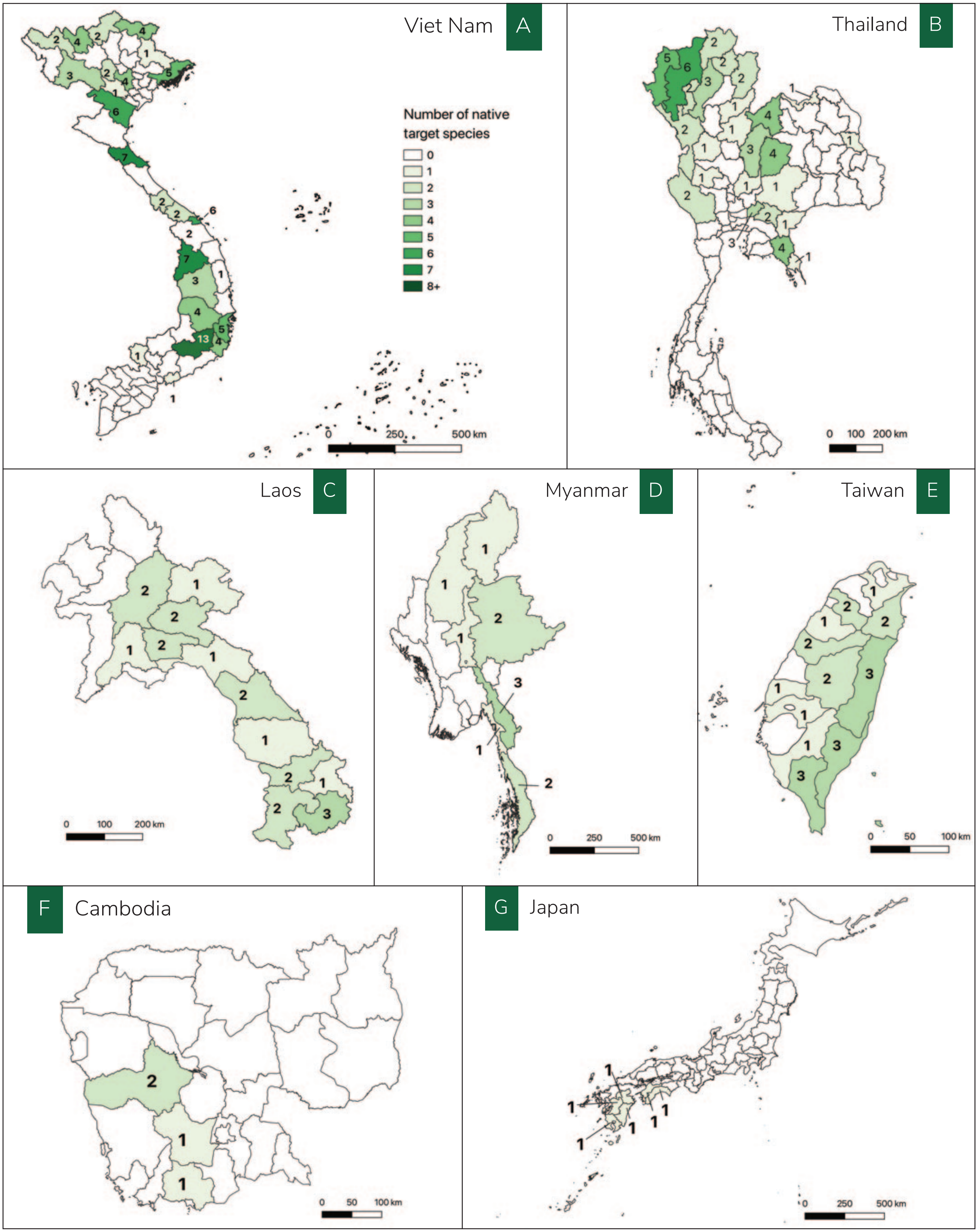


Figure 1A. Province-level richness of 54 threatened or Data Deficient species in A) Viet Nam, B) Thailand, C) Laos, D) Myanmar, E) Taiwan, F) Cambodia, and G) Japan. See Appendix C for a province-level species list.

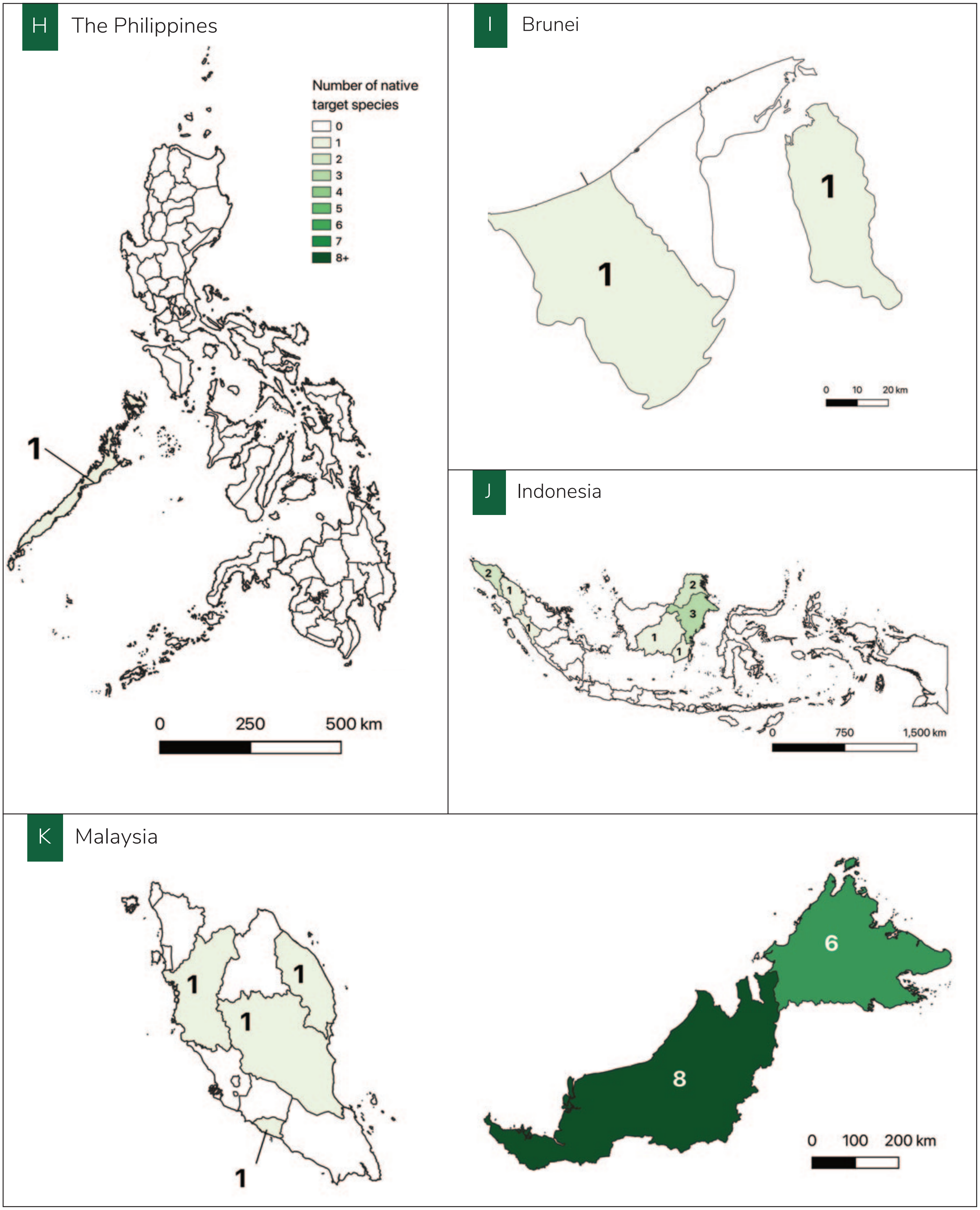


Figure 1B. Province-level richness of 54 threatened or Data Deficient species in H) The Philippines, I) Brunei, J) Indonesia, and K) Malaysia. See Appendix C for a province-level species list.

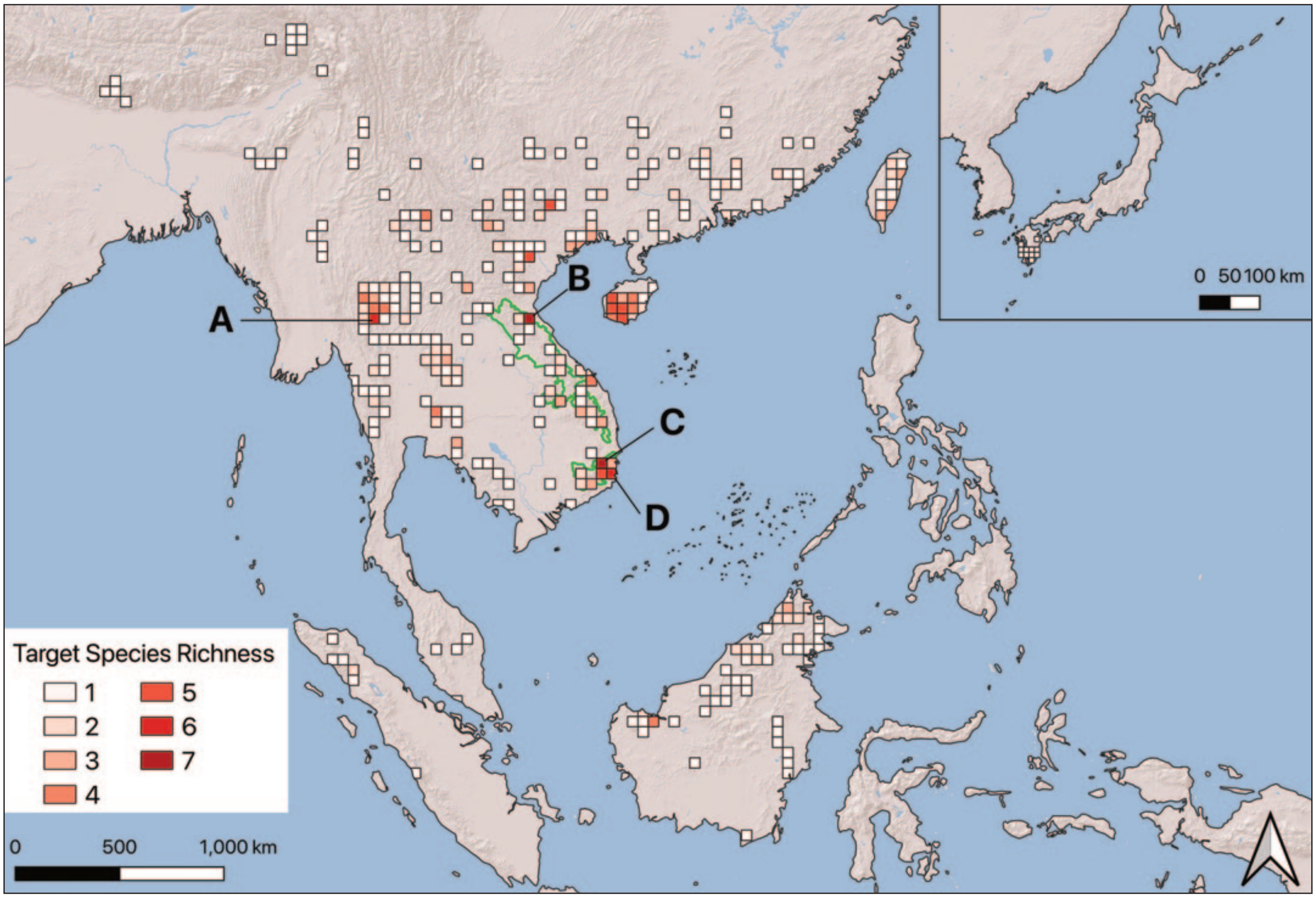


Figure 2. Target species richness per 50 km^2. Japan is in the inset map. The Annamite Range Moist Forest is outlined in green (Olson et al., 2001). See Figures 3A-D for detailed maps and descriptions.

We further divided the study region by 50 km^2 cells to quantify species richness on a finer scale. Several different biodiversity hotspots emerged from this analysis (Figure 2). Three of the four hotspots fall within the Annamite Range Moist Forest. This mountain range, spanning Laos and Viet Nam (and just over the border into southeast Cambodia), is one of the largest and last contiguous forests in all of continental Asia (WWF, 2021). As a "sky island" (i.e., a high elevation area that is geographically isolated), the Annamites act as drivers of diversification and are a hotspot for endemism (McCormack et al., 2009). Our analysis indicates that twenty-three threatened or Data Deficient species of oak are distributed within the Annamite Range, highlighting the region's significance for conservation and for maintaining the genetic diversity of the genus. Descriptions of each biodiverse region (defined here as containing six or more target species) highlighted in Figure 2 are on pages 23-24. Figures 3A-D show that a majority of occurrence points within the four hotspots are found within protected areas. In fact, of the 1,272 total occurrence points in our dataset, 52% are within protected areas. This pattern may reflect the true distribution of these species, given habitat loss outside protected areas. However, it is also likely that this is due to sampling bias within protected areas. More survey work should take place in suitable habitat outside of formally protected areas to determine the true protected area coverage of target species within the region.

Quercus myrsinifolia flower (Atsushi Motohashi)

A) Doi Inthanon National Park, Thailand (6 species): Doi Inthanon National Park is located in Chiangmai Province in Northwestern Thailand (Figure 3A). Over 20,000 people live within the park, where they grow primarily rice, corn, and coffee, as well as fruit, vegetables, and flowers (Meemana & Yujun, 2019). Often referred to as the "summit" of Thailand, Doi Inthanon National Park has an elevation ranging from 400 m by the park entrance to 2,565 m near the northern summit (Teejuntuk et al., 2002). The most common forest community type within the park is montane forests (41.50%), followed by mixed deciduous (15.93%), dry dipterocarp (9.84%), pine-dipterocarp (7.49%), pine-oak (1.21%), and dry evergreen (0.75%; Faculty of Forestry, 1992). Just south of Doi Inthanon is Ob Luang National Park. This park is 560 km^2 and composed primarily of mixed deciduous forest, moist evergreen forest, and deciduous dipterocarp forest (Tourism Authority of Thailand, 2026).

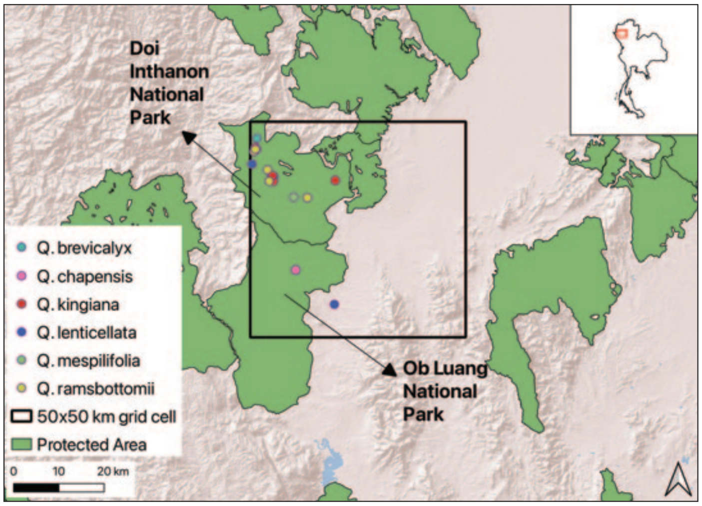


Figure 3A. Wild occurence points of target oak species in Doi Inthanon National Park and surrounding areas.

B) Vu Quang National Park and Huong Son District, Viet Nam (7 species). Vu Quang National Park (Ha Tinh, Central Highlands) was declared an Association of Southeast Asian Nations (ASEAN) Heritage Park in 2018 (Figure 3B). ASEAN Heritage Parks are "protected areas of high conservation importance, preserving in total a complete spectrum of representative ecosystems" of Southeast Asia (ASEAN Center for Biodiversity, 2024). Two target species occur outside of this protected area in Huong Son District, north of the national park. Illegal timber extraction is a major threat, with approximately 6,000 households from eight neighboring communities relying on the national park to meet their fuelwood requirements (Hughes et al., 2004).

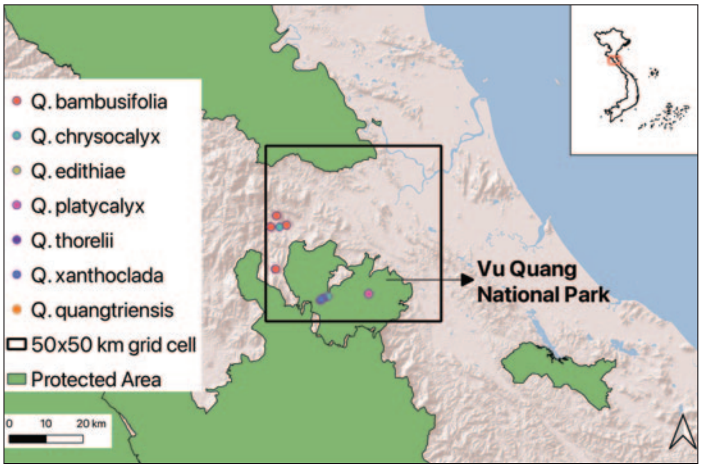


Figure 3B. Wild occurence points of target oak species in Vu Quang National Park and surrounding areas.

Surveying for oaks in Gyeongsangbuk-do, South Korea (Jae-Sun Yi)

C) Chu Yang Sin and Bidoup-Nui Ba National Parks, Viet Nam (7 species). Bidoup-Nui Ba National Park (Lam Dong Province, Central Highlands) is within the core zone of the Langbiang Biosphere Reserve (Figure 3C). The National Park exhibits high floristic diversity, with over 2,000 species of vascular plants (Dat et al., 2021). Habitat includes subtropical evergreen rainforests and low montane subtropical forests (Bidoup-Nui Ba National Park, 2018). Chu Yang Sin National Park (Dak Lak Province, Central Highlands) is considered to be one of the least disturbed protected areas in Viet Nam, with mostly intact forest (BirdLife International & FIPI, 2001). The park ranges in elevation from 600–2,445 m and includes Chu Yang Sin Mountain, the highest mountain in Dak Lak Province.

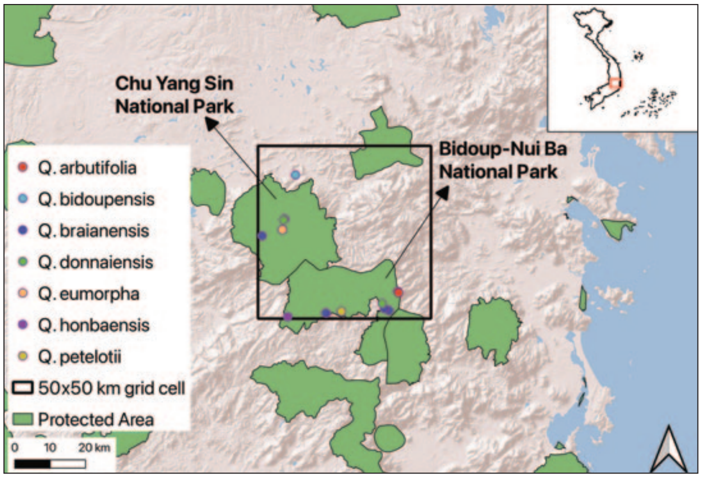


Figure 3C. Wild occurence points of target oak species in Chu Yang Sin and Bidoup-Nui Ba National Parks.

D) Hon Ba Nature Reserve and Nui Chua National Park, Viet Nam (6 species). Hon Ba Nature Reserve (Khanh Hoa, South Central Coast) has two primary forest types: mid-elevation submontane evergreen moist forest and low-elevation tropical evergreen seasonal broadleaf forest (So, 2017; Figure 3D). The Nature Reserve has high plant diversity, with over 1,400 species of plants identified, 15% of which are classified as rare or endangered (So, 2017). Nui Chua National Park (Ninh Thuan, South Central Coast) is a UNESCO World Biosphere reserve in an arid region of Viet Nam. Conservation tourism is the main activity in the park, attracting 200,000–300,000 visitors annually (Le, 2024).

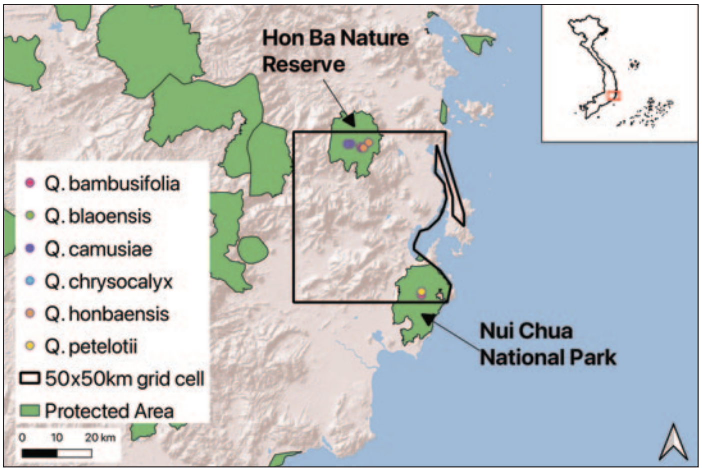


Figure 3D. Wild occurence points of target oak species in Hon Ba Nature Reserve, Nui Chua National Park, and surrounding areas.

