

SDMs: Broad Applications in a Changing World

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Introduction

Species Distribution Models (SDMs) are fundamental tools in modern ecology, critical for understanding and predicting how species' geographical ranges and habitat suitability are influenced by environmental factors, especially under changing climate conditions. These models enable researchers to forecast shifts, expansions, and contractions in species distributions, providing essential information for public health, agriculture, and conservation. Across various studies, SDMs are consistently shown to offer robust insights for proactive management and policy development.

In the realm of public health, SDMs are vital for tackling disease vector challenges. A systematic review and meta-analysis focused on *Anopheles stephensi*, an invasive malaria vector in Africa, demonstrated the models' efficacy in predicting its potential spread. This forecasting capability is indispensable for guiding public health interventions and informing vector control strategies in vulnerable areas, while also highlighting needs for improved data collection [1].

Similarly, ensemble SDMs have been utilized to project the future geographic ranges of key African malaria vectors, *Anopheles gambiae* s.l. and *Anopheles funestus* s.l., under climate change scenarios. These projections reveal significant alterations in their habitats, crucial for anticipating future malaria risks and developing adaptive vector control strategies across Africa [5].

Furthermore, for China, the MaxEnt SDM predicted potential shifts and expansions in the distribution of *Aedes aegypti* and *Aedes albopictus*, major dengue vectors, under climate change. Such predictions are critical for targeted mosquito control and preventing outbreaks [3].

SDMs are equally indispensable for managing invasive species and plant pathogens. For instance, ensemble SDMs projected a significant expansion of suitable habitats for the invasive plant *Ambrosia artemisiifolia* (common ragweed) across Asia under future climate change scenarios. These findings provide crucial insights for early warning systems and management strategies to mitigate its environmental and health impacts [2].

Global SDMs were also developed for *Xylella fastidiosa*, a plant pathogen, and its vectors, identifying current and future invasion risks. The models predict widespread establishment potential in new regions, offering vital intelligence for international biosecurity and guiding eradication programs to protect agricultural and natural ecosystems [6].

Additionally, the MaxEnt model predicted the current and future suitable habitats for *Ailanthus altissima* (tree of heaven), a highly invasive tree in China, under climate change, indicating substantial expansion potential. This provides crucial ecological insights for developing effective management and control strategies [10].

Beyond health and invasion, SDMs are fundamental for conservation and sustainable resource management. Research employing SDMs forecasted future suitable habitats for *Pleurotus eryngii*, a commercially important edible mushroom in China, under climate change. Projections indicated potential distribution shifts and contractions, providing essential information for sustainable cultivation and conservation strategies [4].

An ensemble SDM predicted significant habitat shifts and contractions for the Siberian ibex (*Capra sibirica*) across the Mongolian Plateau under climate change, offering crucial insights for conservation strategies and managing this iconic ungulate [7].

SDMs also projected a substantial reduction and northward shift in the suitable habitat for *Quercus aquifolioides*, an important oak species in southwestern China, under different climate change scenarios, highlighting its vulnerability and informing conservation efforts [9].

Notably, some studies advance SDM methodology by integrating them with other data, such as acoustic telemetry, to enhance predictions of habitat suitability for vulnerable marine fish species. This combined approach offers a more dynamic, fine-scaled understanding of species' space use, proving valuable for designing marine protected areas and adaptive fisheries management strategies [8].

Description

Species Distribution Models (SDMs) stand as foundational tools in contemporary ecological and environmental research, offering invaluable capabilities to discern and forecast the potential geographic ranges of diverse organisms under both current and projected environmental conditions. These sophisticated models are particularly instrumental in elucidating shifts in habitat suitability, which is paramount for addressing a wide array of pressing challenges spanning public health, agricultural security, and the imperative of biodiversity conservation. Across numerous independent investigations, the consistent utility of SDMs is demonstrated in generating actionable insights that directly inform strategic management frameworks and robust policy decisions across an eclectic mix of scientific disciplines.

In the specialized domain of public health, SDMs are profoundly significant for understanding, anticipating, and managing the proliferation of disease vectors. Here's how: a rigorous systematic review and meta-analysis centered on *Anopheles stephensi*, an invasive malaria vector actively spreading across Africa, meticulously highlighted the proven effectiveness of SDMs in projecting its potential geographical expansion. Such foresight is critically important for orchestrating public health interventions and for refining vector control strategies within highly vulnerable regions. The authors of this comprehensive review also pinpointed specific

data gaps, underscoring the ongoing need for enhanced data collection to achieve even more accurate predictive modeling [1]. Concurrently, ensemble species distribution models have been strategically employed to map out the projected future geographic range of two predominant African malaria vector complexes, namely *Anopheles gambiae* s.l. and *Anopheles funestus* s.l., when subjected to various climate change scenarios. The compelling findings from this research unequivocally suggest significant alterations in their suitable habitats, thereby offering crucial insights for accurately anticipating future malaria risk profiles and for meticulously developing adaptive strategies pertinent to vector control and broad public health planning throughout the entire African continent [5]. Furthermore, specific research in China has effectively applied the MaxEnt species distribution model to predict the future geographic distribution of *Aedes aegypti* and *Aedes albopictus*, two major vectors responsible for dengue, across the nation under an array of climate change scenarios. The consequential results emanating from this study critically illuminate potential shifts and expansive movements in their suitable habitats, information that is absolutely vital for judiciously guiding public health interventions and for implementing precisely targeted mosquito control programs designed to preempt and prevent widespread vector-borne disease outbreaks [3].

