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A Critical Review on Biomathematics and Its Applications

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Abstract

Mathematics has become an integral part of biology, giving rise to the distinct field of biomathematics, which has seen significant development and application. This interdisciplinary field employs mathematical models to enhance our understanding of biological phenomena. Modern experimental biology excels at dissecting biological systems at various organizational levels, from genomes to global nutrient cycling, into simpler components for isolated study. Dynamic models play a crucial role in reassembling these components, using equations to represent the system's parts, processes, and their interactions. Mathematical models are essential in diverse biological research areas, including physiology, cellular biology, developmental biology, ecology, evolution, toxicology, epidemiology, immunology, natural resource management, and conservation biology. The analysis and simulation of system-level models help test and expand biological theories, suggesting new hypotheses and experiments. Additionally, models synthesize existing information to provide quantitative answers to practical questions. This review paper highlights the significance and applications of biomathematics, emphasizing its role in advancing our understanding of complex biological systems and guiding future research directions. Moreover, biomathematics continues to evolve with the emergence of new branches, addressing contemporary biological challenges. The integration of mathematical approaches in biology not only aids in theoretical advancements but also in practical applications such as disease modeling, ecosystem management, and the development of biotechnological innovations. The interdisciplinary collaboration between mathematicians and biologists fosters a comprehensive understanding of life sciences, paving the way for groundbreaking discoveries and solutions. This integration also facilitates personalized medicine, where mathematical models predict individual responses to treatments, enhancing therapeutic efficacy and reducing adverse effects. In agriculture, biomathematical models optimize crop yields and pest control strategies, ensuring sustainable practices. The future of biomathematics holds promise for addressing global challenges such as climate change, biodiversity conservation, and public health, making it an indispensable tool in both scientific inquiry and practical applications. As the field advances, continued interdisciplinary collaboration will be crucial in harnessing the full potential of biomathematics to solve complex biological problems and improve human well-being.

Keywords: Biomathematical, mathematical biology, population ecology, life sciences, interdisciplinary

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INTRODUCTION

Mathematical and theoretical biology, also known as biomathematics, is a branch of biology that utilizes theoretical analyses, mathematical models, and abstractions of living organisms to explore the principles that govern their structure, development, and behavior. In contrast to experimental biology, which focuses on conducting experiments to test scientific theories, biomathematics

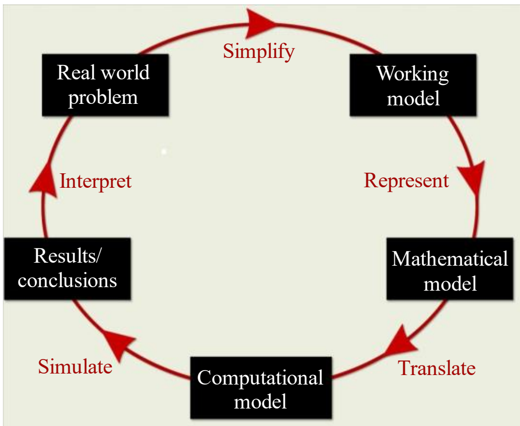

Figure 1. Mathematical modeling process.

emphasizes the use of mathematical tools [1]. This field is sometimes referred to as mathematical biology or theoretical biology, depending on whether the emphasis is on mathematical or biological aspects. While theoretical biology is concerned with developing theoretical principles for biology, mathematical biology uses mathematical tools to study biological systems, although these terms are often used interchangeably. Mathematical biology aims to mathematically represent and model biological processes by employing techniques and tools from applied mathematics [2]. This quantitative approach allows for a better simulation and prediction of system behaviors, revealing properties that might not be apparent through experimentation alone. Theoretical biology draws on various mathematical fields owing to the complexity of living systems and has contributed to the development of new mathematical techniques. Biomathematics is inherently interdisciplinary, combining biology and mathematics to study and analyze biological problems using mathematical methods. This approach enhances our understanding of biology by applying mathematical knowledge, thereby highlighting the significant role of both disciplines. Modern applications of mathematics in biology include environmental studies, epidemiology, and ecology, among other areas, demonstrating high value. In practice, a biological system is modeled as a system of equations. Solving these equations, either analytically or numerically, provides insight into how the system behaves over time or at equilibrium. These models often involve assumptions about the system and potential occurrences within it, enabling a detailed and predictive understanding of biological phenomena [3]. The mathematical modeling process is shown in Figure 1.