SPECIES WITH ONE KNOWN OCCURRENCE

Three of our target species have only one known occurrence in our database: *Quercus dankiaensis*, *Q. dilacerata*, and *Q. trungkhanhensis*. All three species are CR, with *Q. dankiaensis* considered possibly extinct. *Quercus dankiaensis* is a tree up to 30 m tall (Hélardot, 2018). It has been recorded from only Lam Dong Province (Dan Kia ward) in Viet Nam (Binh, 2017). It was last observed in 1934, and there has been no recent confirmation that the species still exists in this locality (Carrero & Strijk, 2020a). *Quercus dilacerata* is known from Lao Cai Province, Lo Qui Ho Pass in Viet Nam. Originally considered a synonym of *Q. langbianensis*, Binh et al. (2018a) now reclassify it as a morphologically distinct member of the *Q. langbianensis* complex. However, the authors note that DNA samples for *Q. dilacerata* are currently unavailable, and further molecular study is needed to confirm its identity. Similarly, *Q. trungkhanhensis*, a tree 5–10 m tall, is known only from Cao Vit Gibbon Conservation Area in Cao Bang Province, Trung Khanh District, Viet Nam (Binh et al., 2018b). As a recently described species with only two known individuals, it is critically rare. These three single-occurrence endemics should be prioritized for future field surveys.

EX SITU COLLECTIONS AND SPATIAL ANALYSES

Forty-five institutions from 12 countries submitted accession data for *Quercus* in response to our *ex situ* collections surveys from 2021 to 2025. We also considered the 267 institutions that submitted *Quercus* accessions data from 2017 to 2022 as part of previous gap analyses (Appendix A). Of the 304 unique institutions that submitted survey data, 172 reported accessions of at least one species of SE-E Asian oak (Figure 4). Surprisingly, there are only 17 (10%) institutions located within Asia that reported having one or more species of SE-E Asian oak in their collection. A majority of institutions reporting SE-E Asian oaks are in the United States and Canada (77 institutions, 45%) and Europe (62, 36%). This may be the product of either the smaller number of botanic gardens in Asia compared to Europe and North America, or lower survey response rate from gardens in this region. It may also, in part, be influenced by historical patterns of plant collection during the colonial period, which contributed to the establishment of *ex situ* collections outside the region of origin. According to BGCI GardenSearch (2025c), there are 556 botanic gardens in Asia, 1,098 in Europe, and 1,150 in North America.

Only 26 institutions in 10 countries reported accessions of at least one species of threatened or Data Deficient SE-E Asian oak. The target species with the greatest representation in *ex situ* collections are *Q. tatakaensis* and *Q. tarokoensis* at 10 institutions each, followed by *Q. bambusifolia* at six institutions (Figure 5). This is in stark contrast with the number of gardens that hold Least Concern (LC) SE-E Asian oaks, which is often in the hundreds. For example, according to BGCI PlantSearch (2025b), two widespread and LC oaks, *Q. acutissima* and *Q. myrsinifolia*, are held in 207 and 99 *ex situ* collections, respectively. Threatened plants are rare in the wild, and as a result less likely to be accessioned into collections (Cano et al., 2025). However, if botanic gardens are to act as a solution to the plant extinction crisis, there must be a concerted effort to include threatened species within collections (Westwood et al., 2021).

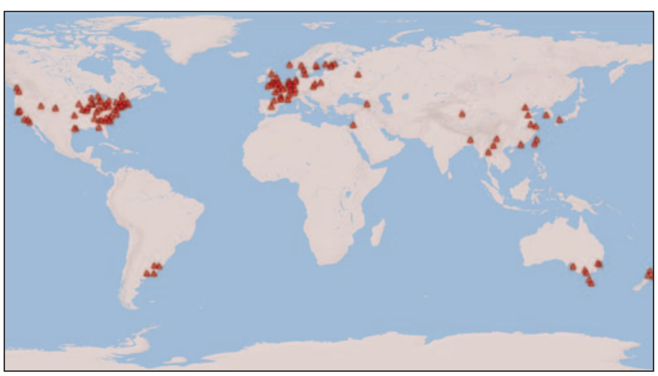


Figure 4. Location of institutions that responded to our *ex situ* surveys and reported having accessions of at least one species of Southeast or East Asian oak.

The species with the most plants living in *ex situ* collections are *Q. bambusifolia* (172 individuals) and *Q. xanthoclada* (161 individuals; Figure 6). Of the 14 target species that are in *ex situ* collections, seven species are held in collections of 10 or fewer individuals, and three species are represented by a single individual. On the positive side, a vast majority of plants in collections are wild origin or cultivated from wild individuals (93%). Of these, 82% had coordinates provided or were able to be geolocated based on a locality description. Only 7% of plants had a provenance type that was unknown or not given. Nine out of the 14 species are found in living collections in Asia, eight in Europe, and three in North America. Only one oak species assessed as CR is found in *ex situ* collections: *Quercus camusiae*, which is reported in one botanic garden in Asia. The rest are EN (four species), VU (two species), or DD (seven species).

Quercus restoration planting in Viet Nam (Nguyen Van Ngoc)

There are 40 threatened or DD SE-E Asian oak species that are not found in any collection anywhere in the world, according to the results of our ex *situ* surveys. This is a significantly greater number of species than was identified in previous gap analyses of the other two major oak biodiversity hotspots: Mesoamerica (22 species not in collections) and the USA (one species not in collections). There is an urgent need to increase representation of threatened SE-E Asian oaks within ex *situ* collections worldwide.

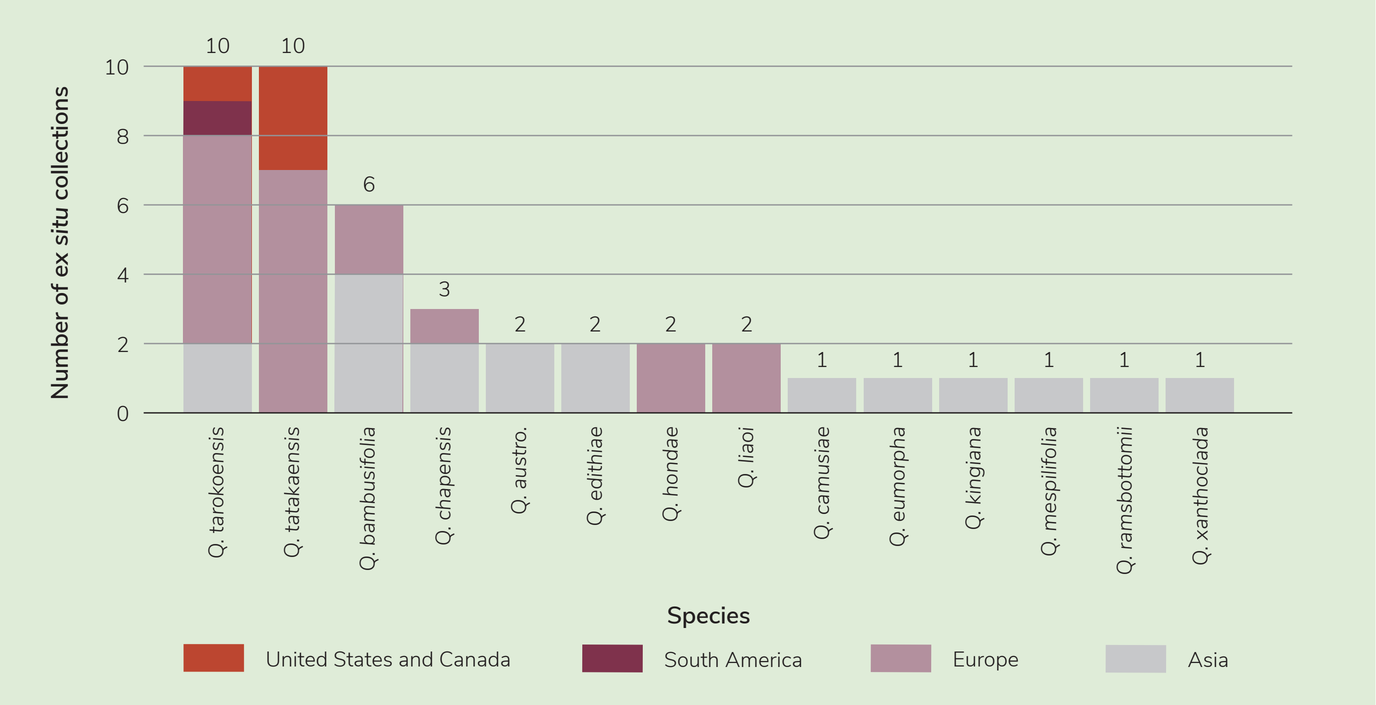


Figure 5. Number of ex *situ* collections of threatened or Data Deficient Southeast and East Asian oak species, categorized by ex *situ* collection location. *Q. austro* = *Quercus austrocochinchinensis*

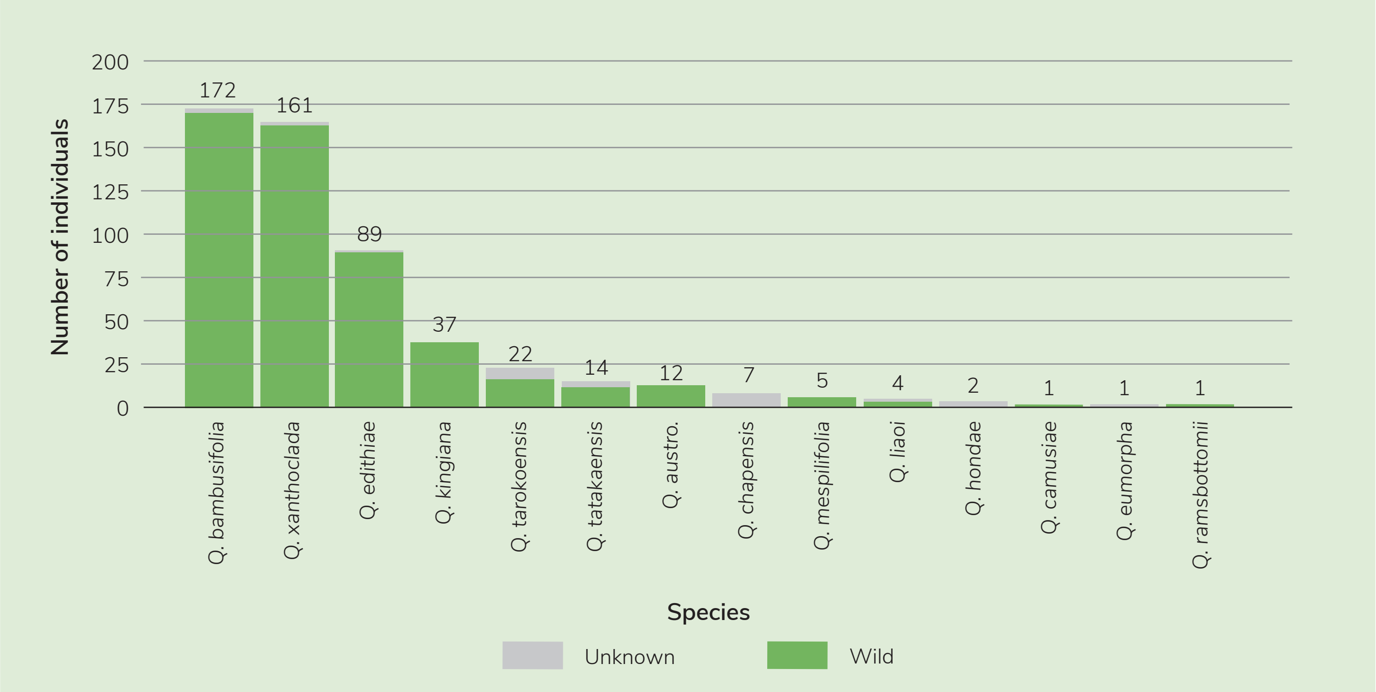


Figure 6. Number of plants per target species in ex *situ* collections, categorized by provenance type. *Q. austro* = *Quercus austrocochinchinensis*

In the absence of comprehensive genetic data, we relied on two surrogate measures to approximate how well *ex situ* collections capture genetic diversity present in the wild: geographic coverage and ecological coverage. These measures are based on the premise that safeguarding a species' genetic variation requires sampling throughout its full native range and across all ecoregions where the species is found. In this analysis, we delineated native range using 50 km buffers around *in situ* occurrence records; however, this approach provides only an estimate of a species' range and should be interpreted cautiously. In addition, it should be noted that our *ex situ* collection points could represent a collection composed of hundreds of plants or just one individual. Evidence suggests that conserving genetic diversity and evolutionary potential may require seed collections from hundreds to more than a thousand individuals sampled across a species' range (Hoban, 2019). Despite these limitations, the spatial analyses presented here offer a framework for identifying priority species, regions, and ecoregions to guide future collecting efforts.

Of the 14 species of SE-E Asia oak that are in *ex situ* collections, we found that 12 had a geographic coverage of less than 10%. The two species with geographic coverage greater than 10% are *Q. tatakaensis* (24%) and *Q. tarokoensis* (41%). All target species of SE-E Asian oak are lacking significant geographic representation in collections. In fact, most are collected from a single location, regardless of range size. Take for example *Q. bambusifolia*; this Endangered species is found throughout southern mainland China, Hainan, Hong Kong, and into central Viet Nam. Despite its wide range (EOO = 912,110 km^2), 123 out of the 125 individuals with detailed provenance information were collected from Hong Kong, resulting in geographic coverage of only 3%.

In all cases, ecological coverage was greater than geographic coverage. This is to be expected, especially for species that occur in a small number of large ecoregions. Ecological coverage ranged from 20% to 82% (median = 34%) for the 14 species in *ex situ* collections. The species with the greatest ecological coverage is *Q. tarokoensis*. This species occurs primarily in the subtropical wet forest, with scattered occurrences in warm temperate wet forest. There are *ex situ* collections of *Q. tarokoensis* with wild provenance from both of these ecoregions. Sampling within all ecoregions in which a species is found is one way to attempt to represent the full spectrum of geographic diversity in *ex situ* collections. However, it should be noted that this may not fully capture local adaptations to microclimate differences within an ecoregion (Hoban & Strand, 2015; Zumwalde et al., 2022).

Ecological coverage is an indicator of how well ex *situ* collections represent the ecological range of the native population. It is calculated by dividing the total number of ecoregions under the *ex situ* buffer area by the total number of ecoregions under the *in situ* buffer area.

Geographic coverage is an indicator of how well the ex *situ* collections represent the geographical range of the native population. It is calculated by dividing the total buffer area around ex *situ* wild provenance collection points by the total buffer area around all *in situ* points.

IN SITU SPATIAL ANALYSES

In order to characterize the degree of *in situ* conservation efforts for each target species, we estimated the percentage of a species' inferred native range that is covered by protected areas. While there is no established rule for how much protected area a species needs, ideally species with small ranges, as is the case for many threatened oaks in SE-E Asia, would have virtually all of their habitat protected. For example, the Species Protection Index is a measurement of how well protected areas conserve a species' habitat (E.O Wilson Biodiversity Foundation, 2025). This index sets a protected area target of 100% for species with a range less than 1,000 km^2 and 15% for species with a range less than 250,000 km^2, with a log linear relationship for species that fall between this range. We found that none of our target species have 100% of their inferred native range covered by protected areas (Figure 7). In fact, they all fall well below this threshold. The species with the greatest protected area coverage are *Q. xuanlienensis* (38%), *Q. lenticellata* (37%), *Q. steenisii* (32%), and *Q. blaoensis* (31%). All remaining target species have less than 30% of their inferred native range within protected areas. The species with the largest range sizes are *Q. chapensis* (EOO = 1,463,180 km^2) and *Q. mespilifolia* (EOO = 1,426,696 km^2), which have 11% and 29% of their native range covered by protected areas, respectively.

The protected areas with the greatest number of target species are Bidoup-Nui Ba National Park and Vu Quang National Park in Viet Nam, at six species each. Bidoup-Nui Ba stands out in particular due to the results of a high resolution, but geographically restricted, study that recognised three new species, and reinstated several synonyms to accepted species (Binh et al., 2018a). As a full review of standing collections was not performed, field surveys were limited, and many of these species are hard to distinguish when sterile, it is possible that one or more of these six species (and the other four treated in the study) may occur in other protected areas described in this analysis.

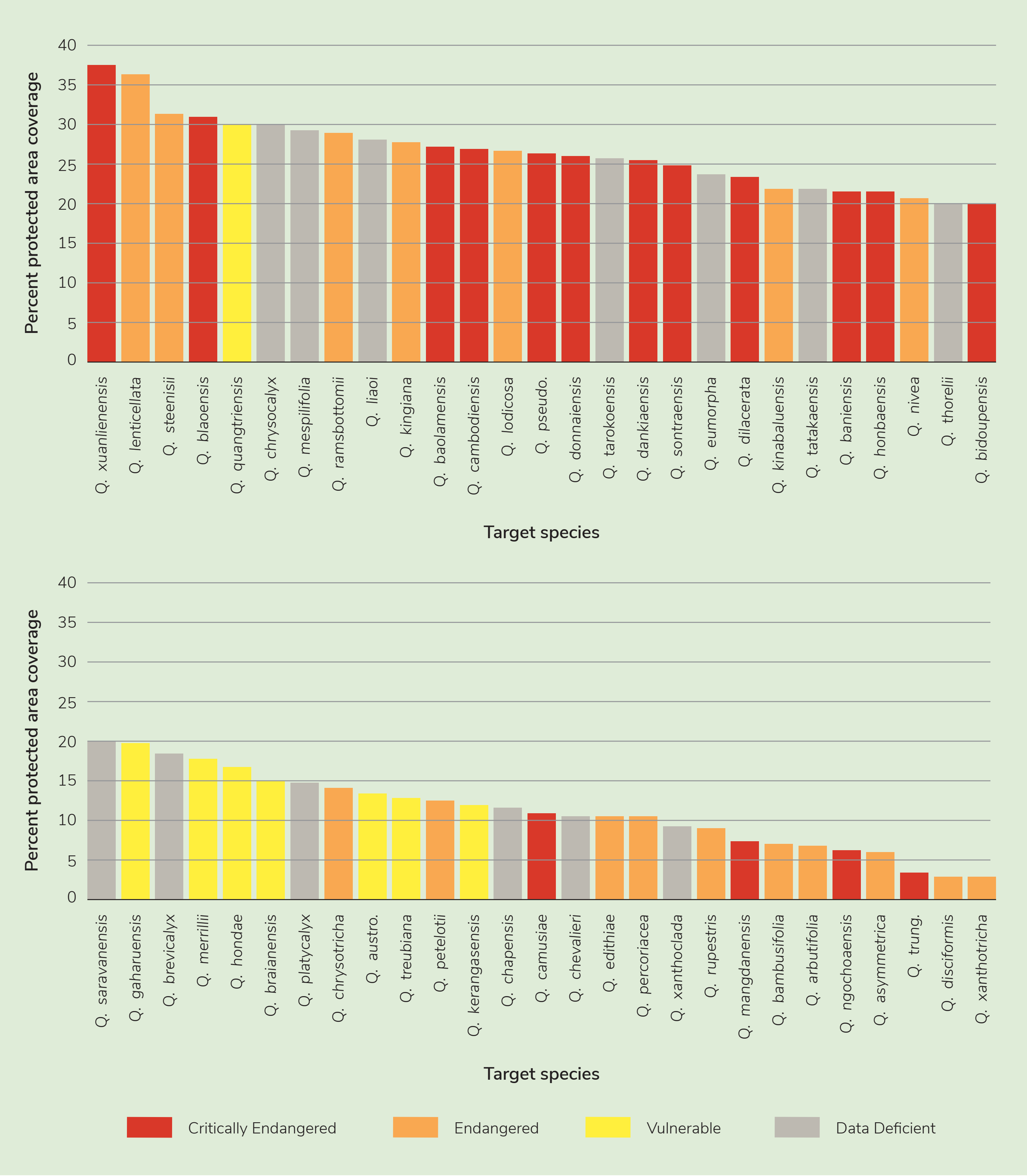


Figure 7. Percent protected area coverage within the inferred native range for each target species. *Q. pseudo.* = *Quercus pseudoverticillata*, *Q. austro.* = *Quercus austrocochinchinensis*, *Q. trung.* = *Quercus trungkhanhensis*

Table 2. The total number of protected areas and the percentage of protected area coverage for our study region.

	Cambodia	Japan	Taiwan	Laos	Thailand	Philippines	Malaysia	Indonesia	Viet Nam	Myanmar
Total number of protected areas *	69	6,954	92	31	239	274	528	699	192	54
Percent coverage of protected areas	40%	30%	20%	19%	18%	16%	13%	12%	8%	7%

* Note: according to the World Database on Protected Areas (WDPA), "Some geographic locations are designated more than once, e.g., as both a National Park (a national designation) and a World Heritage Site (an international designation). In the WDPA, these designations are counted as separate protected areas, meaning this number might appear higher than expected." (UNEP-WCMC and IUCN, 2026)

Across the study region, the effectiveness of protected areas in safeguarding threatened Fagaceae can be compromised by a disconnect between legal designation and on-the-ground enforcement. Within our study region where target species are found, Cambodia has the greatest percentage of land area covered by protected areas at 39.75%. In 2023 alone, Cambodia added more than one million hectares of land to its protected area network. However, continued deforestation and privatization of protected areas in Cambodia, coupled with a Ministry of Environment that is overstretched and underresourced, indicate that protected areas here may be ineffective in preventing biodiversity loss (Flynn, 2023). In contrast to Cambodia, Myanmar has the least protected area coverage at 6.69% (Table 2). Myanmar is an extremely biodiverse country within Southeast Asia, with over 62% of its land area covered by natural forest (Global Forest Watch, 2026). This country has a relatively small protected area system and forested areas face increasing threats, primarily due to agricultural expansion, legal and illegal logging, consumption of fuelwood and charcoal, road construction, mining, and dams (Naing Tun et al., 2021). From 2001 to 2024, Myanmar has lost 5.1 Mha of tree cover, which is equivalent to 12% of the tree cover area for the year 2000 (Global Forest Watch, 2026).