Beyond the realm of disease vectors, SDMs serve as indispensable instruments in the proactive management of invasive species and the pervasive threat of plant pathogens. Consider this: one notable study leveraged ensemble SDMs to project the potential distribution of the highly invasive plant *Ambrosia artemisiifolia* (commonly known as ragweed) across the vast expanse of Asia, meticulously factoring in future climate change scenarios. The resultant findings decisively indicate a significant and concerning expansion of suitable habitats for this allergenic and agriculturally detrimental weed. This provides crucial, actionable insights for developing robust early warning systems and comprehensive management strategies aimed at effectively mitigating its detrimental environmental and health impacts throughout the region [2]. Another pivotal research effort involved the development of global species distribution models specifically for the formidable plant pathogen *Xylella fastidiosa* and its associated insect vectors. This work was critical in pinpointing both current and prospective invasion risks under the dynamic conditions of climate change. The resultant models project a widespread potential for the pathogen's establishment in numerous new geographical territories, thereby providing vital intelligence for international biosecurity initiatives and for guiding targeted surveillance and eradication programs. These programs are designed to stringently protect both agricultural systems and invaluable natural ecosystems from the devastating effects of this disease [6]. Additionally, the MaxEnt species distribution model has been specifically deployed to predict the current and future suitable habitats for *Ailanthus altissima* (commonly known as the tree of heaven), which is recognized as a highly invasive tree species, across China under various climate change scenarios. The projections derived from this research clearly indicate a significant potential for its aggressive expansion into previously uncolonized regions, delivering crucial ecological insights essential for the meticulous development of effective management and control strategies intended to significantly mitigate the widespread invasive impacts of this particular species [10].

SDMs further demonstrate their multifaceted utility in critical conservation efforts and in facilitating the sustainable management of ecological resources. For instance, researchers meticulously utilized species distribution models to forecast the future suitable habitats for *Pleurotus eryngii*, a commercially significant edible mushroom, across China under diverse climate change scenarios. The projections stemming from this study compellingly reveal potential shifts and contractions in its distribution, furnishing critical information essential for ensuring sustainable cultivation practices, formulating effective conservation strategies, and adapting existing agricultural methodologies in direct response to evolving environmental changes [4]. In a similar vein, an ensemble species distribution model was strategically employed to project the potential distribution of the Siberian ibex (*Capra*

sibirica) across the expansive Mongolian Plateau, with explicit consideration of various climate change scenarios. The findings from this particular research predict significant shifts and discernible contractions in its suitable habitats, thereby offering crucial insights that are indispensable for developing highly effective conservation strategies, for prudently establishing new protected areas, and for judiciously managing this iconic mountain ungulate in the face of persistent and ongoing environmental transformations [7]. Furthermore, species distribution models have been expertly applied to project the future suitable habitat of *Quercus aquifolioides*, an important and ecologically significant oak species indigenous to southwestern China, under a spectrum of different climate change scenarios. The compelling findings from this investigation predict a substantial reduction in its overall distribution and a pronounced northward shift, unequivocally highlighting the inherent vulnerability of this specific species. This provides essential information that is foundational for developing targeted conservation strategies and for implementing sustainable forest management plans [9]. Expanding on methodological advancements, one innovative study successfully integrated species distribution models with complementary acoustic telemetry data to significantly enhance the precision of predictions concerning habitat suitability for vulnerable marine fish species. By ingeniously combining these two distinct yet powerful methods, the authors were able to provide a more dynamic, nuanced, and fine-scaled understanding of species' spatial utilization and their specific habitat preferences. This offers invaluable tools for the strategic design of more effective marine protected areas and for the intelligent implementation of truly adaptive fisheries management strategies [8].

Conclusion

Species Distribution Models (SDMs) are widely applied across various ecological contexts, from predicting disease vector spread to informing conservation strategies. Numerous studies highlight the effectiveness of SDMs, often incorporating climate change scenarios, to forecast potential shifts, expansions, and contractions in species' habitats. For public health, SDMs are crucial for understanding and managing disease vectors. Research on *Anopheles stephensi*, an invasive malaria vector in Africa, demonstrated SDMs' utility in predicting its spread and guiding public health interventions. Similarly, projections for *Anopheles gambiae* s.l. and *Anopheles funestus* s.l. in Africa, and *Aedes aegypti* and *Aedes albopictus* in China, under climate change, anticipate future malaria and dengue risks, informing vector control programs. Invasive species management also heavily relies on SDMs. Studies project significant expansions for *Ambrosia artemisiifolia* in Asia and *Ailanthus altissima* in China, under climate change, providing early warnings and management insights. Global models for *Xylella fastidiosa* and its vectors identify invasion risks, supporting international biosecurity efforts in agriculture. Conservation and resource management benefit from SDMs by predicting habitat changes for vulnerable species and economically important organisms. This includes forecasting distribution shifts for the edible mushroom *Pleurotus eryngii* and the oak *Quercus aquifolioides* in China, and the Siberian ibex (*Capra sibirica*) in the Mongolian Plateau, all under climate change. Such insights are essential for sustainable cultivation, conservation strategies, and adapting to environmental changes. Moreover, the integration of SDMs with other data, like acoustic telemetry for marine fish, enhances predictive power for habitat suitability, leading to more effective protected area design and adaptive fisheries management. Collectively, these studies underscore the indispensable role of SDMs in proactive environmental management and policy making in a changing world.

Acknowledgement

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Conflict of Interest

None.

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