Mathematical foundations in modern biology: Bridging theory and practice

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Introduction. Mathematics plays a crucial role in various subfields of biology, providing tools and frameworks for modeling, analysis, and interpretation of biological phenomena (Țălu et al 2012; Oroian et al 2013). This short paper presents some key subfields where mathematics finds extensive application and utility.

Ecology and population biology. Mathematical modeling is fundamental to understanding population dynamics, species interactions, and ecosystem processes (Ghanbari & Djilali 2020). Concepts such as population growth models (e.g., exponential, logistic), predator-prey dynamics (Lotka-Volterra equations), and competition models (e.g., Lotka-Volterra competition models) rely heavily on mathematical principles to simulate and predict ecological patterns and dynamics.

Evolutionary biology. Mathematical models are employed to study evolutionary processes, including natural selection, genetic drift, and speciation. Population genetics utilizes mathematical frameworks such as the Hardy-Weinberg equilibrium (Sun et al 2021), Wright-Fisher model (Roitershtein et al 2023), and coalescent theory to analyze genetic variation within populations and track evolutionary changes over time.

Bioinformatics and computational biology. Mathematics is integral to the analysis and interpretation of biological data, particularly in the fields of genomics, proteomics, and systems biology (Li et al 2022). Computational algorithms and statistical methods are used for sequence analysis, protein structure prediction, gene expression profiling, and network modeling, enabling researchers to uncover biological insights from large-scale datasets.

Neuroscience and systems biology. Mathematical modeling plays a central role in understanding the complex dynamics of neuronal networks, brain function, and physiological systems (Rosario et al 2020). Computational neuroscience utilizes mathematical frameworks such as neural network models, compartmental modeling, and dynamical systems theory to simulate and analyze neural activity patterns, synaptic plasticity, and information processing in the brain.

Biomechanics and biophysics. Mathematics is applied to investigate the mechanical properties, motion, and behavior of biological systems at various scales, from molecules to organisms (Dutta et al 2020). Biomechanical modeling and computational simulations are used to study muscle mechanics, bone structure, fluid dynamics in biological systems, and the locomotion of organisms.

Systems ecology and systems biology. Mathematical modeling is employed to study complex biological systems and their interactions across different organizational levels (Tiwari et al 2021). Systems ecology integrates mathematical models with empirical data to analyze ecosystem dynamics, nutrient cycling, and the response of ecosystems to environmental change. Similarly, systems biology utilizes mathematical modeling and network analysis to understand the behavior of biological systems at the molecular, cellular, and organismal levels.

Conclusion. Mathematics finds extensive application in various subfields of biology, highlighting the interdisciplinary nature of modern biological research and the importance of quantitative approaches in advancing our understanding of living systems.

Conflict of interest. The author declares no conflict of interest.

References

Dutta D., Palmer X. L., Ortega-Rodas J., Balraj V., Dastider I. G., Chandra S., 2020 Biomechanical and biophysical properties of breast cancer cells under varying glycemic regimens. Breast Cancer: Basic and Clinical Research 14: 1178223420972362.

Ghanbari B., Djilali S., 2020 Mathematical analysis of a fractional-order predator-prey model with prey social behavior and infection developed in predator population. Chaos, Solitons & Fractals 138:109960.

Li F., Dong S., Leier A., Han M., Guo X., Xu J., Wang X., Pan S., Jia C., Zhang Y., Webb G. I., Coin L. J. M., Li C., Song J., 2022 Positive-unlabeled learning in bioinformatics and computational biology: a brief review. Briefings in Bioinformatics 23(1):bbab461.

Oroian I. G., Petrescu-Mag I. V., Păsărin L., 2013 Long term exposure to sublethal concentrations of vanadium affects the fertility but not the secondary sexual traits of the guppy fish. Metal Int 18(5):280-284.

Roitershtein A., Rastegar R., Chapkin R. S., Ivanov I., 2023 Extinction scenarios in evolutionary processes: a multinomial Wright-Fisher approach. Journal of Mathematical Biology 87(4):63.

Rosario D., Boren J., Uhlen M., Proctor G., Aarsland D., Mardinoglu A., Shoaie S., 2020 Systems biology approaches to understand the host-microbiome interactions in neurodegenerative diseases. Frontiers in Neuroscience 14:716.

Sun L., Gan J., Jiang L., Wu R., 2021 Recursive test of Hardy-Weinberg equilibrium in tetraploids. Trends in Genetics 37(6):504-513.

Țălu S., Petrescu-Mag I. V., Păsărin B., 2012 Investigation on acute toxicity of lindane in guppies, Poecilia reticulata Peters, 1859. Poec Res 2(1):9-14.

Tiwari K., Kananathan S., Roberts M. G., Meyer J. P., Sharif Shohan M. U., Xavier A., Maire M., Zyoud A., Men J., Ng S., Nguyen T. V. N., Glont M., Hermjacok H., Malik-Sheriff R. S., 2021 Reproducibility in systems biology modelling. Molecular Systems Biology 17(2):e9982.

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