Within Viet Nam, forested land is divided into three categories: production forests, protected forests, and special use forests. Production forests are used for growing and harvesting timber and other forest products. This is the largest forest type by area in Viet Nam, at 80,000 km^2 as of 2020 (Ministry of Agriculture and Rural Development, 2021). Protected forests are used primarily to protect water resources, as well as prevent erosion, protect soil, and regulate climate (World Resources Institute, 2014). Special use forests are protected areas used mainly to conserve nature and its biodiversity. This is the smallest forest type by area, at just over 20,000 km^2 as of 2020. Special use forests are further divided into five categories that provide different levels of protection: 1) national parks, 2) nature reserves, 3) species and habitat reserves, 4) landscape protected areas, and 5) scientific forests (KimDung et al., 2017). Threatened oak species in Viet Nam are most commonly found in nature reserves and national parks (Appendix D).

Protected areas, in addition to being the cornerstone of biodiversity conservation, also allow for protection of species that are economically and culturally important, such as oaks. For example, in Japan, oaks are considered a sacred tree and a symbol of prosperity. *Quercus hondae*, the only threatened oak in Japan, is predominantly found near shrines (Kamiya et al., 2022). The forests within and surrounding shinto shrines in Japan are termed *Chinju no Mori*, meaning "guardian forest" and are generally well preserved, if not formally protected (Nilzén, 2022; see Case Study 4 for more information on oaks and Japanese culture). The establishment of protected areas should, where appropriate, incorporate biocultural conservation (e.g., integrating plant conservation with the cultural practices, beliefs, and traditional knowledge of local communities) as well as the inclusion of sacred and culturally significant sites.

CASE STUDY 3:
Quercus in Korea: Distribution, ecology, and conservation

Authors: Yun-Ha Kim (Baekdudaegan Conservation Office), Jun-Gi Byun (Baekdudaegan Conservation Office), and Yong-Shik Kim (Yeungnam University)

Figure 1 (left): A protected *Quercus variabilis* tree designated as a Natural Monument in Daegok-ri, Andong (Yun-Ha Kim, Baekdudaegan Conservation Office). **Figure 2** (right): A *Quercus mongolica* dominated deciduous broad-leaved forest on a mountain slope (Yun-Ha Kim, Baekdudaegan Conservation Office).

Oaks are a major component of East Asian forest vegetation and a key group for understanding vegetation transitions on the Korean Peninsula. Korea lies at the junction of temperate deciduous broad-leaved forests in the north and warm-temperate evergreen broad-leaved forests in the south, and *Quercus* clearly reflects both the continuity and contrast between these two forest zones. Korean oaks are important not only to forest structure and ecosystem function, but also to long-standing resource use and cultural life. This overview summarizes the distribution, ecological and cultural significance, major threats, and current conservation and research trends of representative native oaks in Korea.

Species Composition of Korean Oaks

The native oaks of Korea comprise a relatively diverse assemblage within their distribution range, and can be divided into two broad groups. The first includes six deciduous species that are widespread across the country: *Quercus acutissima*, *Q. variabilis*, *Q. mongolica*, *Q. serrata*, *Q. dentata*, and *Q. aliena*. The second includes five evergreen species found mainly in southern Korea and on Jeju Island: *Q. myrsinifolia*, *Q. acuta*, *Q. glauca*, *Q. salicina*, and *Q. gilva*. Because species counts vary depending on the treatment of hybrids, a general overview is most effectively framed around these 11 native species.

Distribution and Vegetation Zones

Across East Asia, the deciduous oaks of Korea are associated with the temperate deciduous broad-leaved forest zone, whereas the evergreen oaks are linked to the warm-temperate evergreen broad-leaved forest zone. Some evergreen species in Korea occur near the northern limit of their broader range.

Within Korea, deciduous oaks are widely distributed and form core components of inland deciduous broad-leaved forests in mountains and hills (Figure 1, 2). Evergreen oaks are largely confined to warm-temperate habitats on Jeju Island, the southern coast, and southern offshore islands. Korean oaks thus provide a clear example of how temperate deciduous forests and warm-temperate evergreen forests meet and overlap within a relatively small area.

Ecological Importance

Oaks play a central structural and functional role in Korean forest ecosystems. Deciduous oaks are among the defining elements of mainland broad-leaved forests, while evergreen oaks are essential to the persistence and biogeographic distinctiveness of southern warm-temperate forests. Many evergreen oaks show narrow and discontinuous distributions in restricted southern areas, giving them significance beyond a simple species inventory. As a group, Korean oaks provide a useful framework for linking vegetation-zone boundaries, climate adaptation, and long-term forest change.

Cultural and Resource Value

In Korea, oaks have long held both ecological and cultural value. Deciduous oaks have traditionally been used for timber, charcoal, and mushroom-log production, and acorns have long been part of Korean food culture, especially in foods such as acorn jelly and acorn pancakes.

This history of use makes oaks more than dominant forest trees; they are also familiar cultural species closely tied to daily life. Their conservation value therefore extends beyond ecology alone and includes a strong cultural dimension.

Major Threats

One of the most important threats facing Korean oaks is oak wilt. First reported in Seongnam, Gyeonggi Province, in 2004, the disease has since spread widely across the country. Current research links oak wilt in Korea to the ambrosia beetle *Platypus koryoensis* and pathogenic fungi, with especially severe damage reported in *Quercus mongolica*.

Climate change adds a long-term pressure by altering habitat suitability and shifting distributional boundaries. Studies on vegetation and habitat suitability on the Korean Peninsula suggest that continued warming may expand the potential range of warm-temperate evergreen broad-leaved forests northward. These changes could reshape existing vegetation zones, while the interaction of pests, pathogens, and climatic stress may further affect forest health and ecosystem stability.

Conservation and Research

Conservation and research on Korean oaks are progressing along several lines. Under the IUCN Red List, all 11 species treated here are classified as Least Concern (LC), whereas Korea's national red list recognizes *Quercus gilva* as Endangered (EN) and places the other 10 species in LC.

Quercus gilva deserves particular attention. Across East Asia, it has been associated with population decline, small population size, and low genetic diversity, and the Jeju populations lie near the edge of both the East Asian evergreen broad-leaved forest zone and the species' overall range, giving them clear conservation and biogeographic importance. In response, the Baekdudaegan National Arboretum carried out conservation work on *Q. gilva* in 2024, including seed quality management, nursery production, and transplanting into natural habitat, and is continuing to monitor planted individuals in substitute habitats within the Gotjawal forests of Jeju.

Among evergreen oaks, a representative line of research in Korea has focused on plus-tree selection in *Q. salicina* and *Q. glauca*. Surveys of natural populations in southern Korea and on Jeju Island identified candidate and plus trees, and emphasized the need to integrate utilization with genetic conservation. The results also suggest that evergreen oaks may have value as future reforestation species under a warming climate.

Research on deciduous oaks has focused less on threatened-species conservation itself and more on distributional patterns, climate responses, and restoration and management strategies. Studies on the distribution and habitat characteristics of six deciduous oak species in Korea, on germination and early growth under warming conditions, on phenological responses to climate change, and on the community structure and growth rates of *Q. mongolica* forests, provide an important basis for future *in situ* conservation and restoration planning.

Taken together, current research on Korean oaks spans threatened-species conservation, climate adaptation, restoration, and future silvicultural potential, providing a strong foundation for setting conservation priorities and refining both *in situ* and *ex situ* strategies.

Conclusion

Korean oaks are a key taxonomic group for understanding the vegetation history of the Korean Peninsula, the present structure of its forests, and their future responses to climate change. Viewed together, the temperate deciduous oaks of inland Korea and the warm-temperate evergreen oaks of the south make Korea a distinctive meeting ground for northern and southern elements of East Asian oak diversity. A clearer phytogeographic understanding of Korean oaks can help fill an important regional gap in broader discussions of oak conservation across East Asia.

CASE STUDY 4:
The relationship between the family Fagaceae and Japanese culture: A case study on cognition, foodways, livelihoods, and culture

Author: Atsushi Motohashi (Wildlife Management Office Inc.)

In Japan, plants belonging to the family Fagaceae are broadleaf trees distributed almost nationwide. The Japanese archipelago is home to 22 native Fagaceae species, primarily encompassing the genera *Fagus*, *Quercus*, *Lithocarpus*, *Castanopsis*, and *Castanea* (Yokoyama, 2006). The interactions between Fagaceae and human culture in Japan are exceptionally diverse. This case study examines the relationship between the family Fagaceae and Japanese culture through the lenses of cognitive representation, foodways, livelihoods, and culture.

Cognitive Representation of Fagaceae

First, the acorns of Fagaceae species are highly familiar to the Japanese populace. The collective term *donguri* is widely used across all demographics, from children to the elderly. However, despite the widespread use of this generalized term, specific species names often remain insufficiently recognized (Motohashi, unpublished data). Research investigating the visual representations of acorns among the Japanese populace has demonstrated a tendency to draw an elongated acorn capped with a cupule (Motohashi & Fujimoto, 2024). Furthermore, regarding cupule morphology, while many drawings feature scale-like textures characteristic of species such as *Q. serrata*, anomalous depictions of plain or irregularly lined cupules—which do not exist in the natural environment of Japan—have also been observed. It is possible that modern cultural designs, such as commercial products and illustrations featuring acorn motifs encountered in daily life, significantly influence human cognition and contribute to the emergence of these stylized representations.

Foodways

In contemporary contexts, the culture of acorn consumption is locally preserved as traditional regional cuisine, exemplified by *shidami dango* (acorn dumplings) in Iwate Prefecture and *donguri mochi* (acorn rice cakes) in Nagano Prefecture (Ministry of Agriculture, Forestry

Tama City, Tokyo, where numerous cultivated and wild *Quercus* species can be routinely observed.

and Fisheries, 2025). While acorn consumption in Japan is generally less commonplace compared to other Asian regions—such as South Korea, where dotorimuk (acorn starch jelly) is widely distributed—modern Japanese recipes incorporating acorns are showing signs of diversification. Gastronomic innovations fusing traditional foodways with modern adaptations, such as coffee, tea, cookies, and noodles derived from these acorns, have been documented (Motohashi et al., 2025a). In particular, *L. edulis* and *C. sieboldii* are favored in modern cooking workshops for being relatively easy to process, owing to their low tannin content compared to other native species. Indeed, domestic initiatives have reported the development and production of craft beer utilizing *L. edulis* acorns as a strategy for regional revitalization (Motohashi et al., 2025b). Furthermore, the significance of *C. crenata* is particularly noteworthy. As a culturally vital species in Japan, it is widely cherished as a quintessential symbol of autumnal gastronomy. According to public interest assessments utilizing Wikipedia pageview data, among the 22 native Fagaceae species, *Castanea crenata* garners overwhelmingly high pageviews (both daily and monthly), peaking primarily during the autumn season (approximately August to October), when it is most frequently consumed.

Livelihoods and Culture

The family Fagaceae is deeply integrated into daily life and culture. The utilization of these species in urban landscaping and as street trees is prominent; for example, in Tama City, Tokyo, numerous cultivated and wild species—including *Q. serrata*, *Q. acutissima*, *L. edulis*, *Q. myrsinifolia*, *Q. glauca*, and *C. sieboldii*—can be routinely observed (Motohashi et al., 2024). Additionally, Fagaceae timber has been utilized since antiquity for construction materials, furniture, and agricultural implements. Household items such as wooden spoons crafted from Fagus and miscellaneous goods featuring acorn motifs are sold. Culturally, for example, previous research has indicated that *Quercus dentata* attracts anomalously high public interest leading up to May (Motohashi, 2022). This is largely attributed to the traditional Japanese food culture of consuming *kashiwamochi*—a rice cake enveloped in a *Q. dentata* leaf—during the *Tango no Sekku* (the Boys' Festival) on May 5th to pray for the prosperity of descendants. Moreover, ancient Fagaceae specimens are frequently preserved within Japanese shrines and parks. Nationwide, there are documented cases of these trees being protected and managed as natural monuments, exemplified by the *C. sieboldii* specimens in Tama City (Motohashi et al., 2024).

Conclusion

While this case study has introduced several examples, numerous other diverse interactions between humans and Fagaceae species exist. However, academic documentation of these relationships remains sparse, with much of the knowledge confined to local contexts within the Japanese-language literature. Therefore, academic documentation through action research and web data analysis, as demonstrated in this study, provides crucial insights for re-evaluating the relationship with Fagaceae species and designing future conservation strategies and economic activities.

Fagaceae-dominated forest in Bidoup Nui Ba National Park, Viet Nam (The Morton Arboretum)

Fagaceae-dominated forest near the summit of Phou Bia, Laos (Oudomphone Insisiengmay)

KEY BIODIVERSITY AREAS

Key Biodiversity Areas (KBAs) are sites that are determined to be critically important for the persistence of global biodiversity. They are identified through a globally standardized, science-based framework that allows conservation priorities to be compared consistently across regions and ecosystems. KBAs play a critical role in the implementation of the Convention on Biological Diversity's (CBD) Kunming–Montreal Global Biodiversity Framework (KMGBF) by informing multiple goals and targets. Specifically, KBAs guide spatial planning for biodiversity conservation (Target 1), help prioritize sites for ecosystem restoration (Target 2), and support the expansion of protected and conserved areas under the 30 × 30 commitment (Target 3). In addition, KBAs support strategic species conservation efforts (Target 4), help mainstream biodiversity conservation by identifying globally significant sites (Target 14), assist the private sector in assessing, reporting, and minimising biodiversity impacts (Target 15), and contribute to evidence-based conservation policy through the use of biodiversity data (Target 21; KBA Partnership, 2025).

Ideally, KBA criteria should be applied to all species and ecosystems with available data within a country. Incorporating multiple taxonomic groups into KBA assessments ensures that these sites maximize their effectiveness in conserving biodiversity. Of the 17,608 KBA trigger species globally, only 35.8% are plants (BirdLife International, 2026). This percentage is even smaller in SE-E Asia, where 5% of trigger species are plants. Here, we focus on adding oaks as potential trigger species to KBAs within SE-E Asia.

Our analysis identified six oak species that meet at least one criteria for KBA designation (Figure 8). For four of these species, the majority of known wild occurrences fall within a currently established KBA, making them ideal candidates for inclusion as a trigger species. Notably, *Q. sontraensis*, *Q. trungkhanhensis*, and *Q. xuanlienensis* meet criteria A1e for designation as a KBA trigger species. This criterion relates to a region that holds effectively the entire population size of a CR or EN species. *Quercus sontraensis* (CR) is found exclusively within the Son Tra KBA (Figure 8A). Son Tra, first identified as a KBA in 2012 and reassessed in 2023, also holds the entire known population of the Rowley's Litter Toad (*Leptobrachella rowleyae*; Key Biodiversity Areas Partnership, 2026a). Similarly, all the known occurrences for *Q. trungkhanhensis* (CR) are within the Trung Khan KBA (Figure 8B). Trung Khan was designated as a KBA in 2018, with the Cao-vit Crested Gibbon (Nomascus nasutus) as a trigger species (Key Biodiversity Areas Partnership, 2026b). *Quercus xuanlienensis* (CR) is confined to the Xuan Lien KBA established in 2012 (Figure 8C), where several threatened species are also found, including Gaur (*Bos gaurus*) and Chinese Hickory (*Carya sinensis*; Key Biodiversity Areas Partnership, 2026c). The high degree of spatial congruence between these CR oaks and existing KBAs underscores the critical importance of these sites for preventing the extinction of site-endemic Fagaceae.

Quercus steenisii meets criterion A1a for designation as a KBA. Criteria A1a designates a region with >0.5% of the total population size and >5 reproductive units of a CR or EN species as a KBA. Fifty percent of the known occurrence points of *Q. steenisii*, an EN species, occur within the Gunung Leuser KBA (Figure 8D) in Sumatra, Indonesia. Originally assessed in 2006, three bird species trigger the designation of this KBA: Mountain Serin (*Chrysocorythus estherae*), Rajah Scops-owl (*Otus brookii*), and Rufous-vented Niltava (*Niltava sumatrana*; Key Biodiversity Areas Partnership, 2026d).

Finally, we identified *Q. ngochoaensis* and *Q. baniensis* as species that are not currently found within an existing KBA, but could meet the criteria to establish a new KBA. *Quercus ngochoaensis* has been preliminarily assessed as CR, with its entire known population within the Ba Vi National Park (Figure 8E). Only 20 reproductively mature trees have been identified (Binh et al., 2021). *Quercus baniensis* is also assessed as CR, with its entire known population within Ba Na-Nui Chua Nature Reserve (Figure 8F). In order to be designated as a KBA, a site must be "a geographical area on land and/or in water with defined ecological, physical, administrative or management boundaries that is actually or potentially manageable as a single unit (e.g., a protected area or other managed conservation unit)" (IUCN, 2016). The presence of *Q. ngochoaensis* and *Q. baniensis* within existing protected areas will provide support for the future designation of these sites as KBAs.

One potential challenge to both delineating a new KBA and adding threatened oaks as trigger species to an existing KBA is the age of data used to confirm that a threshold is met. Ideally, data should be collected within the last 12 years (IUCN, 2016). Occurrence data for oaks, especially rare and under-studied species such as those in SE-E Asia, is often several decades old. An exception to this is *Q. ngochoaensis*, a newly described species that has recent occurrence records. Outdated data may necessitate a new field survey before a species can be included in a KBA. This list is by no means comprehensive. As we update occurrence maps with new survey findings, we should evaluate whether these species justify updating or establishing new KBAs.

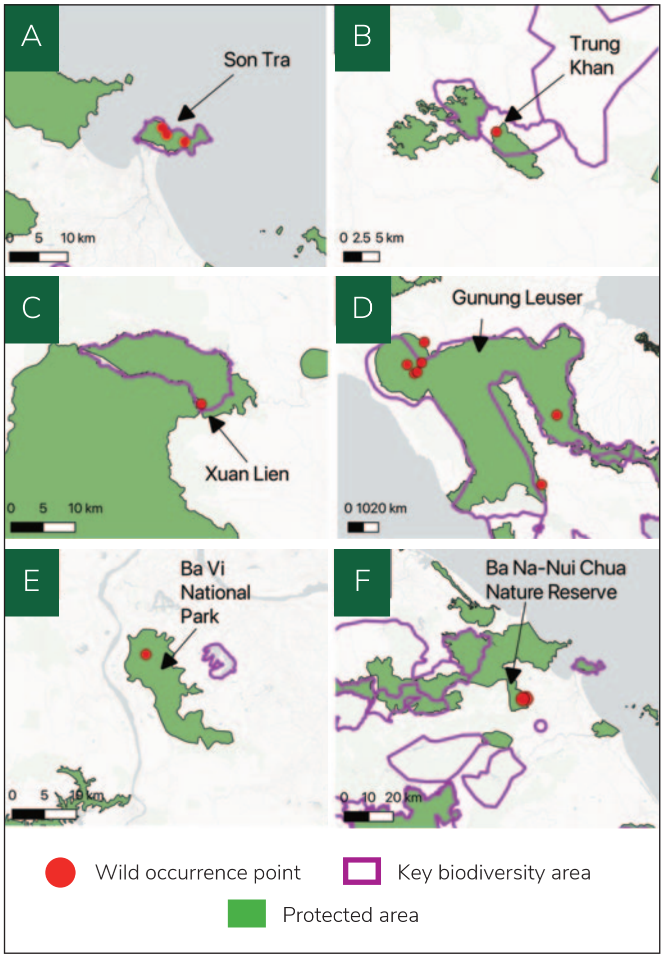


Figure 8. Wild occurrence points of A) *Quercus sontraensis*, B) *Q. trungkhanhensis*, C) *Q. xuanlienensis* D) *Q. steenisii*, E) *Q. ngochoaensis*, and F) *Q. baniensis* in relation to Key Biodiversity Areas.

HOLDRIDGE LIFE ZONES

The Holdridge life zone system uses mean annual precipitation, biotemperature, potential evapotranspiration ratio, latitude, and longitude in delimiting local ecosystems. Within SE-E Asia, there are 35 Holdridge life zones, 16 of which contain a threatened or DD species of oak (Appendix B; Figure 9). A majority of our target species occur in subtropical wet forest (67%), followed by subtropical moist forest (61%; Figure 9). This is not surprising, as these two life zones combined account for 68% of the land area within our study region. Subtropical wet forests are the dominant life zone within the Malay Archipelago, as well as central and southern Viet Nam, Laos, and Myanmar. Subtropical moist forest is found primarily in southern China, northern Viet Nam, northern Laos, and Thailand, as well as southern Viet Nam and central Myanmar (Figure 10). Warm temperate moist forest is a considerably smaller life zone in SE-E Asia at only 7% of our study area. It is found primarily in central Thailand and extends south through Cambodia, as well as southern Japan. Despite its relatively restricted range, this life zone is also important for oaks; twenty-six threatened or DD species occur within warm temperate moist forest.

In contrast to oak species in Mesoamerica (Good et al., 2024), most of our target species did not show a strong preference for one life zone. Of the 51 species with more than one occurrence point, only 18 (35%) had at least 75% of their occurrences within a single life zone. For example Q. *chapensis* is distributed across subtropical moist forest (37% of occurrences), subtropical wet forest (34%), warm temperate wet forest (12%), subtropical wet forest (12%), warm temperate dry forest (2%), and tropical dry forest (2%). Is it also true that most oaks in SE-E Asia are from wet ecosystems versus the western United States and Mexico, where they mainly inhabit dry habitats (Beckman et al., 2019; Good et al., 2024). Identifying preferred life zones for threatened species is essential for refining restoration strategies and planning field surveys. As additional surveys generate more occurrence data, clearer life zone preferences may emerge for these species.

