

Ecological research with artificial intelligence and machine learning in Asia

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Abstract

The use of artificial intelligence (AI) and machine learning (ML) has significantly enhanced ecological research in Asia by improving data processing, analysis, and pattern extraction. Analyzing 1550 articles, I show an overview of the use of AI and ML for Asian ecological research. Following the last 20 year trend, I found that the topics in Asian ecological research have transitioned from technical perspectives to more applied issues, focusing on biodiversity conservation, climate change, land use change, and societal impacts. Non-Asian countries, on the other hand, have focused more on theoretical understanding and ecological processes. The difference between Asian and non-Asian regions may have emerged due to the ecological challenges faced by Asian countries, such as rapid economic growth, land development, and climate change impacts. In both regions, deep learning related technology has been emerging (e.g. big data collection including image and movement). Within Asia, China has been the Asia-leading country for AI/ML applications followed by Korea, Japan, India, and Iran. The number of computer science education programs for education in China has been increasing 3.5x times faster than that in the U.S., indicating that a nationwide strategy for computer science development is key for ecological science with AI. Overall, the adoption of AI and ML technologies in ecological studies in Asia has propelled the field forward and opened new avenues for innovative research and conservation practices.

Keywords

Artificial intelligence (AI), Machine learning (ML), Deep learning, Biodiversity conservation, Asian countries

1. Introduction

Ecological research in Asian countries stands out for its uniqueness compared to studies conducted in other regions of the world (Koh et al., 2013; Sodhi et al., 2010, 2004). The rich

and unique diversity of flora, fauna, and ecosystems are found in Asian ecosystems: The rainforests of Southeast Asia (Ashton, 1993; Ikeya and Balée, 2023), the vast agroecosystems of Central Asia (Bambaradeniya and Amerasinghe, 2004), the unique aquatic ecosystems (Dudgeon, 2000, 1999; Meynell et al., 2021). This unparalleled biodiversity offers researchers in Asian countries the opportunity to delve into unexplored territories and unravel new insights. By studying these distinct ecosystems, ecological research in Asia has the potential to contribute valuable knowledge that cannot be obtained by focusing solely on other parts of the world (Corlett, 2014; Sodhi et al., 2004). Not only its distinctiveness but biodiversity degradation at an unprecedented rate is another key reason to study biodiversity in Asia (Sodhi et al., 2010). It requires an urgent action for biodiversity conservation in the post-2020 global biodiversity framework (Zhu et al., 2021).

Artificial intelligence (AI) and machine learning (ML) have become powerful tools that have revolutionized ecological research globally (Christin et al., 2019; Olden et al., 2008; Pichler and Hartig, 2023; Ryo et al., 2021; Ryo and Rillig, 2017; Thessen, 2016). In recent years, advancements in these technologies have significantly enhanced the efficiency and accuracy of data processing and analysis in the field of ecology. This progress has allowed researchers to tackle complex ecological questions by rapidly examining vast amounts of data. By leveraging AI and ML algorithms, scientists can now extract meaningful patterns from data (Ryo et al., 2021; Ryo and Rillig, 2017), identify unexpected variable nonlinearity and interactions (Olden et al., 2008; Ryo and Rillig, 2017), and make predictions with unprecedented precision (Elith and Leathwick, 2009). These transformative capabilities have paved the way for groundbreaking discoveries and a deeper understanding of ecological systems. Asian countries have embraced these advancements and have incorporated AI and ML techniques into their ecological research practices, leading to significant advancements in the field.