MATHEMATICAL BIOLOGY

Mathematical biology is an interdisciplinary field in which mathematical methods have been developed and applied to enhance our understanding of biological phenomena. The first step in exploring any topic in this field is to gain a thorough understanding of biology and the specific biological questions where mathematics can offer insights. The next step involves developing a mathematical model that accurately represents the biological processes in question. This model was subsequently used to derive mathematical predictions using mathematical theories and computational methods. The final step is to validate these predictions to ensure that they provide a reasonable answer to biological questions. Related biological questions can also be explored using an established mathematical model. Biomathematics is a branch of mathematics that uses both mathematical and numerical methods to solve various biological problems. Since 1922, this field has been mentioned in literature and has seen significant use in the 1930s. Today, it is recognized as a futuristic interdisciplinary study that uses computers to uncover the mysteries of the human body. The human body is studied using different systems, such as the respiratory, circulatory, nervous, nutritional, and digestive systems. The study of the human body through physical and mechanical ideologies is known as biomechanics, which is the scientific examination of the mechanical aspects of biological systems. A subsection of biomechanics is biofluid dynamics, where mathematical methods and principles are used to understand the flow of various biofluids within the human body [4].

The Role of Mathematics in Biology

Mathematics is crucial in numerous scientific disciplines and mainly serves as a tool for mathematical modeling. Innovations and advancements in physics are often driven by mathematics. For instance, calculus has been developed specifically for physics applications. The significance of mathematics in physics is evident through the existence of disciplines, such as mathematical physics and theoretical physics. This raises the question of whether mathematics plays an equally important role in biology and whether the two fields have a common ground. Despite the differences between physics and biology, mathematicians and biologists have established "mathematical biology" or "biomathematics" as a discipline for the mathematical representation of biological processes, with applications in biological, biomedical, and biotechnology research [5].

Mathematical biology, or biomathematics, is a rapidly growing and highly recognized field that represents one of the most exciting modern applications of mathematics. It is an interdisciplinary research area with broad applications in biology, biotechnology, and biomedical sciences. The field may be termed mathematical biology or biomathematics to emphasize the mathematical aspect, or theoretical biology to highlight the biological aspect. Various techniques have been employed in mathematical biology to model biological research. Mathematics, such as calculus, probability theory, statistics, linear algebra, graph theory, combinatorics, algebraic geometry, topology, dynamical systems, differential equations, and coding theory, are increasingly being applied in this field.

Application of Derivatives in Biomathematics

Biomathematics is an interdisciplinary field that uses mathematical techniques and tools to model both natural and biological processes. Biomathematics have been used in areas such as cellular neurobiology, epidemic modeling, and population genetics. Derivatives are used in biomathematics for several different purposes and can be used to determine the rate of muscle contraction, rate of drug dissolution into the bloodstream, and growth of bacteria [6].