Quercus acutissima (Atsushi Motohashi)

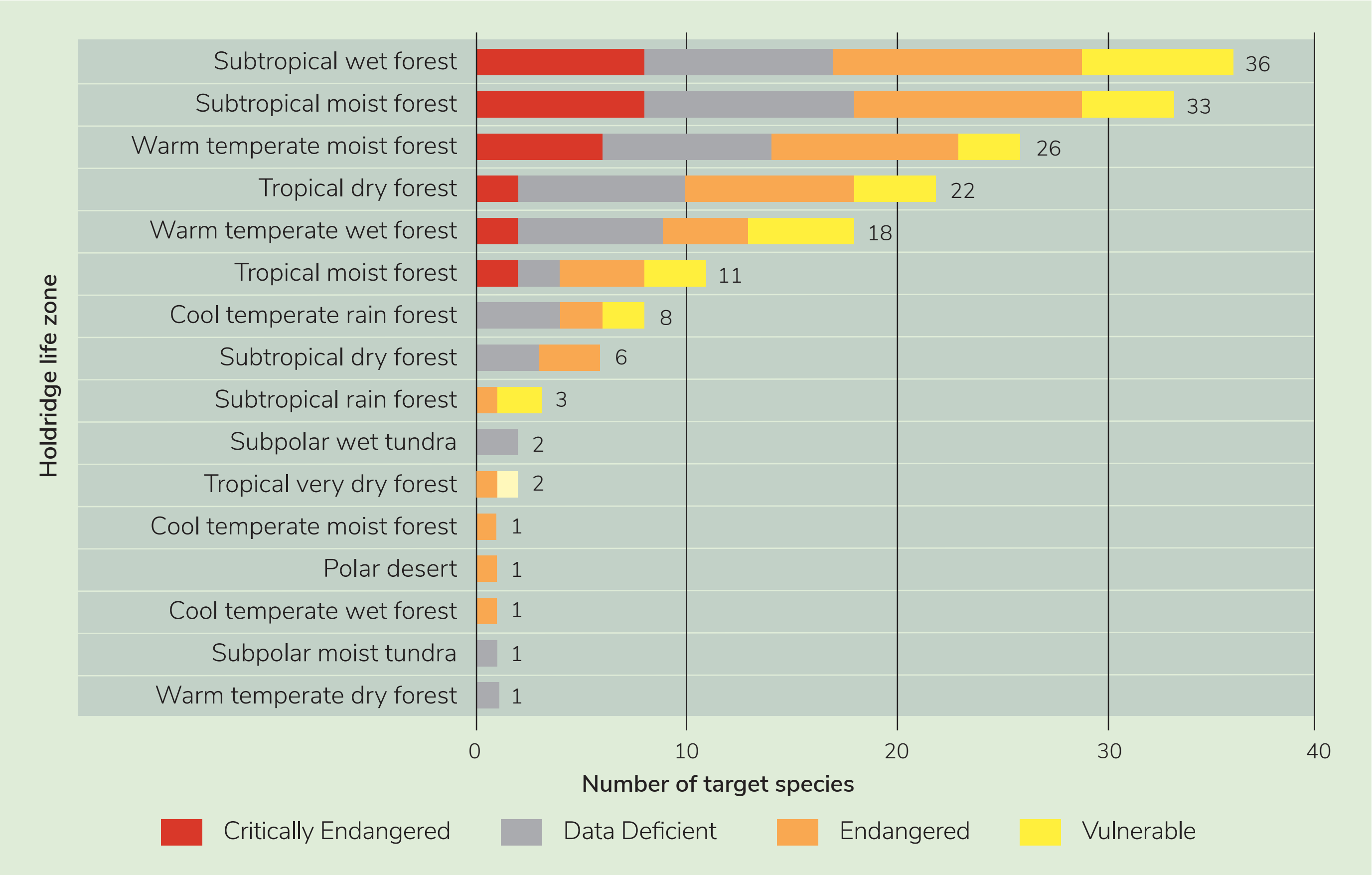


Figure 9. The number of target oak species within each Holdridge life zone in Southeast-East Asia, grouped by IUCN Red List category.

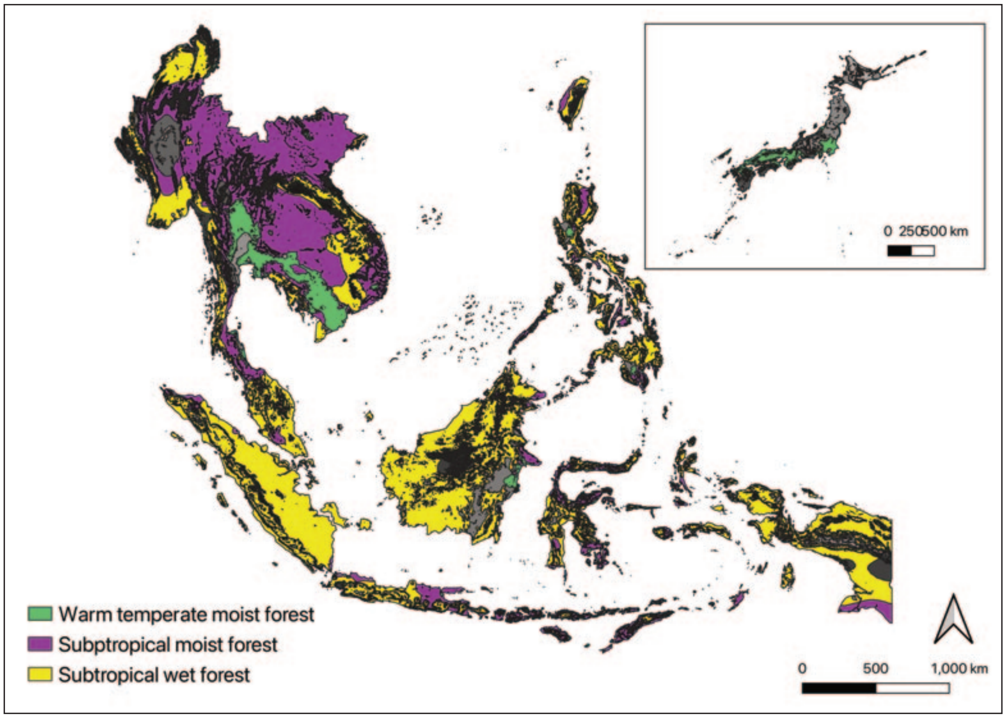


Figure 10. Holdridge life zones within the study region, with Japan in inset map. Subtropical wet forest, subtropical moist forest, and warm temperate moist forest are highlighted. All other life zones are in gray and black. See Appendix B for a detailed map of Holdridge life zones.

THREATS

We compiled information on the threats facing each of the 41 CR, EN, or VU oak species from the IUCN Red List, the Viet Nam Red List of Threatened Species, and literature review. Data Deficient species were excluded in this analysis, since specific threats for these species remain largely unknown. While the IUCN Red List recommends reporting the scope and severity of each threat to better understand its impact, this level of detail was unavailable for many of our target species. Consequently, further research is needed to fully quantify the degree of threat facing the oaks in this region.

The most common threat reported for oaks in SE-E Asia was agriculture, including wood and pulp plantations, which was reported to impact 27/41 species (66%). Agriculture is the most common threat to oaks globally, as reported by the Red List of Oaks (Carrero et al., 2020). Southeast Asia is undergoing some of the highest deforestation rates in the world, contributing substantially to global forest loss in tropical humid and lowland ecosystems (Estoque et al., 2019). Four Southeast Asian nations (Indonesia, Malaysia, Cambodia, and Laos) ranked among the top 10 in the world for humid tropical primary forest loss from 2002–2024 (World Resources Institute, 2025). Agriculture is the dominant driver of forest loss in all four countries. Since 1960, agricultural land in Southeast Asia has more than doubled, with an estimated 1.35 million km^2 in cultivation (FAOSTAT, 2024). Unshaded monocultures, such as oil palm and rubber plantations, are especially a concern, as they drastically reduce biodiversity. Between 2000 and 2021, oil palm and rubber driven deforestation in Indonesia and Malaysia increased by 82% and 250%, respectively (Rahman et al., 2025). Together, these two countries produce approximately 84% of the world's natural rubber (U.S. Department of Labor, 2026). In Cambodia, rubber plantations account for nearly a quarter of the deforestation

Logging truck in Malaysia (The Morton Arboretum)

(Grogan et al., 2019). In Laos, recent deforestation is driven by weak economic conditions and foreign investment, leading to rapid agricultural expansion (World Resources Institute, 2025). Other high "forest-risk" crops include coffee in Viet Nam (Meyfroidt et al., 2013), rice across Thailand, Indonesia, Viet Nam, Myanmar, and the Philippines (Propper et al., 2024), and bananas in Myanmar (Sarma et al., 2023).

Logging and wood harvesting represent the second most common threats to oaks in SE-E Asia (24/41 species, 59%). *Quercus* timber is traded together with the more common *Lithocarpus*, and is primarily used for medium to heavy construction and firewood (Sunarno et al., 1995). While logging is a pervasive threat throughout Southeast Asia, it is particularly acute in dipterocarp forests, which support a high diversity of valuable timber tree species (Struebig et al., 2025). As of 2019, Viet Nam became the second largest wood product exporter in Asia, after China (To, 2020). Of the 14.7 million ha of forests in Viet Nam, approximately 70% are natural. The remainder consists of plantations, primarily for timber production (Preferred by Nature, 2021). Despite a partial logging ban in natural forests since 1993, illegal logging is still widespread, especially in the central highlands of Viet Nam.

The third most common threat is extremely small tree population size, reported for 37% of the species (15/41). These 15 qualify as threatened in part or entirely under Criterion D, which is reserved for taxa with extremely small populations: <50 mature individuals for CR, <250 for EN, and <1,000 for VU taxa. Frequently, when a species is assessed as threatened using Criterion D, no additional threats are identified. For example, *Q. baniensis*, a Vietnamese endemic, is listed as CR (Criterion D). The Red List assessment for this species states, "There is little known information regarding the threats to this species. As the species has a restricted distribution, it is likely threatened by habitat destruction and land changes" (Carrero & Strijk, 2020b). Consequently, further field research is needed to identify additional threats faced by species with extremely small population size.

Only two threatened oaks in SE-E Asia list invasive species competition/disturbances as a threat: *Quercus baolamensis* and *Q. bidoupensis* (see individual Species Profiles for details). There have been studies on invasive species within protected areas that contain threatened oaks, but the direct impact of these species on oaks is rarely made. For example, Ba Vi National Park is home to the entire known population of *Q. ngochoaensis*. Twenty-nine invasive species have been reported in Ba Vi National Park, with Mexican sunflower (*Tithonia diversifolia*) and Lantana (*Lantana camara*) identified as high risk (Tai et al., 2023).

Quercus sontraensis is endemic to the Son Tra Nature Conservation area, where the invasive species *Chromolaena odorata, Mikania micrantha,* and *Mikania diplotricha* have been observed (Tan et al., 2012). More research is needed to determine the impact of invasive species on threatened oaks of SE-E Asia. In addition, forest areas near heavily urbanized zones face potentially dramatic shifts in ecological balances of local fauna assemblages (acorn scatterhoarding vs. acorn predating species). As native (obligate) cache-making species are outcompeted by introduced and urban-adapted seed predators, dispersal and recruitment of seeds to sapling- and tree-stages is reduced, ultimately shrinking population sizes and favouring tree communities dominated by small-seeded, bird-dispersed species (Cramer et al., 2007; Strijk, 2026b). Forest fragmentation also differentially affects seed dispersal of large and small-seeded tropical trees.

Surprisingly, climate change was identified as a threat for only six species: *Q. arbutifolia, Q. austrocochinchinensis, Q. kingiana*, *Q. bidoupensis*, *Q. baolamensis*, and *Q. xanthotricha*. This low number likely reflects a significant knowledge gap rather than a lack of threat. Red List assessments generally rely on past and present distribution and population status, and are less likely to incorporate future projections (Peng et al., 2023). Specifically, Criterion A3 evaluates taxa based on projected population reductions suspected to occur within the next 100 years (IUCN, 2012). Currently, no threatened SE-E Asian oaks are evaluated under Criterion A3. In fact, this Criterion is rarely used for *Quercus*: of the 115 threatened *Quercus* species on the IUCN Red List, only two use Criterion A3.

Species Distribution Modeling (SDM) can be used to estimate population changes under future environmental conditions using Criterion A3 and/or A4 if very specific modeling criteria are met. To date, we have identified only three studies that specifically use SDM to predict the future distribution of selected threatened oaks under varying climate change scenarios in the study region. Each forecasts a drastic range reduction. For *Q. arbutifolia*, available habitat is predicted to shrink significantly by 2050, with restricted populations on just 2–3 mountain ranges in Fujian Province, China. Its current habitat in Guangdong, China, and Viet Nam is projected to disappear entirely (Song et al., 2019). Similarly, *Q. austrocochinchinensis* and *Q. kingiana* are predicted to lose up to 75% and 64% of their habitat, respectively, by 2080 (Vyan et al., 2026). In one of the largest studies on the impact of climate change on oaks in Asia, Sun et al. (2020) modeled the potential distribution of 35 *Quercus* species in China under three different emission scenarios in 2050 and 2070. Although *Q. kingiana* was the only species listed as threatened and within our study region in Sun et al. (2020), their results showed that range contraction increased alongside emission levels. Their work also highlighted the important roles of mountainous regions as a reservoir of biodiversity under climate change.

SE-E Asia faces significant climate change risks over the coming decades, driven by their large and growing human populations, extensive coastlines, and vulnerable low-lying areas. This region is projected to experience more extreme heat waves, increased frequency and intensity of heavy precipitation, increased risk of forest loss from wildfires, and increased drought severity (IPCC, 2023; Huang et al., 2025), all of which will profoundly impact forest ecosystems. A study by Pang et al. (2024), which modeled distributions of 1,498 tree species in Southeast Asia under varying climate change scenarios, predicted a net loss in species distribution area ranging from -9.3% under the most optimistic scenario, to -22.4% under the worst case scenario. Notably, Southeast Asia's tropical montane species showed some of the greatest losses in distribution area of all species groups studied. A challenge in formally classifying climate change as a risk to threatened oaks within the region is the amount of occurrence data required for reliable modeling. While it is extremely unlikely that these oaks would be immune to regional climatic shifts, targeted research is essential to determine the specific severity of this threat for each species, which in turn could inform priority restoration areas.


Collecting acorns from Gangwon-do, Korea (Seonghwan Kim)

Table 3. Threats identified for each target species assessed as Critically Endangered, Endangered, or Vulnerable.

	Logging and wood harvesting	Agriculture, wood and pulp plantations	Residential/commercial development, mining, roads	Tourism and recreation	Fire and fire suppression	Invasive species competition/disturbance	Climate change and severe weather	Genetic material loss	Pests/pathogens	Extremely small populations
Quercus arbutifolia	■	■	■	■	□	□	■	□	□	□
Quercus asymmetrica	■	■	■	■	□	□	□	□	□	□
Quercus austrocochinchinensis	■	■	■	□	□	□	■	■	□	□
Quercus bambusifolia	■	■	□	□	□	□	□	■	□	□
Quercus baniensis	□	□	□	□	□	□	□	□	□	■
Quercus baolamensis	■	■	■	■	■	■	■	■	□	■
Quercus bidoupensis	■	■	■	■	■	■	■	■	□	■
Quercus blaoensis	□	□	□	□	□	□	□	□	□	■
Quercus braianensis	□	■	□	□	□	□	□	□	□	□
Quercus cambodiensis	■	□	■	□	□	□	□	□	■	□
Quercus camusiae	■	■	□	□	□	□	□	□	□	■
Quercus chrysotricha	■	□	□	□	□	□	□	□	□	□
Quercus dankiaensis	□	□	□	□	□	□	□	□	□	■
Quercus dilacerata	■	■	□	■	■	□	□	□	□	■
Quercus disciformis	□	□	■	□	□	□	□	□	□	■
Quercus donnaiensis	□	□	□	□	□	□	□	□	□	■
Quercus edithiae	■	□	■	□	□	□	□	□	□	□
Quercus gaharuensis	■	■	■	□	□	□	□	□	□	□
Quercus honbaensis	■	□	□	□	□	□	□	□	□	■
Quercus hondae	□	■	□	□	□	□	□	□	■	□
Quercus kerangasensis	□	■	□	□	■	□	□	□	□	□
Quercus kinabaluensis	□	■	□	□	■	□	□	□	□	□
Quercus kingiana	■	■	■	□	■	□	■	□	□	□
Quercus lenticellata	■	□	□	□	■	□	□	□	□	□
Quercus lodicosa	■	□	□	□	□	□	□	□	□	□
Quercus mangdenensis	■	■	□	■	□	□	□	□	□	■
Quercus merrillii	□	■	□	□	■	□	□	□	□	□
Quercus ngochoaensis	□	□	□	□	□	□	□	□	□	■
Quercus nivea	□	■	□	□	■	□	□	□	□	□
Quercus percoriacea	□	■	□	□	■	□	□	□	□	□
Quercus petelotii	■	□	□	□	□	□	□	□	□	□
Quercus pseudoverticillata	□	■	□	□	■	□	□	□	□	□
Quercus quangtriensis	■	■	■	□	□	□	□	□	□	□
Quercus ramsbottomii	□	■	□	□	□	□	□	□	□	□
Quercus rupestris	■	■	□	□	□	□	□	□	□	□
Quercus sontraensis	□	□	□	□	□	□	□	□	□	■
Quercus steenisii	■	■	□	□	□	□	□	□	□	□
Quercus treubiana	□	■	□	□	■	□	□	□	□	□
Quercus trungkhanhensis	■	■	□	□	□	□	□	□	□	■
Quercus xanthotricha	■	■	■	□	■	□	■	■	□	□
Quercus xuanlienensis	■	■	□	□	□	□	□	□	□	■

■ Identified threat □ Not a threat or unknown

HUMAN FOOTPRINT INDEX

Southeast and East Asia are biodiversity hotspots. However, with a population of over 2 billion people, the anthropogenic pressure on biodiversity is intense. While studies often focus on the impact of a single pressure on biodiversity loss, such as population density or land use conversion (Paradis, 2018; Davison et al., 2021), multiple stressors often converge and impact the same landscape (Geary et al., 2019). In such cases, the Human Footprint Index (HFI) can be a useful tool to provide a spatially explicit, cumulative measure of human pressure across landscapes (Venter et al., 2016). Rather than measuring a single threat, the HFI combines several drivers of biodiversity loss, including built environments, croplands, pasture, population density, roads, railways, and light pollution. The HFI offers a standardized metric to compare anthropogenic pressures across geographic regions, identify conservation priorities, and track temporal changes in landscape integrity.

Here, we used global Human Footprint maps at 1 km resolution (Mu et al., 2022). Across our study region, a Human Footprint score ranging from 0–50 was calculated for each 1 km^2 grid cell. Scores near zero indicate very low pressure, and scores near 50 indicate very high pressure. For each of our 54 target species, we calculated the total area of each 2024 Human Footprint value within the inferred native range of the species. Forty-six (85%) of our target species had over 50% of their range classified as "High" or "Very High" human pressure as of 2024 (Figure 11). Most critically, five species (*Q. hondae*, *Q. ngochoaensis*, *Q. trungkhanhensis*, *Q. dilacerata*, and *Q. disciformis*) had >90% of their range classified as high-very high pressure. As expected, these five species also have a small percentage of their native range covered by protected areas, ranging from 3% for *Q. disciformis*

Quercus hondae (Arb Bergerette)

Quercus ramsbottomii (Queen Sirikit Botanic Garden)

to 23% for *Q. dilacerata*. Protected areas in Southeast Asia are generally effective at reducing forest loss; research indicates that protected areas within this region have three times less forest cover loss than unprotected areas (Graham et al., 2021). Similarly, a recent study found that 45% of analyzed protected areas in Southeast Asia were effective in reducing forest loss (Sreekar et al., 2024). However, protected areas are not inherently free from anthropogenic pressure. Particularly in areas where management is underfunded or understaffed, threats such as agricultural encroachment and illegal logging often persist. Future analyses should identify protected areas with especially low Human Footprint values as potential priority regions for *in situ* oak conservation.

We also calculated the Human Footprint Index for the year 2000 to determine if pressure has increased or decreased over the past 24 years. Our analysis showed that 51/54 (94%) of our target species showed an increase in the percentage of their range classified as "High" or "Very High" pressure from 2000 to 2024. The most dramatic shift happened to *Q. chevalieri* (Viet Nam and China) which saw its "High-Very High" pressure index of 40% in 2000 surge to 85% in 2024. Conversely, for the three species experiencing a decreased pressure over time, the changes were very small, ranging from 0.71% to 1.77%. These findings align with global trends identifying Southeast Asia, along with Africa and South America, among the top three regions worldwide experiencing the most rapid escalation of anthropogenic pressure over time (Mu et al., 2022). Our results underscore the rapidly intensifying anthropogenic pressures across our target species' ranges and highlight the urgent need for proactive, evidence-based conservation strategies to prevent further declines. It is especially important to engage local communities in forest conservation, given the impact of smallholder agriculture within the region.