The applications of AI and ML in ecological research in Asia is particularly promising because the ecological patterns and processes as well as the anthropogenic pressures can be substantially different from the other continents. For example, in Asian countries, natural resources are often under pressure due to rapid economic growth and land development (Corlett, 2014; Sodhi et al., 2004; Zhao et al., 2006). Major drivers of biodiversity decline are tree-plantation and deforestation, hydropower dam construction, consumption of species for traditional medicines, hunting and trade, and mineral mining (Hughes, 2017). Because of the uniqueness, ecological theories developed mainly in the Western region may not explain the patterns in other understudied regions like Africa and Asia (Ryo et al., 2020). By adapting AI and ML techniques to address these unique challenges, Asian ecological research is pushing the boundaries of knowledge and contributing valuable insights to the global

scientific community as well as managing and conserving Asian unique biodiversity and ecosystems.

In this article, I aim to provide a comprehensive understanding of the current state of ecological studies with AI and ML applications in Asia. This article will not only shed light on the distinctiveness of ecological studies in Asian countries but also provide insights into how the integration of AI and ML technologies has propelled Asian ecological research forward. Ultimately, the goal is to foster a deeper appreciation for the ecological richness of Asia and the innovative approaches being employed to conserve and understand its diverse ecosystems.

2. Methods

I used Web of Science Core Collection for searching articles based on the following keyword query so that I do not miss popular ML algorithm applications in ecology: ("artificial intelligence" or "machine learning" or "deep learning*" or "random forest*" or "convolutional neural" or "neural network*" or "support vector" or "decision tree" or "naive Bayes" or "gradient boost*" or "xgboost*" or "k-means" or "k-nearest neigh*") and (ecolog*) (Topic). The search was refined with the Web of Science Categories "Ecology". The search was conducted on 8th May 2023. In total, 1550 articles were found since 1987, and all of them were used in the following analyses. The publication information such as publication year and keywords was downloaded as a bibtex file. The same search procedure can be taken with the link:

<https://www.webofscience.com/wos/woscc/summary/eaaf68c8-6b69-41d6-a0cf-2a587fcb32ec-885fcd6c/relevance/1>

Bibliometric (scientometric) analysis was conducted to identify some patterns in the publications. I divided the publications into Asian and non-Asian countries based on the corresponding authors' affiliations. Of 1,550 articles, 259 articles belonged to the Asian publication (17%), and 1285 articles belonged to the non-Asian publication (83%).

For publication trend analysis, I investigated the numbers of publications from Asian and non-Asian countries, as well as the entire body of ecological domain (defined by Web of Science category = 'ecology'). I extracted the top 10 most productive countries and the top 5 most published journals from Asia and non-Asian regions in terms of the number of publications.

For topic trend analysis, I extracted the most frequently used keywords for each year since 2001 and the 5 most frequently used keywords since 2020, expecting that they represent the

long-term and short-term trends in publication themes. Web of Science offers two different types of keyword sets for each article: 'Author-defined keyword' and 'WoS-defined keyword', where the former is determined by the authors, while the latter is determined by the *KeyWords Plus*[®] algorithm operated by Web of Science generating keywords automatically from the titles of cited articles. In general, author-defined keywords tend to share the same keywords less frequently among articles than WoS-defined keywords. Based on the assumption that many articles avoid repeating the same terms from the titles, I analyzed both author-defined and WoS-defined keywords to offer a more comprehensive view of topic trends.

I used R programming language version 4.0.4 (R Core Team, 2022) with the following libraries: tidyverse v1.3.1 (Wickham et al., 2019); bibliometrix v4.0.1 (Aria and Cuccurullo, 2022); igraph v1.3.0 (Csárdi and Nepusz, 2006).

3. Results

Publication trend

AI/ML applications in ecology have been increasing sharply since 2017 in both Asian and non-Asian countries, although the topic occupies ca. 1% of the entire ecology domain (**Fig. 1a**). More than 22,000 peer-reviewed articles were published in 2022 in the ecology domain, of which ca. 230 articles were associated with AI/ML topics. AI/ML applications have been growing faster in non-Asian countries than Asian ones.