Development and Application of Biomathematics

1. *Development process of biomathematics:* Biological research typically employs observational and experimental methods to investigate the nature of living organisms; however, these approaches often require extensive data collection. The ability to utilize this data to understand life processes is critical. As experimental data continue to increase geometrically, the practical value of mathematics in biology becomes more pronounced. Historically, mathematics in the life sciences has focused on population problems, with dynamic methods being a prime example of early successful applications. The role of mathematics in biology extends beyond static descriptions to the exploration of complex processes and laws. Mathematical tools have been used to create various models by integrating differential equation models into biological studies. The advent and continual advancement of electronic technology have propelled biomathematics to a new stage, with computer technology facilitating the analysis of complex biomathematical problems and the formation of numerous subfields. With the rapid development of information technology, the applications of biomathematics have expanded significantly, enhancing the efficiency and scope of research in this field. The use of computer technology has provided reasonable explanations for previously difficult-to-analyze biomathematical problems, fostering the growth and efficiency of biomathematics research [7].
2. *Applications of biomathematics in different areas:* Branches of biomathematics have become integral to life sciences and are closely linked to the development of the national economy. Biomathematics research significantly impacts various industries, ranging from agriculture, forestry, animal husbandry, and fisheries to healthcare development. It encompasses activities, such as crop cultivation, breeding of animal and poultry species, and pest control. With the ongoing advancement of new technologies, fields such as bioengineering, human genome projects, brain function simulation, and computer technology continue to be deeply explored by biomathematics. Humanity currently faces challenges, such as energy scarcity, severe

environmental pollution, rapid population growth, and other pressing issues. Biomathematics research should prioritize these problems. This paper focuses on specific applications in key branches of biomathematics, including biological cybernetics, infectious disease dynamics, animal breeding and genetics, population ecology, and molecular ecology [8].

3. *Applications in biological cybernetics:* In recent years, numerous biological phenomena have been observed, and efforts to control these phenomena are ongoing, making it clear that differential or difference equations alone are insufficient for their description. For instance, pharmacodynamic studies have indicated that the absorption, metabolism, and excretion of drugs in the human body follow a continuous process that can be described by dynamic models. However, oral, and intravenous injections exhibit transient impulse behavior. To accurately model both the transient behavior and continuous flow of drugs within the body, an impulse differential equation model is required. This involves the use of impulse differential equation theory and methods to identify the optimal strategies for drug administration. Similarly, in fish farming and forest management, breeding, harvesting, and deforestation programs can be optimized and improved through these mathematical models to ensure sustainable production and benefits. In plant protection research, the best strategies for pest prevention and control can be devised, including the rational use of pesticides and the development of programs for cultivating natural pest predators. Environmental protection efforts can also benefit from studying how to better preserve biodiversity. The theory and practice of impulsive differential equations have been effectively applied in life sciences and various other fields, demonstrating high value in the enhancement of biochemical products [9].
4. *Applications in animal breeding and genetics:* Animal breeding and genetics are a significant branch of biomathematics that focuses on the transmission of life information and coding theory, emphasizing the relationships between information processes, information, and material carriers. Life information can be categorized into major- and memory-type information. The genetic information stored in biological macromolecules primarily determines the genetic traits and activity characteristics of an organism. First, genomic databases related to elite animal breeding were developed. Since livestock economic traits are typically controlled by multiple minor genes and there is also the presence of major genes, sequence alignment, and homology analysis are used to identify and locate major and homologous genes related to these traits within existing organism databases. This process helps form new genomic databases to optimize and improve livestock breeds. Additionally, in non-coding regions of gene fragment sequences, molecular genetic markers should be used to monitor major gene fragments, genotype differences, allele inheritance from parents to offspring, and unknown information. This allows for more precise identification of the genetic differences between individuals. In doing so, subdivisions based on individual phenotypes and their causes can be made, leading to more effective genetic modeling, and enhancing the standard and efficiency of farm animal genetic evaluation. Currently, DNA chip technology is utilized for nucleic acid analysis, whereas two-dimensional gel electrophoresis and mass spectrometry sequencing are employed for protein analysis. These methods have facilitated the construction of large-scale genetic maps. Additionally, efforts have focused on establishing an animal genetic resource database. The primary goal of breed conservation is to scientifically preserve the gene pool of existing livestock and ensure stable gene frequencies across different groups. This involves maintaining the most comprehensive genome of a species using genetic and breeding forms to conduct population genome assessments to identify new characteristic genes and establish a pool of these traits. From a broader perspective, the development of a standardized geographic information system is underway to enhance animal genetic resource databases.
5. *Applications in population ecology:* Population ecology is currently a crucial component of modern ecological theory. Understanding the dynamics of population growth within realistic environmental contexts, including noise interference from both internal and external sources as well as individual behaviors in heterogeneous environments, has become increasingly important.