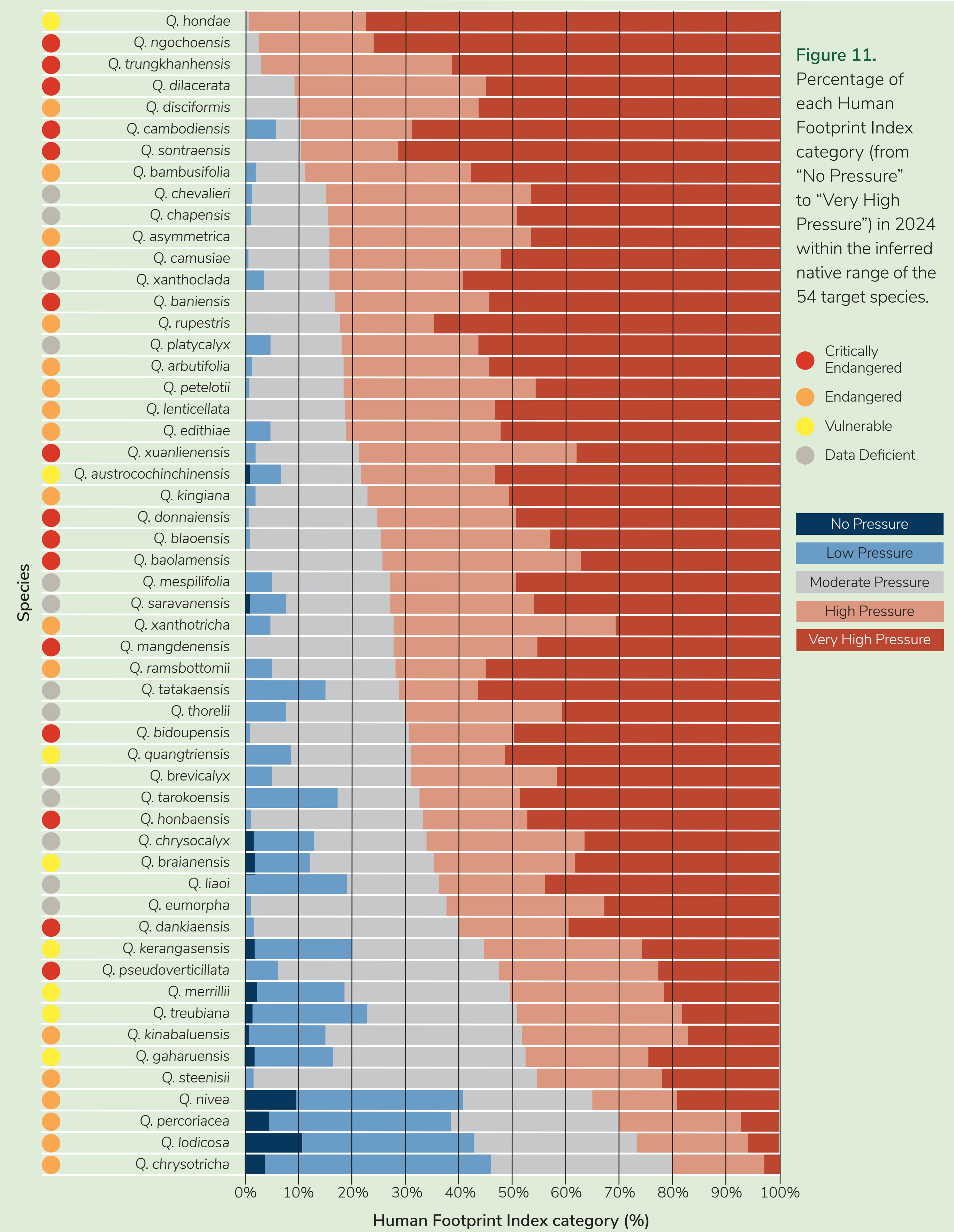


Figure 11. Percentage of each Human Footprint Index category (from "No Pressure" to "Very High Pressure") in 2024 within the inferred native range of the 54 target species.

CONSERVATION ACTION SCORE

To prioritize species for *ex situ* and *in situ* conservation, we calculated a Conservation Action Score by adapting the methods developed by Khoury et al. (2020). Scores range from 0–100, with scores near 100 indicating comprehensive *in situ* and *ex situ* conservation, and scores near 0 indicating poor conservation. To ensure the robustness of the rankings, we tested final conservation scores with three buffer sizes (20 km, 50 km, and 100 km) using Kendall's W test. There was very strong and statistically significant agreement in species rankings among the three different buffer sizes (Kendall's W=0.942, $\chi^2(53) = 150.00$, $p < 0.001$), suggesting that buffer size did not fundamentally alter species prioritization. We therefore used a buffer size of 50 km for all species in this analysis. It is important to note that prioritization in the context of this gap analysis is intended as a strategic guide rather than a rigid prescription. We encourage the GCCO members, botanic gardens, and academic institutions to pursue research and conservation action for any rare or threatened oak within their respective regions.

Our analysis identified 20 species with a final Conservation Action Score of <25, flagging them as urgent priority for conservation (Figure 12). These 20 species are distributed broadly across SE-E Asia, rather than being confined to a single geographic region. *Quercus xanthotrica* has the lowest conservation action score at 5/100. This species occurs in Yunnan Province, China, and Luang Prabang and Xiengkhouang provinces in Laos. *Quercus xanthotrica* is absent in any global *ex situ* collections, and all known occurrences are outside of protected areas. Only 3% of its inferred native range is currently protected.

Given the high number of species requiring urgent intervention, metrics such as the Human Footprint Index can provide a critical secondary filter for prioritization. Of the 20 species with a Conservation Action Score of <25 (indicating urgent priority) and that are not held in collections, six species also had over 75% of their native range subjected to "High" or "Very High" pressure: *Q. dilacerata*, *Q. disciformis*, *Q. chevalieri*, *Q. asymmetrica*, *Q. rupestris*, and *Q. arbutifolia* (Table 4). These species face the highest threat, as they are not in *ex situ* collections, have very little of their native range within protected areas, and are also facing intense anthropogenic pressure *in situ*. Of the 40 species of threatened or Data Deficient SE-E Asian oak not currently held in *ex situ* collections, we propose these six species identified in Table 4 should be a priority. *Ex situ* conservation serves as a critical safeguard against extinction, particularly for species whose native habitats are highly degraded or under threat (Oldfield, 2009). For taxa with little remaining protected habitat and ongoing land-use change, overexploitation, or habitat fragmentation, reliance on *in situ* measures alone may be insufficient to prevent rapid population declines.

Only two species had a final Conservation Action Score >50: *Q. tatakaensis* (55/100) and *Q. tarokoensis* (62/100). Both species are endemic to Taiwan, where 20% of the total land area is protected. The majority of these protected areas are on the eastern side of the island, where both *Q. tatakaensis* and *Q. tarokoensis* are found (UNEP-WCMC & IUCN, 2025). Our *ex situ* survey results indicate that there are currently 14 individuals of *Q. tatakaensis* in 10 botanic gardens in the United States and Europe, and 22 individuals of *Q. tarokoensis* in 10 botanic gardens in the United States, South America, Europe, and Asia. A collecting trip by a local oak enthusiast and subsequent distribution of acorns to botanic gardens around the world led to the relatively good representation of this species *ex situ*. While these species serve as a positive case study for successful *ex situ* establishment, further efforts are required to increase the genetic diversity and the total number of individuals within collections. In particular, strengthening *ex situ* holdings within SE-E Asian institutions should be a priority to ensure regional capacity for long-term conservation, research, and potential future reintroductions.

Table 4. Species with a Final Conservation Action score of 25 or less with over 75% of their native range classified as "Very High" or "High" anthropogenic pressure in 2024 (Mu et al., 2022)

Species	Final Conservation Action Score	Percentage of Native Range Classified as Very High or High Pressure
Quercus dilacerata	21	90.67%
Quercus disciformis	22	90.18%
Quercus chevalieri	18	84.92%
Quercus asymmetrica	21	84.73%
Quercus rupestris	18	82.37%
Quercus arbutifolia	24	81.97%

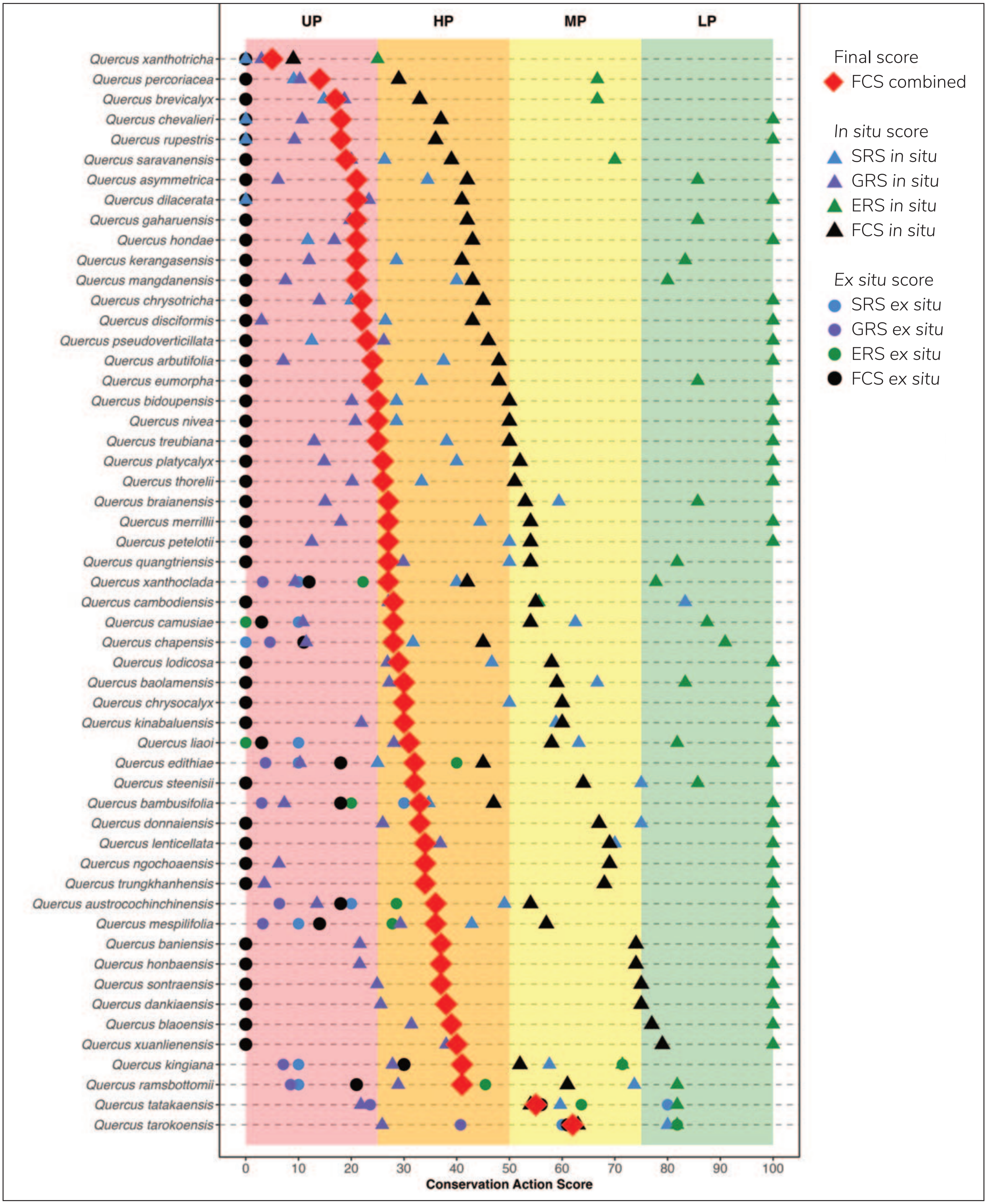


Figure 12. Summary of Conservation Action Scores for 54 target species. Scores range from 0–100, with 100 indicating comprehensive conservation and 0 indicating extremely poor conservation. UP = Urgent Priority (FCS < 25), HP = High Priority (25 ≤ FCS < 50), MP = Medium Priority (50 ≤ FCS < 75), and LP = Low Priority (FCS > 75).

CONCLUSIONS

Quercus rex habitat (Min Deng)

Southeast and East Asia (SE-E Asia) represent global centers of plant diversity, marked by exceptional species richness and high levels of phylogenetic endemism (Qian et al., 2024). From tropical rainforests to subtropical montane forest ecosystems, complex geological histories and specialized climatic refugia have fostered floras found nowhere else on Earth. Yet, this biodiversity faces intensifying pressure; the region's forests are among the most threatened in the world. Rapid agricultural expansion, industrial logging, and urbanization, all compounded by climate change, are driving extensive forest loss, fragmentation, and degradation (Struebig et al., 2025). As these forest ecosystems shrink and become increasingly isolated, narrowly distributed and habitat-specialist plant species face increased extinction risk.

As extinction risks mount, understanding the conservation status of dominant tree groups is critical. Asia is home to the greatest number of native, threatened oak species in the world (Carrero et al., 2020). While recent research has advanced our understanding of the unique flora of this region, significant gaps in our knowledge and active conservation remain. We conducted a conservation gap analysis of 54 threatened and DD oak species of SE-E Asia in an effort to prioritize research and conservation action for oaks in the region. We performed an extensive literature review, distributed and analyzed the results from global ex *situ* surveys over the course of four years, and interviewed species experts throughout SE-E Asia to review occurrence maps, as well as identify threats and conservation activities for our target species. Collaboration with regional species experts produced a curated dataset of over 1,200 occurrence points and distribution maps for each of our target species. This dataset will be a foundational resource for future studies on oaks within the region, and it should continue to be updated as additional survey work takes place, taxonomic changes are made, and additional herbarium records are digitized and reviewed. It is crucial that conservation practitioners work collaboratively in the gathering and sharing of data. Ensuring that data is open, accessible, accurate, compliant, standardized, and secure enhances their value for research and conservation alike (Brockington et al., 2026).

Quercus oidocarpa (Queen Sirikit Botanic Garden)

This gap analysis identified several urgent conservation priorities for threatened and DD oaks throughout SE-E Asia:

1) **Prioritize botanical surveys and data accessibility**
Gathering accurate and up-to-date occurrence data is a critical first step in conservation planning. Botanical exploration in Southeast Asia peaked in the late 18th and early 19th centuries (Webb et al., 2010), and many oak species are still only known from their type locality. Hence, occurrence data within this region is often very old or sparse. Rapid urbanization and land use change necessitate urgent surveys to verify historical records and identify new populations. Furthermore, while preserved herbarium specimens are essential for taxonomic and ecological research, many herbaria, especially in the Global South, lack the capacity to mount large-scale digitization efforts (Zhigila et al., 2025). Our manual transcription of records during this study identified crucial data that would otherwise have been lost. Scaling up and supporting the digitization and global sharing of these collections is vital to closing regional knowledge gaps.

2) **Expand the protected area network in the region considering Key Biodiversity Areas for oaks**
In situ conservation remains the ideal and effective way to prevent extinction (Cavender et al., 2015). One way to conserve species within their natural habitat is through the protected areas network. However, our results showed that none of our target species had more than 40% of their inferred native range covered by protected areas. In fact, over half (29/54) of threatened and DD SE-E Asian oaks have 20% or less protected area coverage within their native range. While expanding or creating new protected area networks is a pillar of the Kunming–Montreal Global Biodiversity Framework, the Global South often faces significant challenges in meeting ambitious international targets. Building capacity and providing sustainable economic opportunities must be incorporated into conservation activities. Collaborating with local communities is a priority, especially those that live within the boundaries of protected areas, in order to build capacity through training, education, and incentives for sustainable livelihoods as an alternative to clearing the forest. For species with minimal protection, including the oak species in this analysis, establishing new populations through *in situ* or near *situ* restoration should also be considered a primary strategy.

Oak habitat in Gangwon-do, South Korea (The Morton Arboretum)

3) **Expand living collections of native oaks within the country or region of origin**
Compared to other global oak biodiversity hotspots, SE-E Asia has an alarmingly low representation of threatened or DD species in *ex situ* collections. According to the results of our *ex situ* surveys, 40 of our target species are not found in any living collection, anywhere in the world. Fourteen species are found in at least one collection, but only nine of those are located in living collections in Asia. The remaining collections are located in Europe (8 species) or North America (3 species). Those that are in collections are often represented by a single individual, or found at a single botanic garden, and are often collected from a very narrow range. Therefore, more botanical surveys, exploration, and collection of material from multiple populations/occurrences is needed. In some regions or countries, new gardens, arboreta, or "safe sites" where trees can be planted may need to be created, since the majority of botanic gardens of the world are located outside of biodiversity hotspots (Westwood et al., 2021). When planning and conducting new *ex situ* collecting efforts, institutions should prioritize the collection of species that fall outside of existing protected areas, lack representation in *ex situ* collections, and are experiencing high anthropogenic pressure within their native range. Building capacity of local gardens, especially in oak propagation, nursery development/management, data collection and sharing, can greatly advance the goal of increasing representation of native oaks *ex situ*. This recommendation directly aligns with Action 20 of the Global Strategy for Plant Conservation 2020–2030, which is to "establish or strengthen professional training and capacity-building initiatives related to plant conservation, scientific research and monitoring, taxonomy and information management, horticulture, botany, plant conservation biology research, biotechnology and ecological restoration" (Global Partnership for Plant Conservation, 2025). In addition, the recently published IUCN Species Survival Commission (SSC) position statement highlights the important role of botanic gardens in providing training and capacity building programs that "equip, train and mentor conservation professionals in all stages of their career, including from low-capacity regions" (IUCN SSC, 2023).

Quercus ramsbottomii (Queen Sirikit Botanic Garden)

These urgent conservation priorities require collaboration across sectors. The Global Conservation Consortium for Oak (GCCO) serves as a vital network, bridging institutions to prevent extinctions through capacity building, propagation support, and training programs. Launched in December 2019, the GCCO, in collaboration with local partners, hosts capacity building workshops, supports oak propagation, surveys wild populations, and leads the Species Stewards Training Program. The GCCO has Species Stewards assigned for each of the priority oak species in the United States and Mesoamerica, but not yet SE-E Asia.

In 2025, the GCCO was awarded Fondation Franklinia and Arthur and Elaine Johnson Foundation grants to support on-the-ground conservation efforts for threatened Fagaceae (including several oak species) in Viet Nam and Laos. As part of these efforts, the GCCO is working with international partners (Alliance for Conservation Tree Genomics and Botanic Gardens Conservation International), as well as local partners (Dalat University, Bidoup Nui Ba National Park, Vu Quang National Park, Vietnam National University of Forestry, the Laos Ministry of Education and Sports, and Institute of Research for Sustainable Development-Centre International de Recherche Environnementale de Nakaï). The GCCO is supporting these partners' project objectives through the coordination of conservation action planning workshops. These workshops aim to engage representatives from across sectors, such as NGOs, national parks, and universities, to come together in Laos and Vietnam to outline the strategies and actions they can collaboratively implement to better understand and safeguard the threatened Fagaceae in these regions. Over 50 participants attended two workshops in March 2026 at the Laos Ministry of Education and Sports and at Dalat University to brainstorm and discuss the development of the action plans. The final drafted action plans will be initiated by the end of 2026 and will include strategies that address the conservation gaps and challenges outlined for several of the threatened oak species in this analysis.

As the network continues to grow within this oak biodiversity hotspot, this gap analysis provides a roadmap to identify priority oak species for potential Species Stewards in SE-E Asia. Networks such as the GCCO that bring together multidisciplinary groups are vital in addressing a conservation challenge of this magnitude. It is our hope that this gap analysis further facilitates partnerships, supports the prioritization of conservation action, and ultimately makes progress toward the goal of conserving threatened SE-E Asian oaks.

Quercus myrsinifolia (Queen Sirikit Botanical Garden)

REFERENCES

Fagaceae-dominated forest near the summit of Phou Bia, Laos (Oudomphone Insisiengmay)

All Asia TCN. (2025). Available at https://allasiatcn.org/index.php. Accessed on 16 May 2025.

ASEAN Center for Biodiversity. (2024). ASEAN Heritage Parks.available at https://www.aseanbiodiversity.org/the-asean-heritage-parks-programme/?e-filter-00aa5a6-country=viet-nam. Accessed on 9 December 2024.

Austin, K. G., González-Roglich, M., Schaffer-Smith, D., Schwantes, A. M. & Swenson, J. J. (2017). Trends in size of tropical deforestation events signal increasing dominance of industrial-scale drivers. *Environmental Research Letters*, 12(5), p.054009.

Beckman, E., Meyer, A., Denvir, A., Gill, D., Man, G., Pivorunas, D., Shaw, K., & Westwood, M. (2019). *Conservation Gap Analysis of Native U.S. Oaks*. Lisle, IL: The Morton Arboretum.

Beckman, E., Meyer, A., Pivorunas, D., Hoban, S., & Westwood, M. (2021a). *Conservation gap analysis of U.S. trees in nine priority genera*. Lisle, IL: The Morton Arboretum.

Beckman, E., Meyer, A., Pivorunas, D., Hoban, S., & Westwood, M. (2021b). *Conservation Gap Analysis of American Beech*. Lisle, IL: The Morton Arboretum.

Beckman Bruns, E., Khoury, C. K., McCarry, N., Meyer, A., Mims, R., & Warschefsky, E. (2023a). Distributions and conservation status of North American fruit and nut tree crop wild relatives. https://northamericanfruitnuttreecwr.github.io

Beckman Bruns, E., Still, S. M., Good, K., & Hoban, S. (2023b). Conservation-gap-analysis (Version 1.0.0) [Computer software]. https://doi.org/10.5281/zenodo.8246949

BGCI. (2025a). GlobalTreeSearch online database. Botanic Gardens Conservation International. Richmond, UK. Available at https://tools.bgci.org/global_tree_search.php. Accessed on 1 November 2025.

BGCI. (2025b). PlantSearch. Botanic Gardens Conservation International. Richmond, U.K. Available at https://plantsearch.bgci.org/ Accessed on 1 November 2025.

BGCI. (2025c). GardenSearch online database. Botanic Gardens Conservation International. Richmond, UK. Available at http://gardensearch.bgci.org. Accessed on 1 November 2025.

Bidoup-Nui Ba National Park. (2018). Overview of Biodiversity of Bidoup-Nui Ba National Park. Bidoup-Nui Ba National Park, Dalat.

Binh, H. T. (2017). A taxonomic study of *Quercus* (Fagaceae) in Vietnam based on molecular phylogeny and morphological observations. PhD Thesis. Kyushu University.