China has been the Asia-leading country for AI/ML applications, followed by Korea, Japan, India, and Iran (**Fig. 1b**). China is also the second most productive country in this subdomain in the world, following the USA (**Fig. 1c**). The USA has published articles in this subdomain nearly three times higher than China (420 and 148 articles, respectively). The top 10 ranking of non-Asian countries is occupied by the Western world (USA, Australia, and western European countries). Therefore, one can imagine that the comparisons between Asian and non-Asian countries in the following sections in this study are almost equivalent to the comparisons of Asian and Western regions.

'Ecological modeling' and 'ecological informatics' were the top 2 publication outlets for both Asian and non-Asian countries (**Table 1**). In non-Asian countries, the top 3-5 were 'methods in ecology and evolution', 'ecology and evolution', and 'ecosphere'. Meanwhile, in non-Asian countries, the top 3-5 were 'ecological engineering', 'applied ecology and environmental research', and 'frontiers in ecology and environmental research'. The difference may indicate

that the target audience in non-Asian countries is still within the ecology domain with a generic audience, but that in Asian countries is more for the applied environmental science domain including environmental and ecosystem engineering.

Table 1. Top 5 popular journals for AI and machine learning application for ecological studies

Rank	Asia	Non-Asia
1	Ecological modeling	Ecological modeling
2	Ecological informatics	Ecological informatics
3	Ecological engineering	Methods in ecology and evolution
4	Applied ecology and environmental research	Ecology and evolution
5	Frontiers in ecology and environmental research	Ecosphere

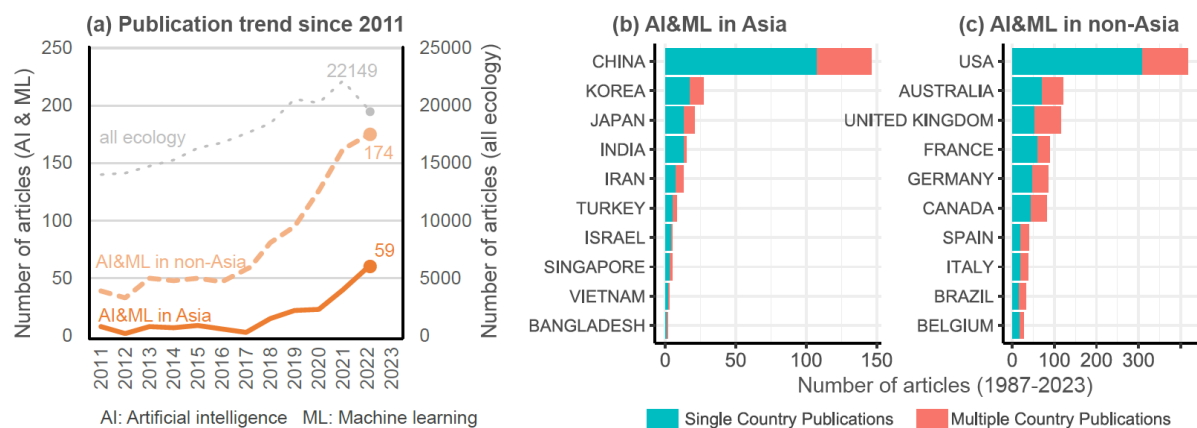


Figure 1. Publication trend in ecological studies with artificial intelligence (AI) and machine learning (ML), divided into Asian and non-Asian countries. Since 2017, AI and ML applications have been increasing nonlinearly, of which growth rate is faster than the growth of ecological domain (a). China and the USA are the top countries in terms of publications regarding AI and ML applications in ecology in Asia and non-Asian regions, respectively (b, c).

Long-term topic trends since 2001

As a long-term trend, in Asian countries (**Fig. 2**, upper-left panel), understanding and predicting ecological patterns and dynamics (species distribution, biodiversity, dynamics, communities, community structure, population dynamics) are a central theme over the decades, and in particular, there is an increase in the level of ecological hierarchy starting from population, community, to biodiversity. Aquatic ecosystems were an important target

(phytoplankton, fish, river, and Nakdong river), while terrestrial vegetation has been gaining more attention in recent years.

