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Editorial: Modeling ecological and epidemiological interactions for sustainable practices

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Editorial on the Research Topic
Modeling ecological and epidemiological interactions for sustainable practices

1 Introduction

In recent decades, global environmental change, accelerated urbanization, and increasing anthropogenic pressures have significantly altered the balance of natural ecosystems [1]. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), approximately one million species are currently at risk of extinction, primarily due to human activities such as deforestation, land-use change, and climate disruption [2]. These environmental pressures not only threaten biodiversity but also increase the likelihood of zoonotic spillovers, where diseases transfer from wildlife to humans. A landmark study by Jones et al. [3] revealed that over 60% of emerging infectious diseases (EIDs) since 1940 have been zoonotic in origin, with 71.8% of these originating in wildlife. More recently, Carlson et al. [4] highlighted how climate change is accelerating cross-species viral transmission, creating new ecological and epidemiological risks worldwide. These disruptions have led to more frequent and severe interactions between ecological instability and disease dynamics, highlighting an urgent need to adopt integrative modeling approaches. The convergence of environmental and epidemiological sciences offers a promising avenue to develop sustainable strategies that consider both environmental balance and public health outcomes. This Research Topic, *Modeling Ecological and Epidemiological Interactions for Sustainable Practices*, brings together interdisciplinary contributions that harness mathematical models to explore and address these pressing challenges.

2 Integrated modeling approaches for ecological, epidemiological, and economic dynamics

The overarching aim of this Research Topic has been to foster integration between ecological and epidemiological modeling to enhance our ability to predict, control, and mitigate the effects of ecological disturbances on disease transmission and vice versa. The convergence of these fields supports the development of holistic frameworks that inform sustainable resource management and public health strategies, especially in the face of global environmental change.

The accepted contributions to this Topic reflect the thematic diversity and methodological richness of this growing research area. The articles address various challenges through innovative modeling techniques, ranging from fractional calculus and discrete-time systems to optimal control theory.

One of the innovative contributions in this collection (Elmire et al.) addresses economic sustainability through a dynamic analysis of duopoly market stability. The study proposes a model wherein two firms, operating under Cournot competition, seek to optimize profits through open innovation strategies. Intellectual property rights, such as patent licensing and royalties, are introduced as a secondary income source, allowing firms to collaborate without compromising their competitive stance. By examining the impact of these elements on strategic equilibrium, the research offers nuanced recommendations for managing intellectual property in a way that enhances both innovation and sustainability. This work broadens the concept of sustainability by incorporating economic and innovation-driven dimensions alongside ecological considerations.

3 Mathematical modeling of infectious diseases: COVID-19, Zika, and Monkeypox

Another key paper focuses on the propagation of COVID-19 in Thailand, offering a sophisticated mathematical model that employs both integer-order and Caputo fractional-order derivatives. The model rigorously analyzes equilibrium points, the basic reproduction number, and the overall system stability. The application of fixed point theory ensures the existence and uniqueness of solutions, while numerical simulations, rooted in real Thai data, demonstrate the modelâĂŹs relevance and accuracy. Of particular interest is the integration of traditional home remedies and precautionary measures as control strategies. This approach offers a culturally sensitive, holistic framework that complements formal health interventions and underscores the importance of local context in public health modeling (Shamil et al.).

The spread of multiple COVID-19 strains is the subject of another timely contribution. This study presents a discrete-time mathematical model that tracks the dynamics of virus variants, integrating two core control strategies: vaccination and tailored medical treatment. Optimal control theory, particularly PontryaginâĂŹs Maximum Principle in discrete time, is applied to derive and implement these strategies. The results, supported by numerical simulations, reveal the significant impact of these interventions on the containment of mutant strains. This model provides important implications for public health planning in the face of evolving epidemiological landscapes, demonstrating the value of adaptability and precision in policy responses (Elqaddaoui et al.).