Binh, H. T., Nguyen, N.V., Tagane, S., Toyama, H., Mase, K., Mitsuyuki, C., Strijk, J.S., Suyama, Y. & Yahara, T. (2018a). A taxonomic study of the *Quercus langbianensis* complex with morphology and DNA barcodes. *PhytoKeys* 95, 37–70.

Binh, H. T., Van Ngoc, N., Tai, V. A., Son, H. T., Tagane, S., & Yahara, T. (2018b). *Quercus trungkhanhensis* (Fagaceae), a New Species from Cao Vit Gibbon Conservation Area, Cao Bang Province, northeastern Vietnam. *Acta Phytotaxonomica et Geobotanica*, 69(1), 53-61.

Binh, H. T, Nguyen, N. V., Bon, T. N., Tagane, S., Suyama, Y. & Yahara, T. (2018c). A new species and two new records of *Quercus* (Fagaceae) from northern Vietnam. *PhytoKeys* 92, 1–15.

Binh, H. T., Nguyen, N. V., Son, H. T., Tagane, S., Suyama, Y. & Yahara, T. (2021). *Quercus ngochoaensis*, a new species from Ba Vi National Park, Hanoi. *Phytotaxa* 516(3), 283–288.

BirdLife International. (2026). The World Database of Key Biodiversity Areas. Developed by the KBA Partnership: BirdLife International, International Union for the Conservation of Nature, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, Wildlife Conservation Society and World Wildlife Fund. Available at www.keybiodiversityareas.org. Accessed on 11 February 2026.

BirdLife International & FIPI. (2001). Sourcebook of existing and potential protected areas in Vietnam. BirdLife International Vietnam Programme and Forest Inventory and Planning Institute, Hanoi, Vietnam.

Brennan, A. N., McKenna, J. R., Hoban, S.M., & Jacobs, D.F. (2020). Hybrid Breeding for Restoration of Threatened Forest Trees: Evidence for Incorporating Disease Tolerance in Juglans cinerea. *Frontiers in Plant Science* 11, 580693.

Brockington, S. F., Malcolm, P., Aiello, A. S., Almeida, T. H., Apple, M., Aragón-Rodríguez, S., ... & Smith, P. (2026). High-performance living plant collections require a globally integrated data ecosystem to meet twenty-first-century challenges. *Nature Plants*, 1-8.

Cannon, C. H. & Kua, C-S. (2025). Diversify first! Fatten the tails of phenotypic diversity to enhance adaptive capacity in the Anthropocene. *Global Ecology and Conservation* 62, e03739.

Cano, Á., Powell, J., Aiello, A. S., Andersen, H. L., Arbour, T., Balzer, A., Bauer, D. S., Bugarchich, J., Cano, F., Contreras, M. P. & Cubey, R. (2025). Insights from a century of data reveal global trends in *ex situ* living plant collections. *Nature Ecology & Evolution*, 9(2), 214-224.

Carrero, C. & Strijk, J. S. (2020a). *Quercus baniensis*. The IUCN Red List of Threatened Species 2020: e.T138192385A173042515. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T138192385A173042515.en. Accessed on 16 February 2026.

Carrero, C. & Strijk, J. S. (2020b). *Quercus dankiaensis*. The IUCN Red List of Threatened Species 2020: e.T78910765A173042191. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T78910765A173042191.en. Accessed on 27 January 2026.

Carrero, C., Jerome, D., Beckman, E., Byrne, A., Coombes, A. J., Deng, M., González-Rodríguez, A., Hoang, V. S., Khoo, E., Nguyen, N., Robiansyah, I., Rodríguez-Correa, H., Sang, J., Song, Y-G., Strijk, J. S., Sugau, J., Sun, W. B., Valencia-Ávalos, S., & Westwood, M. (2020). The Red List of Oaks 2020. The Morton Arboretum. Lisle, IL.

Cavender, N., Westwood, M., Bechtold, C., Donnelly, G., Oldfield, S., Gardner, M., Rae, D., & McNamara, W. (2015). Strengthening the conservation value of *ex situ* tree collections. *Oryx*, 49(3), 416–424. https://doi.org/10.1017/S0030605314000866

Cho, E.-S., Yang, G.-S., Kim, Y.-S., & Cho, D.-G. (2023). Community Structure and Growth Rate of Korean Quercus mongolica Forests by Vegetation Climate Zone. *Sustainability*, 15(8), 6465. https://doi.org/10.3390/su15086465

Choi, W. I., Lee, D.-H., Jung, J. B., & Park, Y.-S. (2022). Oak Decline Syndrome in Korean Forests: History, Biology, and Prospects for Korean Oak Wilt. *Forests*, 13(6), 964. https://doi.org/10.3390/f13060964

Conservation Biology Institute. (2026). Data Basin. Available at https://databasin.org/. Accessed on 13 February 2026.

Convention on Biological Diversity. (2026) Republic of Korea - Country Profile. Available at https://www.cbd.int/countries/profile?country=kr. Accessed on 19 February 2026.

Cramer, J.M., Mesquita, R.C. & Williamson, G.B. (2007). Forest fragmentation differentially affects seed dispersal of large and small-seeded tropical trees. *Biological conservation*, 137(3), 415-423.

Surveying Gangwon-do, South Korea for oaks (The Morton Arboretum)

Quercus myrsinifolia (Atsushi Motohashi)

Crowley, D. (2019). *Prioritization of Acer species and populations for ex situ conservation based on threat level and current representation in living collections* [Unpublished master's thesis]. University of Reading. Reading, Berkshire, England.

Dat, T. N., Tru, N. L., Hiep, N. M., Dai, D. A., Hung, L. A., & Thinh, N. A. (2021) Special Use Forests Viet Nam. Department of Protected Area Management. Hanoi, Viet Nam.

Davison, C. W., Rahbek, C., & Morueta-Holme, N. (2021). Land-use change and biodiversity: Challenges for assembling evidence on the greatest threat to nature. *Global Change Biology*, 27(21), 5414-5429.

Derguy, M. R., Martinuzzi, S., & Arturi, M. (2022). Bioclimatic changes in ecoregions of southern South America: Trends and projections based on Holdridge life zones. *Austral Ecology* 47, 580– 589. https://doi.org/10.1111/aec.13142

E.O. Wilson Biodiversity Foundation. (2025). Species Protection Index. Available at https://eowilsonfoundation.org/which-half/national-report-cards/species-protection-index/. Accessed on 8 January 2026.

Estoque, R. C., Ooba, M., Avitabile, V., Hijioka, Y., DasGupta, R., Togawa, T., & Murayama, Y. (2019). The future of Southeast Asia's forests. *Nature communications*, 10(1), 1829.

Faculty of Forestry. (1992). Master plan for management Doi Inthanon National Park, Chiangmai. Kasetsart University, Bangkok (mimeographed in Thai).

FAOSTAT. (2024). Food and agricultural data. Food and Agriculture Organization of the United Nations https://www.fao.org/faostat/en/#home

Feng, Y., Ziegler, A. D., Elsen, P. R., Liu, Y., He, X., Spracklen, D. V., Holden, J., Jiang, X., Zheng, C. & Zeng, Z. (2021). Upward expansion and acceleration of forest clearance in the mountains of Southeast Asia. *Nature Sustainability*, 4(10), 892-899.

Fick, S. E. & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37(12), 4302–4315. https://doi.org/10.1002/joc.5086

Flynn, G. (2023). Skepticism as Cambodia expands protected areas by more than a million hectares. Mongabay. Available at https://news.mongabay.com/2023/08/skepticism-as-cambodia-expands-protected-areas-by-more-than-a-million-hectares/. Accessed on 12 January 2026.

GBIF.org (28 March 2025) GBIF occurrence download. DOI10.15468/dl.sbdue8

Geary, W. L., Nimmo, D. G., Doherty, T. S., Ritchie, E. G., & Tulloch, A. I. (2019). Threat webs: Reframing the co-occurrence and interactions of threats to biodiversity. *Journal of Applied Ecology*, 56(8), 1992-1997.

Global Forest Watch. (2026). Available from https://www.globalforestwatch.org/. Accessed on 10 January 2026.

Global Partnership for Plant Conservation. (2025). The Global Strategy for Plant Conservation 2020-2030, Botanic Gardens Conservation International (BGCI), London, UK.

Good, K., Coombes, A. J., Valencia-A., S., Rodríguez-Acosta, M., Beckman Bruns, E., & Alvarez-Clare, S. (2024). Conservation Gap Analysis of Native Mesoamerican Oaks. Lisle, IL: The Morton Arboretum.

Graham, V., Geldmann, J., Adams, V. M., Negret, P. J., Sinovas, P., & Chang, H. C. (2021). Southeast Asian protected areas are effective in conserving forest cover and forest carbon stocks compared to unprotected areas. *Scientific Reports*, 11(1), 23760.

Graul, C. (2016). LeafletR: Interactive Web-Maps Based on the Leaflet JavaScript Library. R package version 0.4-0.

Griffith, P. M., Beckman, E., Callicrate, T., Clark, J., Clase, T., Deans, S., Dosmann, M., Fant, J., Gratacos, X., Havens, K., Hoban, S., Lobdell, M., Jiménez-Rodriguez, F., Kramer, A., Lacy, R., Magellan, T., Maschinski, J., Meerow, A. W., Meyer, A., Sanchez, V., Spence, E., Toribio, P., Walsh, S., Westwood, M., & Wood, J. (2019). *Toward the Metacollection: Safeguarding plant diversity and coordinating conservation collections.* Botanic Gardens Conservation InternationalUS (San Marino, USA).

Grogan, K., Pflugmacher, D., Hostert, P., Mertz, O., & Fensholt, R. (2019). Unravelling the link between global rubber price and tropical deforestation in Cambodia. *Nature Plants*, 5(1), 47-53.

Hamilton, J. A. & Miller, J. M. (2016). Adaptive introgression as a resource for management and genetic conservation in a changing climate. *Conservation Biology*, 30, 33–41.

Han, E. K., Cho, W. B., Park, J. S., Choi, I. S., Kwak, M., Kim, B. Y., & Lee, J. H. (2020). A Disjunctive Marginal Edge of Evergreen Broad-Leaved Oak (*Quercus gilva*) in East Asia: The High Genetic Distinctiveness and Unusual Diversity of Jeju Island Populations and Insight into a Massive, Independent Postglacial Colonization. *Genes*, 11(10), 1114. https://doi.org/10.3390/genes11101114

Hélardot, J. L. (2018). *Quercus dankiaensis*. Oaks of the world online. Available at http://oaks.of.the.world.free.fr/quercus_dankiaensis.htm. Accessed on 10 January 2026.

Hipp, A. L. (2024). *Oak Origins: From acorns to species and the tree of life*. The University of Chicago Press.

Hoban, S. (2019). New guidance for *ex situ* gene conservation: Sampling realistic population systems and accounting for collection attrition. *Biological Conservation*, 235, 199–208. https://doi.org/10.1016/j.biocon.2019.04.013

Hoban, S., & Strand, A. (2015). *Ex situ* seed collections will benefit from considering spatial sampling design and species' reproductive biology. *Biological Conservation*, 187, 182-191.

Holdridge, L. R. (1967). Life zone ecology. Tropical Science Center: San José, Costa Rica.

Hord, A. M., Fischer, D. G., Schweitzer, J. A., LeRoy, C. J., Whitham, T. G. & Bailey, J. K. (2025). Hybrid introgression as a mechanism of rapid evolution and resilience to climate change in a riparian tree species. *Communications Biology*, 8, 1173. https://doi.org/10.1038/s42003-025-08410-3

Huang, K., Wu, X., Zhang, L., Geng, H., & Qu, Y. (2025). Increasing risk of global forest loss from extreme wildfires under climate change. *International Journal of Digital Earth*, 18(1), 2483982.

Hughes, A. C. (2017). Understanding the drivers of Southeast Asian biodiversity loss. *Ecosphere*, 8(1), e01624. 10. 1002/ecs2.1624

Hughes, R., Le Trong Trai, Tordoff, A. W., & Vu Van Dung. (2004). Sourcebook of existing and proposed protected areas in Vietnam: Vol. 2. BirdLife International Vietnam Programme & Forest Inventory and Planning Institute.

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647.

IUCN. (2012). IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32pp.

IUCN. (2016). A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. First edition. Gland, Switzerland: IUCN.

IUCN. (2022). Threats Classification Scheme, v 3.3. International Union for Conservation of Nature. https://www.iucnredlist.org/resources/threat-classification-scheme

IUCN. (2025). The IUCN Red List of Threatened Species. Version 2025-2. https://www.iucnredlist.org. Accessed on 13 March 2023.

IUCN SSC. (2023). *Position Statement on the role of botanic gardens, aquariums, and zoos in species conservation*. IUCN Species Survival Commission (SSC), Gland, Switzerland. 8 pp.

Janes, J. K. & Hamilton, J. A. (2017). Mixing it up: the role of hybridization in forest management and conservation under climate change. *Forests*, 8(7), 237.

Jeong, H. M., Kim, H.-R., & You, Y. H. (2021). Impact of Germination and Initial Growth of Deciduous Six Oak Species under Climate Change Environment Condition. *Korean Journal of Ecology and Environment*, 54(4), 334–345.

Quercus myrsinifolia (Queen Sirikit Botanic Garden)

Kamiya, K., Ogasahara, M., Kenzo, T., Muramoto, Y., Araki, T., & Ichie, T. (2022). Genetic diversity and structure of Quercus hondae, a rare evergreen oak species in Southwestern Japan. *Forests*, 13(4), 579.

Karunarathne, P., Zhou, Q., Lascoux, M. & Milesi, P. (2024). Hybridization mediated range expansion and climate change resilience in two keystone tree species of boreal forests. *Global Change Biology*, 30, e17262.

KBA Partnership. (2025). KBA Programme Annual Report 2025.

Key Biodiversity Areas Partnership. (2026a). Key Biodiversity Areas factsheet: Son Tra. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Downloaded from https://keybiodiversityareas.org/ on Jan 27, 2026.

Key Biodiversity Areas Partnership. (2026b). Key Biodiversity Areas factsheet: Trung Khanh. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Downloaded from https://keybiodiversityareas.org/ on Jan 27, 2026.

Key Biodiversity Areas Partnership. (2026c). Key Biodiversity Areas factsheet: Xuan Lien. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Downloaded from https://keybiodiversityareas.org/ on Jan 27, 2026.

Key Biodiversity Areas Partnership. (2026d). Key Biodiversity Areas factsheet: Gunung Leuser. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re:wild, NatureServe, Rainforest Trust, Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Downloaded from https://keybiodiversityareas.org/ on Jan 27, 2026.

Khatun, K., Imbach, P., and Zamora, J. (2013). An assessment of climate change impacts on the tropical forests of Central America using the Holdridge Life Zone (HLZ) land classification system. *iForest - Biogeosciences and Forestry*, 6(4), 183–189. https://doi.org/10.3832/ifor0743-006

Khoury, C. K., Carver, D., Greene, S. L., & Frances, A. (2020). Crop wild relatives of the United States require urgent conservation action. *PNAS*, 117(52), 33351–33357. https://doi.org/10.1073/pnas.2007029117

Kim, I. S., Lee, K. M., Shim, D., Kim, J. J., & Kang, H.-I. (2020). Plus Tree Selection of *Quercus salicina* Blume and *Q. glauca* Thunb. and Its Implications in Evergreen Oaks Breeding in Korea. *Forests*, 11(7), 735. https://doi.org/10.3390/f11070735

Kim, Y.-H., & Kim, J.-W. (2017). Distributional Uniqueness of Deciduous Oaks (Quercus L.) in the Korean Peninsula. *Journal of the Korea Society of Environmental Restoration Technology*, 20(2), 37–59. https://doi.org/10.13087/kosert.2017.20.2.37

Kim, Y. S. (1985). Variation of leaf characters of *Quercus mongolica* in response to altitudinal gradient in Mt. Paekwoon. *Journal of Natural Resources, Yeungnam University*, 4(1), 137-142. (in Korean)

KimDung, N., Bush, S. R., & Mol, A. P. J. (2017). The Vietnamese Legal and Policy Framework for Co-Management in Special-Use Forests. *Forests*, 8(7), 262. https://doi.org/10.3390/f8070262

Koontz, A. C., Carver, D., Khoury, C. K., Richards, C. M., Reeves, P. A., Loza Rivera, M. I., Eserman, L. A., Migicovsky, Z., Walsh, S. K., Deans, S., & Hoban, S. M. (2026). How well does ecogeographic variation predict genetic diversity? An exploration of commonly used *ex situ* conservation metrics. [Manuscript in preparation]. The Morton Arboretum.

Korea National Arboretum. (2021). The National Red List of Vascular Plants in Korea. Korea National Arboretum, Pocheon, Korea. (in Korean)

Le, Nguyen H. (2024). Conflict between Tourism and Conservation at Nui Chua National Park, Ninh Thuan Province, Vietnam IOP Conference Series: Earth and Environmental Science 1403 012003.

Lee, J.-M., Kim, E.-J., Park, J.-W., Park, Y.-B., Park, J.-H., & You, Y.-H. (2025). Phenological Responses of Six Native Quercus Species in Korea under Elevated CO2 and Temperature Treatment. *Journal of Ecology and Environment*, 49(2), 12. https://doi.org/10.5141/jee.25.035

Li, X., Zhou, Y., Zhao, M., & Zhao, X. (2020). A harmonized global nighttime light dataset 1992–2018. *Scientific data*, 7, 168.

Liang, Y. Y., Shi, Y., Yuan, S., Zhou, B. F., Chen, X. Y., An, Q. Q., Ingvarsson, P. K., Plomion, C. & Wang, B. (2022). Linked selection shapes the landscape of genomic variation in three oak species. *New Phytologist*, 233(1), pp.555-568.

Lim, C.-H., Yoo, S., Choi, Y., Jeon, S. W., Son, Y., & Lee, W.-K. (2018). Assessing Climate Change Impact on Forest Habitat Suitability and Diversity in the Korean Peninsula. Forests, 9(5), 259. https://doi.org/10.3390/f9050259

Linsky, J., Crowley, D., Beckman Bruns, E. & Coffey, E. E. D. (2022a). Global Conservation Gap Analysis of Magnolia. Atlanta, GA: Atlanta Botanical Garden.

Linsky, J., Bellemare, J., Berryhill, J., Conrad, K., Lobdell, M., Moon, B., de la Mota Daniel, F. J., Rahaim, K., Rounsaville, T., Sanders, A., West, T., Zale, P.J., Meyer, A., Beckman Bruns, E., & Coffey, E. E. D. (2022b). Conservation Gap Analysis of Native Magnolias of the U.S. and Canada. Atlanta, GA: Atlanta Botanical Garden.

McCormack, J. E., Huang, H., Knowles, L. L., Gillespie, R., & Clague, D. (2009). Sky islands. *Encyclopedia of islands*, 4, 841-843.

Meemana, J., & Yujun, Z. (2019). Community participation mechanisms in ecotourism in Thai national parks: A case study of Doi Inthanon National Park. *International Journal of Thai Tourism*, 15 (1), 67–83.

Meyfroidt, P., Vu, T. P., & Hoang, V. A. (2013). Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam. *Global Environmental Change*, 23(5), 1187-1198.

Ministry of Agriculture and Rural Development. (2021). Decision: National Forest Status Report 2020. Number: 1558/QD-BNN-TCLN

Ministry of Agriculture, Forestry and Fisheries. (2025). shidami dango. https://www.maff.go.jp/j/keikaku/syokubunka/k_ryouri/search_menu/menu/28_28_iwate.htm. Accessed on 21 March, 2025.

Missanjo, E., Utila, H., Munthali, M., & Mitembe, W. (2019). Modelling of climate conditions in forest vegetation zones in Malawi. *World Journal of Advanced Research and Reviews*, 1(03), 036–044. https://doi.org/10.30574/wjarr.2019.1.3.0023

Motohashi, A. (2022). Survey of interest level in Fagaceae using web data. *Science Report of the Toyohashi Museum of Natural History*, 32, 41-50.

Motohashi, A., & T. Fujimoto, T. (2024). How do the general public imagine acorns? -A case study from a workshop and Web questionnaire in Tama City-. *Journal of the Japanese Society of Revegetation Technology*, 49(2), 204-207. https://doi.org/10.7211/jjsrt.49.204.

Motohashi, A., Nakagawa, T. & Fujimoto, T. (2024). Creating Local Relationships between Plants and People -Focusing on Fagus Species -Report on the Tama Acorn Club (2022/2-2023/7)-. *Studies on Tama Newtown*, 26, 58-61.

Motohashi, A., Miyazaki, K., Nogiwa, R., Matsuda, R., & Fujimoto, T. (2025a). Cultural diversity of Fagaceae by cooking and crafts of a local acorn -Report on the Tama Acorn Club (2023/ 8 -2025/ 2)-. *Studies on Tama Newtown*, 27, 35-40.

Motohashi, A., Miyazaki, K., & Fujimoto, T. (2025b). Action research on the modern acorn eating culture in Tama City, Tokyo. *Journal of the Japanese Society of Revegetation Technology*, 50(3), 204-207. https://doi.org/10.7211/jjsrt.50.270

Mu, H., Li, X., Wen, Y., Huang, J., Du, P., Su, W., Miao, S., & Geng, M. (2022) A global record of annual terrestrial Human Footprint dataset from 2000 to 2018. *Scientific Data*, 9, 176. https://doi.org/10.1038/s41597-022-01284-8

Quercus kingiana habitat (Min Deng)

Mu, H., Li, X., Wen, Y., Huang, J., Du, P., Su, W., et al. (2025). An annual global terrestrial Human Footprint dataset from 2000 to 2018. figshare. Figure. https://doi.org/10.6084/m9.figshare.16571064.v8

Naing Tun, Z., Dargusch, P., McMoran, D., McAlpine, C., & Hill, G. (2021). Patterns and Drivers of Deforestation and Forest Degradation in Myanmar. *Sustainability*, 13(14), 7539. https://doi.org/10.3390/su13147539.