In Non-Asian countries (**Fig. 2**, lower-left panel), understanding and predicting ecology (species distribution, biodiversity, richness, population dynamics, abundance, biomass) is also a common theme over the decades in line with Asian countries. The keywords started with aquatic ecosystems (fish species richness and trout), suggesting that AI/ML applications in ecological research have started from aquatic ecology. In line with the recent trends (2020-), computational and technological terms are more prevalent, especially statistical/ML techniques (classification, prediction, artificial neural network, neural network, generalized additive models, logistic regression, classification trees).

Recent topic trends in 2020-2022

A hot topic in Asian countries since 2020 (**Fig. 2**, upper-right panel) seems to be analyzing the impacts of climate change (including climate and temperature) and land use (landscape) on biodiversity, vegetation, and species distributions (also habitat, suitability) is a major trend. In non-Asian countries, hot topics since 2020 (**Fig. 2**, bottom-right panel) are (1) data and computational approaches and infrastructures (including acceleration, regularization, big-data, identification, r package, database, framework) and (2) species distribution with maxent, behavior, evolution, and connectivity. While understanding species distribution is a common theme for both Asian/non-Asian countries, we observe that non-Asian countries are more onto developing the analytical approaches while Asian countries are more onto

applications.

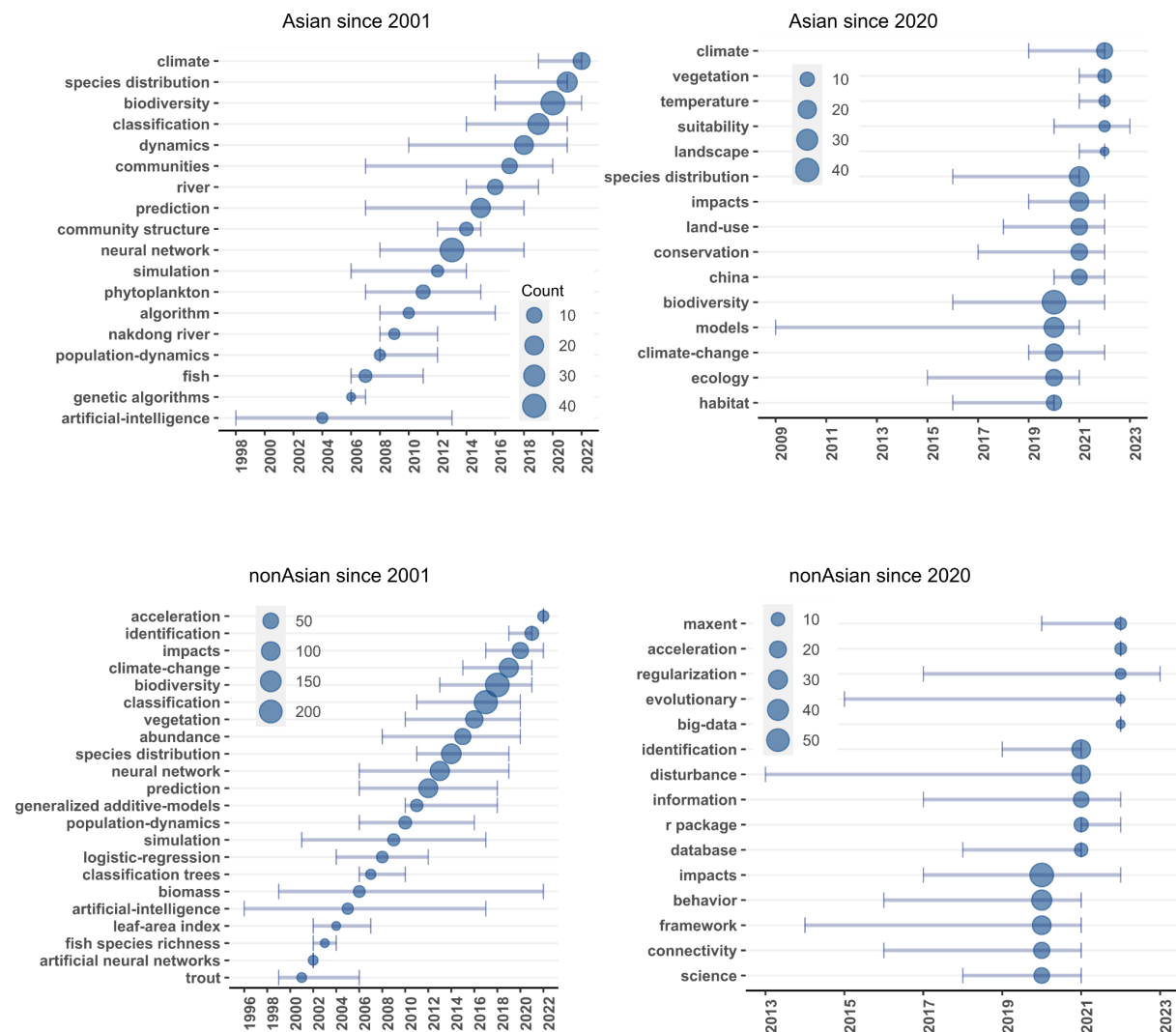


Figure 2. Topic trend in ecological studies with artificial intelligence (AI) and machine learning (ML), divided into Asian/non-Asian countries and long-term (since 2001) and recent (since 2020) trends. The bar and circle of each term represents the Q1, Q3, and median of the keyword occurrence frequency. A shorter bar represents an emerging or short-lived topic, and the relative position of the circle within the bar indicates the trend type (left-sided as 'peak out'; middle as 'consistent popularity'; right-sided as 'trending'). For each year, the most used keyword that positions the median (circle) at the year is selected (for the right panels; 5th most used ones).