Effective integration of these aspects has led to the emergence of numerous individual-based models with a strong biological foundation. Contemporary research combines spatial heterogeneity, individual behavioral differences, and environmental randomness to explore population dynamics comprehensively. This approach involves gathering life-history data with individual variations through biological tests, incorporating various forms of random noise into models, and using computer simulations to generate dynamic ecological models. These models were then analyzed and compared with real-world data to obtain precise insights.

6. *Applications in molecular ecology:* Today, molecular ecology represents a burgeoning interdisciplinary field bridging mathematics and biology, addressing current focal points, such as mathematical modeling of spatial variables, ecological trait dynamics, behavioral patterns, and genetic flow transformations. The author highlights three primary areas of interest. First, mathematical models are employed to simulate and differentiate small organism units, focusing largely on the dissemination, expansion, expression, and response of biological signals during the differentiation processes. Second, molecular techniques are used to track populations across different times and locations and statistically analyze biological relationships to enhance the understanding of macroecological patterns. Third, mathematical modeling has been utilized to construct spatial structures at the molecular level, providing insights into the formation and functions of basic biological units [10].

CONCLUSIONS

With the continuous development of society, biomathematics has been widely used in all areas, and biomathematics also has been continuously improved and optimized, able to be more comprehensively applied. Simultaneously, owing to the continuous development of modern information technology, the efficient combination of biomathematics and information technology can effectively enhance the actual role of biomathematics. Thus, the future development of biomathematics is promising and can provide strong support for research in multiple disciplines.

REFERENCES

1. Volkov A. Geometrical diagrams in traditional Chinese mathematics. In: Graphics and text in the production of technical knowledge in China; 2007 Jan 1. Brill; 2007. pp. 425–59.
2. Guo S. Development and application of biomathematics. In: International Conference on Economics, Social Science, Arts, Education and Management Engineering. Atlantis Press; 2016. pp. 132–5. DOI: 10.2991/essaeme-16.2016.26.
3. Li J. Hilbert’s 16th problem and bifurcations of planar polynomial vector fields. Int J Bifurc Chaos. 2003;13:47–106. DOI: 10.1142/S0218127403006352.
4. Mou H, Tang J, Liu J, Xu W, Hou Y, Zhang J. High dynamic bipedal robot with underactuated telescopic straight legs. Mathematics. 2024;12:600. DOI: 10.3390/math12040600.
5. Yu X, Yu X, Lu Y. Evaluation of an agricultural meteorological disaster based on multiple criterion decision making and evolutionary algorithm. Int J Environ Res Public Health. 2018;15:612. DOI: 10.3390/ijerph15040612. PubMed: 29597243.
6. Buonocore A, Di Crescenzo A, Hastings A. Preface for the special issue of Mathematical Biosciences and Engineering, BIOCOMP 2012. Math Biosci Eng. 2014;11:i–ii. DOI: 10.3934/mbe.2014.11.2i. PubMed: 24245712.
7. Chemla K. Geometrical figures and generality in ancient China and beyond: Liu Hui and Zhao Shuang, Plato and Thabit ibn Qurra. Sci Context. 2005;18:123–66. DOI: 10.1017/S0269889705000396.
8. Bartlett MS, Bartlett MS. Biomathematics: Probability, statistics and time. 1975;72–97.
9. Segel LA, editor. Mathematical models in molecular and cellular biology. Cambridge: Cambridge University Press; 1980.
10. Niederer PF. Mathematical foundations of biomechanics. Crit Rev Biomed Eng. 2010;38:533–77. DOI: 10.1615/CritRevBiomedEng.v38.i6.30. PubMed: 21303323.