National Specimen Information Infrastructure (2020). 中国自然保护区数据资源 (Data Resources of Nature Reserves in China). Available at https://gitcode.com/Premium-Resources/60f2d.

Ngoc, N. V., Binh, H. T., Son, H. T., Suyama, Y., & Yahara, T. (2022). A new species of Quercus genus (Fagaceae) from Son Tra Peninsula, Central Vietnam. *PhytoKeys*, 206, 61–73.

Ngoc, N. V. & Binh, H. T. (2022). *Quercus mangdenensis*, a new species of *Quercus* (Fagaceae) from Kon Tum Province, Vietnam. *PhytoKeys*, 215, 73–79.

Ngoc, N.V., & Binh, H.T. (2023). Fagaceae of Vietnam, Volume I: *Quercus Linnaeus*. Agricultural Publishing House (APH), Ha Noi, Vietnam.

Nilzén, O. (2022). *The Guardian Forest – sacred trees and ceremonial forestry in Japan.* [Unpublished master's dissertation] Swedish University of Agricultural Sciences.

Northeast Asian Flora. (2025). http://147.47.106.44/index.php. Accessed on 16 May, 2025.

Oldfield, S. F. (2009). Botanic gardens and the conservation of tree species. *Trends in Plant Science*, 14, 581–583.

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, J. F. Lamoreux, T. H. Ricketts, I. Itoua, W. W. Wettengel, Y. Kura, P. Hedao, & K. Kassem. (2001). Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience*, 51(11), 933-938.

Pang, S. E., Slik, J. F., Chisholm, R. A., & Webb, E. L. (2024). Conserving Southeast Asian trees requires mitigating both climate and land-use change. *Nature Sustainability*, 7(10), 1313-1323.

Paradis, E. (2018). Nonlinear relationship between biodiversity and human population density: evidence from Southeast Asia. *Biodiversity and Conservation*, 27(10), 2699-2712.

Quercus hypophaea in Taiwan (The Morton Arboretum)

Peng, S., Shrestha, N., Luo, Y., Li, Y., Cai, H., Qin, H., Ma, K. & Wang, Z. (2023). Incorporating global change reveals extinction risk beyond the current Red List. *Current Biology*, 33(17), pp.3669-3678.

Preferred by Nature. (2021). "Timber Legality Risk Assessment - Viet Nam". Version 2.0.

Propper, C. R., Sedlock, J. L., Smedley, R. E., Frith, O., Shuman-Goodier, M. E., Grajal-Puche, A., Stuart, A. M. & Singleton, G. R. (2024). Balancing food security, vertebrate biodiversity, and healthy rice agroecosystems in Southeast Asia. *Crop and environment*, 3(1), 43-50.

Qian, H., Mishler, B. D., Zhang, J., & Qian, S. (2024). Global patterns and ecological drivers of taxonomic and phylogenetic endemism in angiosperm genera. *Plant Diversity*, 46(2), 149-157.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at https://www.R-project.org/.

Rahman, M. H., Naito, D., Moeliono, M., Mitani, Y., & Susaeta, A. I. (2025). Oil palm-and rubber-driven deforestation in Indonesia and Malaysia (2000–2021) and efforts toward zero deforestation commitments. *Agroforestry Systems*, 99(1), 20.

Raven, P. H., Gereau, R. E., Phillipson, P. B., Chatelain, C., Jenkins, C. N., & Ulloa Ulloa, C. (2020). The distribution of biodiversity richness in the tropics. *Science Advances*, 6(37), eabc6228.

Ross, G. M. & Pence, V. C. (2023). Shoot-Tip Cryopreservation for Oak Conservation. *International Oaks*, 34, p149.

Sarma, J., Rippa, A., & Dean, K. (2023). 'We don't eat those bananas': Chinese plantation expansions and bordering on Northern Myanmar's Kachin borderlands. *Eurasian Geography and Economics*, 64(7-8), 842-868.

Simkin, R. D., Seto, K. C., McDonald, R. I., & Jetz, W. (2022). Biodiversity impacts and conservation implications of urban land expansion projected to 2050. *Proceedings of the National Academy of Sciences*, 119(12), e2117297119.

So, K. (2017). Hon Ba – Home to thousands of rare plants and animals. The official press agency of Vietnam Ministry of Agriculture and Environment. Available at https://van.nongnghiepmoitruong.vn/hon-ba-home-to-thousands-of-rare-plants-and-animals-d764283.html

Song, Y. G., Petitpierre, B., Deng, M., Wu, J. P., & Kozlowski, G. (2019). Predicting climate change impacts on the threatened *Quercus arbutifolia* in montane cloud forests in southern China and Vietnam: Conservation implications. *Forest Ecology and Management*, 444, 269-279.

Song, Y.-G., Wang, T.-R., Lu, Z.-J., Ge, B.-J., Zhong, X., Li, X.-C., Jin, D.-M., Li, Y., Kang, Y.-X., Ning, X., Zheng, S.-S., Yi, L.-T., Dai, X.-L., Cao, J.-G., Lee, J.-H., & Kozlowski, G. (2023). Population Survey Combined with Genomic-Wide Genetic Variation Unravels the Endangered Status of *Quercus gilva. Diversity*, 15(2), 230. https://doi.org/10.3390/d15020230

Sreekar, R., Koh, L. P., Lamba, A., Mammides, C., Teo, H. C., Dwiputra, A., & Zeng, Y. (2024). Conservation opportunities through improved management of recently established protected areas in Southeast Asia. *Current Biology*, 34(16), 3830-3835.

Stibig, H.-J., Achard, F., Carboni, S., Raši, R., & Miettinen, J. (2014). Change in tropical forest cover of Southeast Asia from 1990 to 2010, *Biogeosciences*, 11, 247–258, https://doi.org/10.5194/bg-11-247-2014

Strijk, J.S. (2026a). AsianFagaceae.com – The complete database for information on the evolutionary history, diversity, identification and conservation of over 700 species of Asian trees. http://www.asianfagaceae.com/. Accessed on 23 February, 2026.

Strijk, J.S. (2026b). Flora of Singapore, Vol. 9: "Fagaceae". Singapore Botanical Garden Press. (*In Press*).

Struebig, M. J., Lee, J. S., Deere, N. J., Gevaña, D. T., Ingram, D. J., Lwin, N., Nguyen, T., Santika, T., Seaman, D. J., Supriatna, J. & Davies, Z. G. (2025). Drivers and solutions to Southeast Asia's biodiversity crisis. *Nature Reviews Biodiversity*, 1(8), 497-514.

Sun, S., Zhang, Y., Huang, D., Wang, H., Cao, Q., Fan, P., Yang, N., Zheng, P. & Wang, R. (2020). The effect of climate change on the richness distribution pattern of oaks (*Quercus* L.) in China. *Science of the Total Environment*, 744, 140786.

Sunarno, B., Wong, W. C., Nguyen Dinh Hung & Sosef, M. S. M. (1995). *Quercus* L. In: Lemmens, R.H.M.J., Soerianegara, I. and Wong, W.C. (Editors): Plant Resources of South-East Asia No 5(2): Timber trees; Minor commercial timbers. PROSEA Foundation, Bogor, Indonesia. Database record: prota4u.org/prosea

Tai, V. A., Thi Bich Hong, N., Thi Thuy Van, T., & Thi Kim Thoa, L. (2023). Results of Survey and Evaluation of Invasive Plants in Ba Vi National Park, Vietnam.

Tan, D. T., Thu, P. Q., & Dell, B. (2012). Invasive plant species in the national parks of Vietnam. *Forests*, 3(4), 997-1016.

Teejuntuk, S., Sahunalu, P., Sakurai, K., & Sungpalee, W. (2002). Forest Structure and Tree Species Diversity along an Altitudinal Gradient in Doi Inthanon National Park, Northern Thailand. *Tropics*, 12(2), 85-102.

To, P. X. (2020) "Efforts to exclude illegal timber from public purchasing: Unfolding developments of a public procurement policy in Vietnam" Forest Trends Association.

Tourism Authority of Thailand. (2026). *Doi Luang National Park*. Available at https://www.tourismthailand.org/Attraction/doi-luang-national-park-2. Accessed on 20 April 2026.

Trejo, I. & Cuervo, A. (2016). Cartographic model for the life zone system according to Holdridge (1971). GitHub Repository. Available at https://github.com/AngelaCrow/Zonas-de-vidaFuturo/blob/master/zonasdevida.R. Accessed on 25 September 2023.

UNEP-WCMC & IUCN. (2025). Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM) [Online], April 2025, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.

U.S. Department of Labor. (2026). From Plantations to Your Pantry. Available at https://www.dol.gov/agencies/ilab/reports/child-labor/list-of-goods/supply-chains/palm-oil. Accessed on 13 February 2026.

Valencia-A., S. (2010). Notes on the Genus *Quercus* in Mexico. *International Oaks*, 21, 100–120.

Venter, O., Sanderson, E., Magrach, A. Allan, J. R., Beher, J., Jones, K. R., Possingham, H. P., Laurance, W. F., Wood, P., Fekete, B. M., Levy, M.A., & Watson, J. E. M. (2016). Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nature Communications*, *7*, 12558 https://doi.org/10.1038/ncomms12558

Vietnam Academy of Science and Technology. (2024). Vietnam Red List of Threatened Species. Available at http://vnredlist.vast.vn/tro-giup/ban-quyen/. Accessed on 9 February 2026.

Vyan. (2026). *Integrating climate projections and human footprint data to reassess conservation priorities for endemic oaks in the Indo–China Peninsula*. [unpublished master's thesis]. Yunnan University.

Vyan, Yang, Y-J-W, Good, K., Lin, L., & Deng, M. (2026). Integrating climate projections and human footprint data to reassess conservation priorities for endemic oaks in the Indo–China Peninsula. [Manuscript in preparation]. Yunnan University.

Wang, Y., Xu, C., Wang, Q., Jiang, Y., & Qin, L. (2022). Germplasm resources of oaks (*Quercus* L.) in China: utilization and prospects. *Biology*, 12(1), 76.

Webb, C. O., Slik, J. F., & Triono, T. (2010). Biodiversity inventory and informatics in Southeast Asia. *Biodiversity and Conservation*, 19(4), 955-972.

Westwood, M., Cavender, N., Meyer, A., & Smith, P. (2021). Botanic garden solutions to the plant extinction crisis. *Plants, people, planet*, 3(1), 22-32.

World Database on Protected Areas (WDPA), ENVIS Centre on Wildlife & Protected Areas (Wildlife Institute of India, WII). (2019). Available at https://www.protectedplanet.net and http://wiienvis.nic.in/Home.aspx. Used in Srivathsa, A., Vasudev, D., Nair, T. et al. Prioritizing India's landscapes for biodiversity, ecosystem services and human well-being. Nat Sustain 6, 568–577 (2023). https://doi.org/10.1038/s41893-023-01063-2

World Resources Institute. (2014). Forest Governance and Policy: Vietnam. Available at https://forestpolicy.org/sites/default/files/pdf/vietnam.pdf. Accessed on 12 January 2026.

World Resources Institute. (2025). "Top 10 Lists." Global Forest Review. Washington, DC:. Available at https://research.wri.org/gfr/top-ten-lists. Accessed 12 January 2026.

WWF. (2017). Annamite Range Moist Forests. Available at http://wwf.panda.org/about_our_earth/ecoregions/annamite_moist_forests.cfm. Accessed on 13 February 2026.

WWF. (2021). "Central Annamites". Available at https://asiapacific.panda.org/priority_places/central_annamites/. Accessed on 16 February 2026.

Xiao, Z. T., Song, Y., Liu, L. T., Chen, B., Xu, Y., Huang, L. J., Li, H., Jiang, X. L., Liu, X. S. & Deng, M. (2025). Mitochondrial Genome Assembly and Comparative Analysis of Three Closely Related Oaks. *Horticulturae*, 11(10), p.1231.

Yokoyama, K. (2006). How to identify acorns; a field lesson on oak trees (Fagaceae). *Science for environment & sustainable society*, 3, 9-18.

Zhigila, D. A., Schmidt-Knapik, R. J., Thiers, B. M., Abdul, S. D., Abdullahi, S., AbdulRahaman, A. A., Aigbokhan, E. I., Ajibade, G. A., Ajikah, L. B., Akomaye, F. A. & Ayodele, A. E. (2025). Biodiversity science is improved when silent herbaria speak. *Plants, People, Planet*, 1-9. https://doi.org/10.1002/ppp3.70091

Zizka, A., Silvestro, D., Andermann, T., Azevedo, J., Duarte Ritter, C., Edler, D., Farooq, H., Herdean, A., Ariza, M., Scharn, R., Svanteson, S., Wengstrom, N., Zizka, V., & Antonelli, A. (2019). "CoordinateCleaner: standardized cleaning of occurrence records from biological collection databases." Methods in Ecology and Evolution, -7. doi:10.1111/2041-210X.13152, R package version 3.0.1, https://github.com/ropensci/CoordinateCleaner

Zumwalde, B. A., Fredlock, B., Beckman Bruns, E., Duckett, D., McCauley, R. A., Spence, E. S., & Hoban, S. (2022). Assessing *ex situ* genetic and ecogeographic conservation in a threatened but widespread oak after range-wide collecting effort. *Evolutionary Applications*, 15(6), 1002-1017.

Quercus tarokoensis (Ming-I Weng)

APPENDICES

Fagaceae forest, Taiwan (The Morton Arboretum)

APPENDIX A

Institutional contributors of *Quercus* data during annual requests for ex *situ* accessions data between 2017 and 2025.

Adelaide Botanic Gardens | Adkins Arboretum | Aiken Citywide Arboretum | Ambler Arboretum of Temple University | Arboreto de la Mota, Miraflores de la Sierra, Madrid, Spain | Arboretum at Penn State, The | Arboretum Bokrijk | Arboretum Chocha | Arboretum de la Bergerette | Arboretum des Pouyouleix | Arboretum du Passadou | Arboretum Leśnego Banku Genów Kostrzyca | Arboretum Mustila | Arboretum Robert Lenoir | Arboretum Wespelaar | Arboretum Zampach | Arboretum-Pinetum Lucus Augusti | Arizona-Sonora Desert Museum | Arnold Arboretum of Harvard University, The | Atlanta Botanical Garden | Auckland Botanic Gardens | Australian Botanic Garden, Mount Annan, The | Baker Arboretum | Bamboo Brook Outdoor Education Center | Bangladesh Agricultural University Botanic Garden | Barnea Oak Nursery | Bartlett Arboretum | Bartlett Tree Research Laboratories Arboretum | Barton Arboretum and Nature Reserve of Medford Leas | Batumi Botanical Garden | Bayard Cutting Arboretum | Bedgebury National Pinetum and Forest | Bellefontaine Cemetery and Arboretum | Bendigo Botanic Gardens | Bergen Botanical Garden | Bergius Botanic Garden | Bernheim Arboretum and Research Forest | Birmingham Botanical Gardens and Glasshouses | Blue Mountains Botanic Garden, Mount Tomah | Bok Tower Gardens | Bonn University Botanic Gardens | Boone County Arboretum | Borde Hill Garden | Botanic Garden Meise | Botanic Garden of Smith College, The | Botanic Garden, Delft University of Technology | Botanic Gardens of South Australia | Botanic Gardens of Sydney | Botanical Garden of Moscow Palace of Pioneers | Botanical Garden of the University of Bern | Botanischer Garten der Philipps-Universität Marburg | Botanischer Garten der Universität Osnabrück | Botanischer Garten der Universitaet Zürich | Botanischer Garten Frankfurt am Main | Botanischer Garten Oldenburg | Bowman's Hill Wildflower Preserve | Boyce Thompson Arboretum | Brenton Arboretum, The | Brookgreen Gardens | Brooklyn Botanic Garden | Buckingham Palace | Butte County (Butte Environmental Council) | Caerhays Estate | California Botanic Garden | Cambridge University Botanic Garden | Carl von Ossietzky Universität | Cephalonia Botanica | Chateau Perouse | Chelsea Physic Garden | Chevithorne Barton | Chicago Botanic Garden | Chinese Academy of Forestry |Chollipo Arboretum Foundation | Cincinnati Zoo & Botanical Garden | Cindy Newlander, PCN Quercus Multisite | Connecticut College Arboretum | Cornell Botanic Gardens | Cultivated Oaks of the World | Darts Hill Garden Park | Dawes Arboretum, The | Dayton VA Medical Center Gardens & Grotto | Delft University of Technology Botanic Garden (Botanische Tuinen) | Dendrologická Zahrada | Denver Botanic Gardens | Denver Zoological Gardens | Descanso Gardens | Desert Botanical Garden | Donald E. Davis Arboretum | Dongguan Botanical Garden | Dr. Cecilia Koo Botanic Conservation Center | Dunedin Botanical Garden | Eastwoodhill Arboretum | EcoJardín IIES-UNAM | Ed Shinn | Eden Project, The | Eddy Arboretum | Elmhurst College Arboretum | Estancia San Miguel | Evergreen Burial Park and Arboretum | Exbury Gardens | Fairchild Tropical Botanic Garden | Fairy Lake Botanical Garden | Ferme d'Azy at Chassepierre Belgium | Fernwood Botanical Garden and Nature Preserve | Finnish Museum of Natural History / Helsinki University Botanic Garden / Kaisaniemi Botanic Garden, Kumpula Botanic Garden | Florida field genebank | For-Mar Nature Preserve & Arboretum | Forstbotanischer Garten Tharandt | Franklin Park Conservatory and Botanical Gardens | Frelinghuysen Arboretum, The | Fushan Botanical Garden | Gabis Arboretum at Purdue Northwest (Taltree Arboretum) |

Quercus crispula (Atsushi Motohashi)