Transitions in Asian ecological research with AI and ML

In Asian countries from 2001 to 2020, the most frequent keyword was (artificial) neural network, and the associated largest interest was the application of (artificial) neural networks for predicting ecological dynamics including behavior, population, community, and ecosystems, especially in relevance to aquatic environments (phytoplankton, fish, river) (**Fig. 3, top-left, red cluster**). Also, analyzing biodiversity patterns relevant to species distribution and assemblage under climate change and land use change was a major topic (**Fig. 3,**

top-left, blue cluster). These major topics were also found as the major topics in non-Asian countries (**Fig. 3**, bottom-left).

Nowadays (2020–), a deviation in interests between Asian and non-Asian countries becomes more apparent. In Asian countries, the major focus has shifted from a technical perspective (i.e. neural network) to more applied issues, which is biodiversity conservation under climate change using species distribution modeling (**Fig. 3**, top-right, red cluster). Also, the focal ecosystem has expanded from aquatic to terrestrial (land use, vegetation, ndvi, aboveground biomass) to study the impacts of land use and temperature. China as a keyword has also emerged significantly (**Fig. 3**, top-right, blue cluster). The keywords linked with 'China' may suggest that the productivity, growth, and biomass of vegetation and associated ecosystem functions under climate change are the central interest in China. Therefore, in Asian countries, there was a thematic shift from ML application itself to more societally important agenda including climate change, land use change, and biodiversity loss. The central interest is shared with Non-Asian countries (**Fig. 3**, bottom-right).