Expanding the focus beyond COVID-19, another article investigates the transmission of Zika virus through a fractional-order model. The population is divided into human and tick compartments to more accurately represent vector-host interactions. Two primary controls, public awareness programs and medical treatment, are incorporated to reduce exposure and infection. The use of Caputo derivatives enables the model to account for memory and hereditary properties in disease dynamics, offering a more nuanced understanding of ZikaâĂŹs spread. By applying PontryaginâĂŹs Maximum Principle and validating results through simulations, the study illustrates how fractional calculus can be effectively employed in vector-borne disease modeling. The findings emphasize the importance of early intervention and targeted education in preventing outbreaks (Kouidere et al.).

Finally, the transmission dynamics of monkeypox are examined through a deterministic model that includes the influence of contaminated surfaces an often overlooked yet critical vector. The research calculates the basic reproduction number and investigates the stability of disease-free and endemic equilibria. A forward bifurcation is identified at the critical threshold, while the absence of a backward bifurcation simplifies the interpretation of the reproduction number as the sole determinant of endemicity. Sensitivity analysis identifies key parameters driving disease spread, which inform the development of an optimal control framework. Numerical simulations highlight the efficacy of control measures in reducing infection levels. This study offers important insights into managing re-emerging infectious diseases, particularly in settings where environmental transmission plays a significant role (Hassan et al.).

4 Spatiotemporal ecological dynamics and predator-prey interactions

In addition to these models, one contribution explores ecological complexity through a spatiotemporal predator-prey system incorporating ecological mechanisms such as the Allee effect, fear-induced prey response, cooperative hunting via Holling type II functional response, and fishing activities with distinct impacts on prey and predator populations. The model further integrates toxicity with time delays, reflecting more realistic ecological interactions. By leveraging tools from partial differential equations, stability analysis, and Hopf bifurcation theory, the authors identify the critical thresholds beyond which system stability gives way to oscillations. They also analyze how spatial diffusion influences pattern formation, revealing conditions for predator-prey segregation and the emergence of Turing structures. Numerical simulations validate the theoretical insights, demonstrating how delays and spatial factors jointly shape ecological outcomes. This work offers valuable ecosystem management and conservation implications, emphasizing the complex interplay between biological processes and spatial-temporal dynamics (Hafdane et al.).

5 Conclusion

Together, these five contributions highlight the transformative potential of mathematical modeling in advancing sustainable practices. Each article represents a fusion of rigorous theoretical development and real-world applicability. By spanning domains such as economics, virology, public health, and vector ecology, the Research Topic illustrates the versatility and necessity of modeling in addressing multifaceted sustainability challenges. A recurring theme throughout these studies is the importance of optimal control, whether applied to economic decisions, vaccination strategies, or public health interventions, as a means to achieve desirable outcomes in complex dynamic systems.

This editorial endeavor reflects the belief that sustainable practices cannot be achieved in disciplinary isolation. The integration of ecological and epidemiological modeling provides a robust platform for understanding system-wide dynamics, identifying critical thresholds, and designing evidence-based interventions. As global crises, be they pandemics, climate change, or biodiversity loss, continue to converge, the need for such integrative approaches has never been more evident.

In conclusion, this Research Topic serves as a compelling demonstration of how mathematical modeling can bridge ecological and epidemiological perspectives to inform sustainable solutions. The articles within this collection collectively affirm that robust analytical tools, when grounded in real world contexts, can yield meaningful insights that transcend disciplinary boundaries. As we move forward, it is essential to continue fostering interdisciplinary collaborations that unite theory with practice. To quote Albert Einstein, “Look deep into nature, and then you will understand everything better.” It is in this spirit of inquiry and integration that we hope this Research Topic will inspire further research, dialogue, and action toward a more sustainable and resilient future.

Author contributions

NB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. SJ: Validation, Writing – review & editing. IA: Investigation, Validation, Writing – review & editing. AI: Validation, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

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