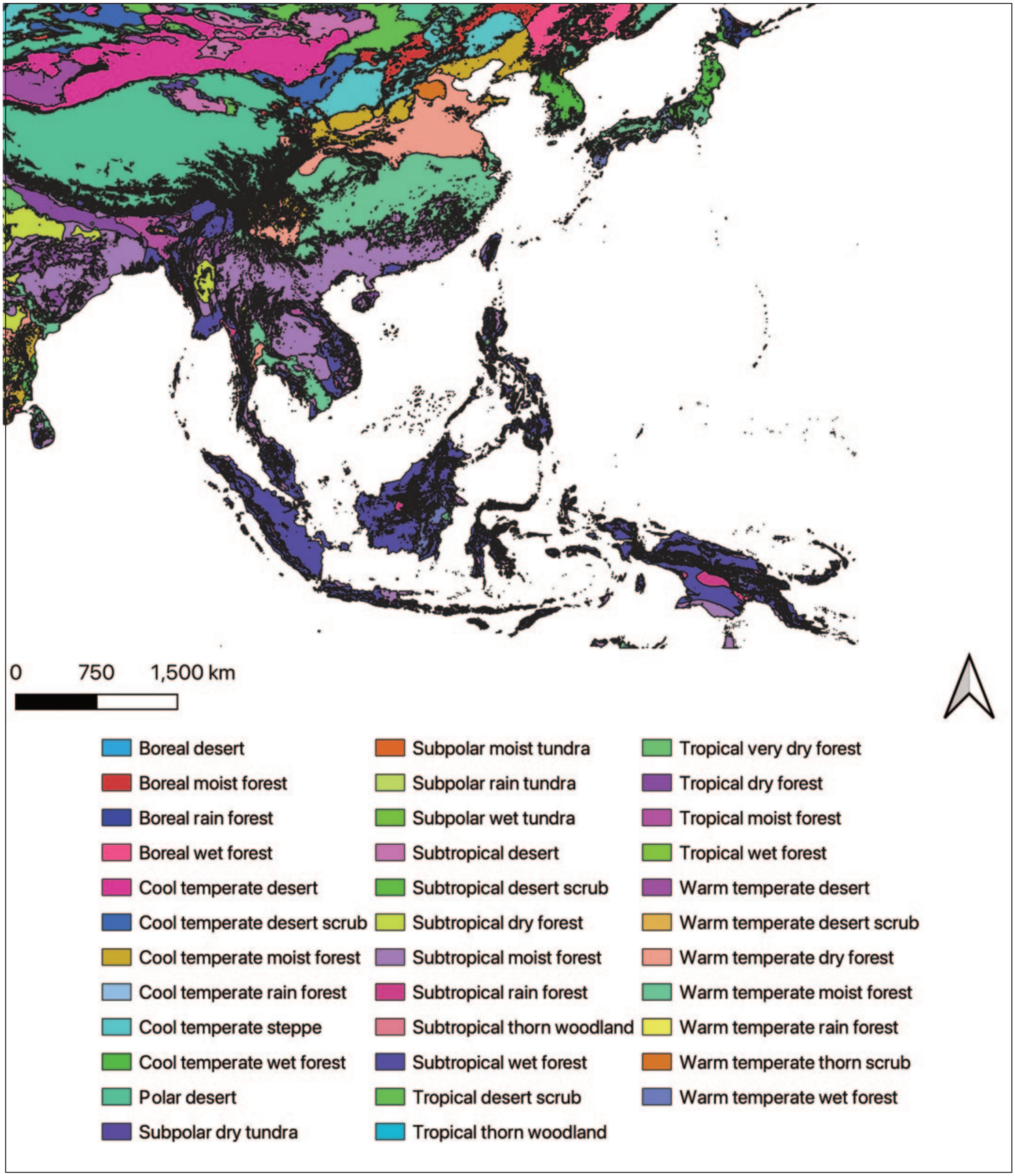
Ganna Walska Lotusland | Gannan Arboretum | Gardens of the Big Bend: Magnolia Garden | George G. Willis Jr. Arboretum at Furman University | Georgia Tech Arboretum | Giardino Botánico "Nuova Gussonea" Monte Etna | Gothenburg Botanical Garden | Gradina Agrobotanica din Cluj-Napoca | Green Bay Botanical Garden | Green Spring Gardens | Greenwood Cemetery | Grigadale Arboretum | GRIN National Plant Germplasm System | Grounds and Gardens University of Exeter, The | Gwavas Garden Homestead | Hackfalls Arboretum | Harmas de Fabre | Hergest Croft Gardens | Hof ter Saksen Arboretum | Holden Arboretum, The | Holden Forest and Garden | Hollard Garden | Horsholm Arboretum | Hortus Botanicus Amsterdam | Houston Botanic Garden | Hoyt Arboretum | Huntington Botanical Gardens | Huntsville Botanical Garden | Jardín Botànic de Sóller | Jardín Botánico "Carlos Thays" | Jardín Botánico de Acapulco | Jardín Botánico Universitario de la Benemérita Universidad Autónoma de Puebla (JBU-BUAP) | Jardín Botánico del Instituto de Biología (UNAM) | Jardín Botánico Francisco Javier | Jardín Botánico Francisco Javier Clavijero | Jardín Botánico Iturraran | Jardín Botánico Louise Wardle de Camacho | Jardin Botanique Alpin de la Jaÿsinia | Jardin Botanique de l'Université de Strasbourg | Jardin Botanique de le Villa Thuret | Jardin botanique de Lyon | Jardin botanique de Paris | Jardin Botanique Exotique | Jardin des Plantes, Nantes | JC Raulston Arboretum | Jean Louis Helardot collection in France | Jerusalem Botanical Gardens | Kadoorie Farm and Botanic Garden | Keith Arboretum, The Charles R. | Kruckeberg Botanic Garden | Kunming Botanical Garden | Lady Bird Johnson Wildflower Center | Landis Arboretum | Le Havre | Le Jardín Le Vasterival | Les chênes plantés à l'Arboretum de La Bergerette | Les Souffrettes | Lewis Ginter Botanical Garden | Lincoln Park Zoo | Linnaean Gardens of Uppsala (Uppsala University), The | Living Desert Zoo & Gardens State Park | Longwood Gardens | Los Angeles County Arboretum and Botanic Garden | Madison Park, Chicago | Madronia Cemetery and Arboretum | Main Botanical Garden of Russian Academy of Sciences, Arboretum (Department of Dendrology) | Marie Selby Botanical Gardens | Masaryk University Faculty of Medicine Medicinal Herbs Centre | Maymont Foundation | Memorial University of Newfoundland Botanical Garden | Mercer Botanic Gardens | Michigan State University | Missouri Botanical Garden | Miyajima Natural Botanical Garden | MNHN: Arboretum de Chèvreloup | MNHN: Harmas de Fabre | MNHN: Jardin botanique alpin la Jaysinia | MNHN: Jardin botanique du Val Rahmeh | MNHN: Jardín des Plantes de Paris | Montgomery Botanical Center | Montreal Botanic Garden (Jardin botanique de Montreal) | Moore Farms Botanical Garden | Morris Arboretum of the University of Pennsylvania | Morris Arboretum, The | Morris County Park Commission | Morton Arboretum, The | Moscow State University Botanical Garden | Mount Auburn Cemetery | Mount Lofty Botanic Garden | Mt. Airy Arboretum | Mt. Cuba Center | Muséum National d'Histoire Naturelle | Nanjing Botanical Garden Memorial Sun Yat-Sen | Nanning Botanical Garden | Naples Botanical Garden | National Arboretum Canberra | National Botanic Garden of Georgia | National Museum "d'Histoire Naturelle"- Seed Bank | National Tropical Botanical Garden | New Plymouth Reserves/ Parklands | New York Botanical Garden | Niagara Parks Botanical Gardens | Nicholas Reis | Norfolk Botanical Garden | North Carolina Arboretum Society, The | North Carolina Botanic Garden | Ohio DNR Park | Orto Botánico dell'Università degli studi di Siena | Orto Botánico dell'Universita di Pavia | Paignton Zoo Environmental Park | Palomar College | Parque Ecológico y Estación Experimental la Soledad | Patterson Garden Arboretum | PCN Quercus Multisite (APGA) | Peckerwood Garden | Penrice Castle | Polly Hill Arboretum, The | Pukekura Park | Quarryhill Botanical Garden | Queen Sirikit Botanic Garden | Quercus Collection of Terry Hanlon | Rancho Santa Ana Botanic Garden | Real Jardín Botánico Juan Carlos I | Red Butte Garden and Arboretum | Regis University Arboretum | Riverwoods Arboretum | Roderick Cameron collection in Uruguay | Rogów Arboretum of Warsaw University of Life Sciences | Royal Botanic Garden Edinburgh | Royal Botanic Garden Kew | Royal Botanic Gardens Sydney |

Quercus kingiana (Queen Sirikit Botanic Garden)

Royal Botanic Gardens Victoria | Royal Botanical Gardens, Hamilton | Royal Botanical Gardens, Ontario | Royal Tasmanian Botanical Gardens | San Diego Botanic Garden | San Diego Zoo Safari Park | San Francisco Botanical Garden | San Luis Obispo Botanic Garden | Santa Barbara Botanic Garden | Sarah P. Duke Gardens | Scott Arboretum of Swarthmore College | Shanghai Botanical Garden | Shanghai Chenshan Botanical Garden | Shaw Nature Reserve | Sheffield Botanical Gardens | Shing Mun Arboretum | Sir Harold Hillier Gardens, The | Sister Mary Grace Burns Arboretum of Georgian Court University | Smithsonian Gardens - Tree Collection | St. Andrews Botanic Garden | Starhill Forest Arboretum | State Botanical Garden of Georgia, University of Georgia | State Botanical Garden of Kentucky | Stavanger Botanic Garden | Stephen's Lake Park Arboretum | Stichting Belmonte Arboretum | Taipei botanical garden | Tallinn Botanic Garden | Taltree Arboretum | Tasmanian Arboretum Inc., The | Thenford House | Timaru Botanic Gardens | Tregrehan Garden Cornwall | Trompenburg Gardens & Arboretum | Tulsa Botanic Garden | Tupare Garden | Tyler Arboretum | U.S. Botanic Garden | UC Davis Arboretum and Public Garden | United States National Arboretum | Universidad Zamorano | University of British Columbia Botanical Garden | University of California Botanic Garden | University of California Botanical Garden at Berkeley | University of California Davis Arboretum | University of Exeter Grounds | University of Guelph Arboretum | University of Oslo Botanical Garden | University of Turku - Botanic Garden | University of Washington Botanic Gardens | Uppsala Linnaean Gardens | US Capitol Grounds and Arboretum | USDA North Central Regional Plant Introduction Station | Utrecht University Botanic Garden | VanDusen Botanical Garden | Village of Riverside, Illinois | Von Gimborn Arboretum | W. J. Beal Botanical Garden and Campus Arboretum | Wellington Botanic Garden | Wesleyan College Arboretum | West Chester University Arboretum | West Laurel Hill Cemetery | Willowwood Arboretum | Winona State University, The Landscape Arboretum at | Wuhan Botanical Garden | Wynkcoombe Arboretum | Xishuangbanna Tropical Botanical Garden | Yorkshire Arboretum, The | Zoo and BG Plzeň

APPENDIX B

Holdridge life zone map of Southeast and East Asia.



APPENDIX C

Province-level species richness for target species in Southeast and East Asia.

BRUNEI DARUSSALAM		
Province	Number of target species	Species
Belait	1	*Q. kerangasensis*
Temburong	1	*Q. percoriacea*

CAMBODIA		
Province	Number of target species	Species
Kâmpóng Spœ	1	*Q. mespilifolia*
Kâmpôt	1	*Q. cambodiensis*
Pursat	2	*Q. chrysocalyx, Q. saravanensis*

INDONESIA		
Province	Number of target species	Species
Aceh	2	*Q. gaharuensis, Q. steenisii*
Kalimantan Selatan	1	*Q. treubiana*
Kalimantan Tengah	1	*Q. kerangasensis*
Kalimantan Timur	3	*Q. gaharuensis, Q. kerangasensis, Q. treubiana*
Kalimantan Utara	2	*Q. chrysotricha, Q. merrilliii*
Sumatera Barat	1	*Q. gaharuensis*
Sumatera Utara	1	*Q. steenisii*

JAPAN		
Province	Number of target species	Species
Ehime	1	*Q. hondae*
Kagoshima	1	*Q. hondae*
Kumamoto	1	*Q. hondae*
Kōchi	1	*Q. hondae*
Miyazaki	1	*Q. hondae*
Ōita	1	*Q. hondae*

LAO PEOPLE'S DEMOCRATIC REPUBLIC		
Province	Number of target species	Species
Attapeu	3	*Q. austrocochinchinensis, Q. braianensis, Q. chrysocalyx*
Bolikhamxai	1	*Q. xanthoclada*
Champasak	2	*Q. chrysocalyx, Q. saravanensis*
Houaphan	1	*Q. thorelii*
Khammouan	2	*Q. mespilifolia, Q. quangtriensis*
Luang Prabang	2	*Q. thorelii, Q. xanthotricha*
Salavan	2	*Q. chapensis, Q. saravanensis*
Savannakhét	1	*Q. austrocochinchinensis*
Sekong	1	*Q. saravanensis*
Vientiane	1	*Q. thorelii*
Xaisomboun	2	*Q. austrocochinchinensis, Q. brevicalyx*
Xiangkhouang	2	*Q. braianensis, Q. xanthotricha*

MALAYSIA		
Province	Number of target species	Species
Melaka	1	*Q. nivea*
Pahang	1	*Q. nivea*
Perak	1	*Q. gaharuensis*
Sabah	6	*Q. gaharuensis, Q. kerangasensis, Q. kinabaluensis, Q. merrillii, Q. pseudoverticillata, Q. treubiana*
Sarawak	8	*Q. chrysotricha, Q. gaharuensis, Q. kerangasensis, Q. kinabaluensis, Q. merrillii, Q. nivea, Q. percoriacea, Q. treubiana*
Terengganu	1	*Q. nivea*

MYANMAR		
Province	Number of target species	Species
Kachin	1	*Q. lodicosa*
Kayin	3	*Q. eumorpha, Q. mespilifolia, Q. ramsbottomii*
Mandalay	1	*Q. mespilifolia*
Mon	1	*Q. ramsbottomii*
Sagaing	1	*Q. xanthoclada*
Shan	2	*Q. kingiana, Q. mespilifolia*
Tanintharyi	2	*Q. quangtriensis, Q. ramsbottomii*

TAIWAN		
Province	Number of target species	Species
Chiayi	1	*Q. tatakaensis*
Hsinchu	2	*Q. tarokoensis, Q. tatakaensis*
Hualien	3	*Q. liaoi, Q. tarokoensis, Q. tatakaensis*
Kaohsiung City	1	*Q. tatakaensis*
Miaoli	1	*Q. tatakaensis*
Nantou	2	*Q. liaoi, Q. tatakaensis*
New Taipei City	1	*Q. tarokoensis*
Pingtung	3	*Q. liaoi, Q. tarokoensis, Q. tatakaensis*
Taichung City	2	*Q. liaoi, Q. tatakaensis*
Taitung	3	*Q. liaoi, Q. tarokoensis, Q. tatakaensis*
Yilan	2	*Q. liaoi, Q. tatakaensis*
Yunlin	1	*Q. tatakaensis*

THAILAND		
Province	Number of target species	Species
Chaiyaphum	4	*Q. kingiana, Q. mespilifolia, Q. quangtriensis, Q. ramsbottomii*
Chanthaburi	4	*Q. austrocochinchinensis, Q. quangtriensis, Q. saravanensis, Q. thorelii*
Chiang Mai	6	*Q. brevicalyx, Q. chapensis, Q. kingiana, Q. lenticellata, Q. mespilifolia, Q. ramsbottomii*
Chiang Rai	2	*Q. chapensis, Q. mespilifolia*
Kamphaeng Phet	1	*Q. quangtriensis*
Kanchanaburi	2	*Q. mespilifolia, Q. ramsbottomii*
Lampang	3	*Q. kingiana, Q. lenticellata, Q. mespilifolia*
Lamphun	2	*Q. kingiana, Q. quangtriensis*
Loei	4	*Q. brevicalyx, Q. mespilifolia, Q. quangtriensis, Q. ramsbottomii*
Lop Buri	1	*Q. quangtriensis*
Mae Hong Son	5	*Q. chapensis, Q. chrysocalyx, Q. eumorpha, Q. kingiana, Q. mespilifolia*
Mukdahan	1	*Q. mespilifolia*
Nakhon Nayok	3	*Q. quangtriensis, Q. ramsbottomii, Q. saravanensis*
Nakhon Ratchasima	1	*Q. mespilifolia*
Nan	2	*Q. brevicalyx, Q. kingiana*
Nong Khai	1	*Q. quangtriensis*
Phayao	2	*Q. kingiana, Q. mespilifolia*
Phetchabun	3	*Q. kingiana, Q. mespilifolia, Q. quangtriensis*
Phitsanulok	1	*Q. ramsbottomii*
Prachin Buri	2	*Q. ramsbottomii, Q. saravanensis*
Sa Kaeo	1	*Q. saravanensis*
Tak	2	*Q. mespilifolia, Q. quangtriensis*
Trat	1	*Q. austrocochinchinensis*
Uthai Thani	1	*Q. mespilifolia*
Uttaradit	1	*Q. kingiana*

THE PHILIPPINES		
Province	Number of target species	Species
Puerto Princesa	1	*Q. merrillii*

VIET NAM		
Province	Number of target species	Species
Ba Ria-Vung Tau	1	*Q. austrocochinchinensis*
Cao Bang	4	*Q. chapensis, Q. disciformis, Q. petelotii, Q. trungkhanhensis*
Da Nang	6	*Q. austrocochinchinensis, Q. bambusifolia, Q. baniensis, Q. chapensis, Q. donnaiensis, Q. sontraensis*
Dak Lak	4	*Q. bidoupensis, Q. braianensis, Q. donnaiensis, Q. eumorpha*
Gia Lai	3	*Q. edithiae, Q. mangdenensis**, *Q. thorelii*
Ha Giang	2	*Q. disciformis, Q. thorelii*
Ha Noi	4	*Q. disciformis, Q. ngochoaensis, Q. platycalyx, Q. xanthoclada*
Ha Tinh	7	*Q. bambusifolia, Q. chrysocalyx, Q. edithiae, Q. platycalyx, Q. quangtriensis, Q. thorelii, Q. xanthoclada*
Hoa Binh	1	*Q. chapensis*
Khanh Hoa	5	*Q. blaoensis, Q. braianensis, Q. camusiae, Q. honbaensis, Q. rupestris*
Kon Tum	7**	*Q. austrocochinchinensis, Q. baolamensis, Q. braianensis, Q. chapensis, Q. chevalieri, Q. mangdanensis, Q. saravanensis*
Lai Chau	2	*Q. asymmetrica, Q. petelotii*
Lam Dong	13	*Q. arbutifolia, Q. austrocochinchinensis, Q. baolamensis, Q. bidoupensis, Q. blaoensis, Q. braianensis, Q. chapensis, Q. chrysocalyx, Q. dankiaensis, Q. donnaiensis, Q. honbaensis, Q. mespilifolia, Q. petelotii*
Lang Son	1	*Q. bambusifolia*
Lao Cai	4	*Q. chapensis, Q. chevalieri, Q. chrysocalyx, Q. petelotii*
Ninh Thuan	4	*Q. bambusifolia, Q. camusiae, Q. chrysocalyx, Q. petelotii*
Phu Tho	2	*Q. austrocochinchinensis, Q. bambusifolia*
Quang Ninh	5	*Q. asymmetrica, Q. bambusifolia, Q. edithiae, Q. platycalyx, Q. quangtriensis*
Quang Trị	2	*Q. arbutifolia, Q. quangtriensis*
Son La	3	*Q. asymmetrica, Q. mespilifolia, Q. petelotii*
Tay Ninh	1	*Q. austrocochinchinensis*
Thanh Hoa	6	*Q. chapensis, Q. chrysocalyx, Q. dilacerata, Q. platycalyx, Q. rupestris, Q. xuanlienensis*
Thua Thien - Hue	2	*Q. austrocochinchinensis, Q. bambusifolia*

* *Quercus mangdenensis* occurrence points in Gia Lai should be verified. They are from recent human observations in Kon Kah Kin National Park, but to our knowledge no herbarium samples were collected.

** *Quercus bidoupensis* has also been collected from Măng Đen (Kon Tum) at 1,200 m in 2024. However, this record is not part of the dataset in the present study.

APPENDIX D

Protected areas within Southeast and East Asia that contain three or more species of threatened or Data Deficient oak. Protected area designations and area in square kilometers from UNEP-WCMC and IUCN (2025) and the Data Resources of Nature Reserves in China Repository (National Specimen Information Infrastructure, 2020).

Name	Designation	Location	Area (km^2)	Number of Target Species	Species Name
Bidoup-Nui Ba	National Park	Viet Nam	575.12	6	*Q. arbutifolia, Q. bidoupensis, Q. braianensis, Q. donnaiensis, Q. honbaensis, Q. petelotii*
Vu Quang	National Park	Viet Nam	527.41	6	*Q. chrysocalyx, Q. edithiae, Q. platycalyx, Q. quantriensis, Q. thorelii, Q. xanthoclada*
Doi Inthanon	National Park	Thailand	475.19	5	*Q. brevicalyx, Q. kingiana, Q. lenticellata, Q. mespilifolia, Q. ramsbottomii*
Nui Chua	National Park	Viet Nam	225.13	4	*Q. bambusifolia, Q. camusiae, Q. chrysocalyx, Q. petelotii*
Ba Na - Nui Chua	Nature Reserve	Viet Nam	279.8	4	*Q. bambusifolia, Q. baniensis, Q. chapensis, Q. donnaiensis*
Ba Vi	National Park	Viet Nam	96.96	4	*Q. disciformis, Q. ngochoaensis, Q. platycalyx, Q. xanthclada*
Lum Nam Pai	Wildlife Sanctuary	Thailand	1197.13	4	*Q. chapensis, Q. chrysocalyx, Q. kingiana, Q. mespilifolia*
海南五指山 (Wuzhishan)	National Park	China	134.36	4	*Q. austrocochinchinensis, Q. bambusifolia, Q. disciformis, Q. xanthoclada*
Khao Yai	National Park and ASEAN Heritage Park	Thailand	2196.21	4	*Q. mespilifolia, Q. quangtriensis, Q. ramsbotoomii, Q. saravanensis*
Hon Ba	Nature Reserve	Viet Nam	192.85	3	*Q. blaoensis, Q. camusiae, Q. honbaensis*
Rung Thong Da Lat	Cultural and Historical Site	Viet Nam	233.92	3	*Q. braianensis, Q. chapensis, Q. dankiaensis*
Chu Yang Sin	National Park	Viet Nam	669.8	3	*Q. braianensis, Q. donnaiensis, Q. eumorpha*
Dong Phayayen-Khao Yai Forest Complex	World Heritage Site	Thailand	6155	3	*Q. mespilifolia, Q. ramsbottomii, Q. saravanensis*
Chiang Dao	Wildlife Sanctuary	Thailand	504.27	3	*Q. kingiana, Q. lenticellata, Q. mespilifolia*
Doi Suthep-Pui	National Park	Thailand	265.69	3	*Q. kingiana, Q. lenticellata, Q. mespilifolia*
Taroko	National Park	Taiwan, Province of China	980.4	3	*Q. liaoi, Q. tarokoensis, Q. tatakaensis*
Kinabalu Park	World Heritage Site	Malaysia	753.7	3	*Q. kinabaluensis, Q. pseudoverticillata, Q. treubiana*
海南霸王岭 (Bawangling)	Nature Reserve	China	299.8	3	*Q. asymmetrica, Q. austrocochinchinensis, Q. disciformis*
海南吊罗山 (Diaoluoshan)	Nature Reserve	China	183.9	3	*Q. asymmetrica, Q. bambusifolia, Q. xanthoclada*
海南尖峰岭 (Jianfengling)	National Forest Park	China	201.7	3	*Q. asymmetrica, Q. bambusifolia, Q. xanthoclada*
广东南岭 (Nanling)	National Forest Park	China	500	3	*Q. arbutifolia, Q. asymmetrica, Q. bambusifolia*

APPENDIX E

Species Profiles for eight threatened Southeast and East Asian oak species can be accessed at the link provided in the table below. The page numbers within the full electronic report are also given.

Species	URL	Page numbers
Quercus arbutifolia	mortonarb.org/gap-analysis/asia/species-profile-quercus-arbutifolia	65-71
Quercus austrocochinchinensis	mortonarb.org/gap-analysis/asia/species-profile-quercus-austrocochinchinensis	72-79
Quercus baolamensis	mortonarb.org/gap-analysis/asia/species-profile-quercus-baolamensis	80-86
Quercus bidoupensis	mortonarb.org/gap-analysis/asia/species-profile-quercus-bidoupensis	87-93
Quercus hondae	mortonarb.org/gap-analysis/asia/species-profile-quercus-hondae	94-100
Quercus kingiana	mortonarb.org/gap-analysis/asia/species-profile-quercus-kingiana	101-108
Quercus nivea	mortonarb.org/gap-analysis/asia/species-profile-quercus-nivea	109-114
Quercus xanthotrica	mortonarb.org/gap-analysis/asia/species-profile-quercus-xanthotrica	115-121

Taroko national park, Taiwan (The Morton Arboretum)

Conservation Gap Analysis of Select Native

Asian Oaks

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