Asian countries tend to use more specific keywords relevant to the society including water quality, urbanization, productivity and carbon, while non-Asian countries tend to use more generic keywords relevant to ecological processes and mechanisms such as connectivity, niche, selection, dispersal, and scale. Asia focuses more on societally relevant applied issues, while non-Asian countries focus more on theoretical understanding.

big-data (non-Asia). This list supports the difference in interest, and a similar pattern is seen also in 2020 and 2021 (**Fig. 2**). One potential reason is the economic difference. The top 5 most-publishing countries in Asia are, on average, economically less developed than the top 5 ones in non-Asian countries. Therefore, Asian countries face a harder challenge to manage ecosystem conservation under a stronger pressure of economic development under global change than developed countries mostly located in the Western world (Cao et al., 2021). On the contrary, ecosystems in the Western countries might have been more conserved because of economic maturity (Gren et al., 2016). Addressing societally important problems with application was identified as a key agenda for Asian ecology (Wu and Overton, 2002).

One promising strategy for Asian countries is to transfer technological development in the Western countries as quickly as possible for more effective monitoring and management of biodiversity and ecosystems. For instance, deep learning (regularization, big-data), r package, database, new monitoring device (acceleration) are trending keywords in non-Asian countries (**Fig. 2**), and such latest developments can be swiftly tested. The quick technical transfer may be one of the biggest advantages in AI/ML applications in ecology, because theory cannot be readily transferred due to context dependency (Catford et al., 2022). Paying attention to emerging topics in developed countries especially in the Western countries can be crucial for AI-powered ecological conservation in Asian countries.

Understanding why China has strikingly rich AI/ML applications is worth investigating. It seems that AI/ML applications in natural science have been rapidly growing especially in China and India: For instance, these countries are the most-publishing countries regarding deep learning applications in the agriculture domain (Ryo et al., 2023). Probably, the number of publications per country is associated with education such as the number of computer science programs at undergraduate level. The number of computer science programs for education in China and India has been increasing 3.5x times faster than that in the U.S. (Loyalka et al., 2019). Therefore, strategy for computer science development at the national level can have a significant influence also on ecological science.

As a common historical trend, AI/ML implementation started in aquatic ecology, moving to terrestrial (**Fig. 2**). Aquatic ecology was a frontier in AI/ML applications, perhaps because one of the highly cited articles introducing AI/ML algorithms to ecology at an early stage was done in the freshwater domain (Olden et al., 2008). Another common trend is that species distribution modeling has been one of the key application areas of AI/ML in ecology regardless of countries. Another investigation in Ryo and Rillig (2017) suggests that AI/ML applications in ecology have gained momentum mainly because of species distribution

modeling, which requires environmental covariates and the presence/absence information of a target species in space (Elith and Leathwick, 2009; Guisan and Thuiller, 2005). It has been a powerful predictive tool under climate change.

Terrestrial vegetation including grassland and forest is currently the popular target for AI/ML applications (**Fig. 2**), perhaps because they do not move and are visible. Microbes including fungi and bacteria and animals are less studied (at least, they did not appear in the keyword list). However, they can be studied more often in the near future thanks to the emergence of deep learning in combination with various monitoring devices including microscopic imaging, environmental DNA, metabarcoding, camera trap, and other proximal sensing for sounds and smells (Christin et al., 2019).

This study may have oversimplified the representation of the world: Asia and the others. Indeed, the publication dominance was imbalanced to China in Asia and the US in non-Asian categories. Differentiating China and the other Asian countries may also reveal some interesting patterns. Nevertheless, this kind of attempt can help increase the resolution of the understanding of regional differences in ecological research.

Ecological science is a discipline that attempts to discover general principles of biotic and abiotic interactions in space and time (Ryo et al., 2019). However, understanding a globally applicable rule does not necessarily help explaining local patterns due to context dependency (Catford et al., 2022). AI/ML applications can identify patterns that differ in scale and regions and unexpected from well-accepted theories (Ryo et al., 2021; Ryo and Rillig, 2017). Biodiversity and ecosystem as well as anthropogenic pressures are unique in Asian regions, but most patterns are still largely unknown (Hughes, 2017; Sodhi et al., 2010). AI/ML applications can uncover Asia-unique patterns and solutions for biodiversity loss.

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