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ZHIEN MA'S CONTRIBUTIONS TO DYNAMICAL SYSTEMS, ECOTOXICOLOGY AND EPIDEMIOLOGY – A SCIENTIFIC LEADER, EDUCATOR AND SCHOLAR

The Guest Editors

Zhien Ma's love for mathematics has strongly shaped his educational pursuits. He received formal training from the strong Chinese School of Dynamical System over a period of two years at Peking University and during his later visit to Nanjing University where the internationally renowned professor Yanqian Ye mentored him. Yet, it is well known that Zhien's curiosity and love of challenges have made him his own best teacher. Hence, it is not surprising to see his shift from an outstanding contributor to the field of dynamical systems to a pioneer in the field of mathematical biology. Zhien's vision and courage became evident when he abandoned a promising career in pure mathematics and enthusiastically embraced a career in the field of mathematical biology soon after his first visit to the United States in 1985. His rapid rise to his current role as an international leader and premier mentor to 11 Ph.D. students has facilitated the placement of Chinese scientists and scholars at the forefront of research in the fields of mathematical, theoretical and computational biology.

Zhien was born in Shandong Province on January 3, 1935, and graduated from Beijing University in 1954. He is currently a full professor at Xian Jiaotong University. He has held visiting positions at many prestigious institutions, including

Nanjing University, the University of Wisconsin, the University of Tennessee, and the University of Napoli. He has also had various administrative positions including those of the chairman of the mathematics department and dean of the College of Science at Xian Jiaotong University. He was appointed chair of the Supervisory Committee of Mathematical Education of the Chinese Ministry of Education and elected vice chairman of the Society of Chinese Mathematical Biology. Zhien has lectured all over the world including Belgium, Germany, Italy, Netherlands, Japan, and the United States. He has served as an editor or as an editorial board member for many journals, including the *Journal of Biological Systems*, *Mathematical Modeling and Analysis of Complex Systems*, *Annals of Differential Equations*, and *Journal of Theoretical Biology*.

Through his academic career, Zhien has made significant contributions in teaching and research, and his influence has been felt by the mathematical community in his own homeland as well as abroad.

Zhien is an active reformer of mathematics teaching. Many of his ideas and philosophy have been adopted and implemented by the Chinese Ministry of Education. They include a focus on basic mathematical ideas and principles as well as the need for coupling mathematical theory with modeling and experiments. He has led a national project on mathematical education reform that involves many well recognized scholars and key universities in China.

Zhien is the author of several textbooks of mathematics for undergraduates and graduates. His textbook, *Elementary Mathematical Analysis of Engineering Students*, is highly regarded among students and professors and won the Chinese Ministry of Education's first prize for excellent textbook. He is currently writing a calculus textbook in English with Canadian professor Fred Brauer (Department of Mathematics, University of British Columbia) that will be used in Chinese universities.

In September, 2003, Zhien was recognized as one of the top 100 famous professors by the Chinese Ministry of Education. This award recognized his excellent teaching and outstanding contributions to mathematical education in China.

Zhien's research contributions have had a significant effect on applied mathematics, particularly in the area of biomathematics. Prior to the 1980s, Zhien's research concentrated on the qualitative analysis and stability of differential equations, especially the existence and stability of limit cycles, and separatrix cycles of polynomial differential systems. In this early work, he developed effective ways to study the stability of separatrix limit cycles and the bifurcation of limit cycles from separatrix cycles. This work led to the publication of his well received joint monograph, with Yanqian Ye and other scholars entitled *Theories of Limit Cycles*.

Since the 1980s, Zhien's main research area has been biomathematics. He has played an important role in establishing and developing the Chinese Society of Biomathematics and the Chinese Journal of Biomathematics.

In 1988, he and his Chinese colleagues organized the first International Conference of Biomathematics which took place at Xian Jiaotong University. The conference was a great success, with more than 200 participants from 14 countries.

Zhien has made contributions to mathematical biology in the areas of population dynamics, mathematical ecotoxicology, immunology and epidemiology. The focus of his work has been on the influence of toxicants or pollution on the survival and dynamics of species. Specific contributions include the formulation and analysis of mathematical models that have identified survival thresholds for populations

in fluctuating and polluted environments. His work has also led to the study of the effects of toxicants on species in chemostat models under various conditions that include periodic nutrient and fluctuating toxicant inputs. His interest in the environment has led him to carry out extensive theoretical work on the effect of pollution. Zhien has analyzed the effects of toxicants on species competing for nutrients while identifying survival thresholds for food chains all in the context of polluted environments.

Zhien has developed effective and novel methodologies, including the method of averaging integrals for getting thresholds for critical points of some nonautonomous population systems, new methods for the determination of stability regions in parametric space, persistence functions, and the monotonic comparison method in his efforts to addressed the above biological questions in which *time delays* often play a critical role. Consequently, Zhien has had to address difficult mathematical problems related to the stability of functional differential equations. In particular, he has made important contributions related to the classification of the stability regions of population models with discrete-time delay.

For the past 10 years, Zhien and his research group at Xian Jiaotong University have focused primarily on the study of disease dynamics. His group has made important contributions to epidemiological modeling, with recent important incursions into immunology as well as to the fields of mathematical epidemiology and immunology. They have formulated and analyzed mathematical models for various infectious diseases, including AIDS/HIV and SARS (Severe Acute Respiratory Syndrome). Their work has contributed to not only our general understanding of disease dynamics and its evolution but also the field of public health and policy.

For example, while researching SARS, Zhien and his group provided models and results that suggested specific ways to control emerging and reemerging diseases. In Spring, 2003, SARS was rapidly transmitted worldwide with more than 30 countries directly affected. The epidemic seriously affected people's life and the economy of China, where the cumulative number of diagnosed SARS cases and deaths accounted for two thirds of the total cases in the world. The spread of SARS and its effect resulted in an international effort coordinated by the World Health Organization (WHO). The SARS infection was controlled by the use of stringent control measures. This was the first time ever (to the best of our knowledge) that international efforts and cooperation have stopped the spread of a disease with *relatively* minimal consequences.

However, many questions about SARS transmission remain unanswered. How many infections can be produced by each SARS infected per day? How many people may become infected in a future outbreak? When do the infection peaks take place? How long will an infection peak last and how high can it be? Will the current public-health measures be enough to bring SARS under control? More importantly, the strict active preventive measures were effective, but they had significant negative effects on people's lives and the economy. Can these strict control measures be relaxed? If so, how and when?

To provide quantitative answers to the above questions, Zhien led a group of mathematicians, epidemiologists, software engineers, and statisticians to develop SARS transmission models. Combining the epidemic features of SARS transmission and statistical data in China, this group started with a very simple model, which is described below.

Let $I(t)$ be the number of SARS infected individuals at the time t and $\beta(t)$, $\delta(t)$, and $\gamma(t)$ be the infection rate, SARS induced death rate, and the recovery rate at time t, respectively. They formulated the following equation:

$$I(t+1) = I(t) + \beta(t)I(t) - (\delta(t) + \gamma(t))I(t),$$

which can be rewritten as

$$I(t+1) = I(t) + f(t)I(t), \quad f(t) = \frac{I(t+1) - I(t)}{I(t)}.$$

Using the hospitalized SARS infected number of the first two weeks to fit the function $f(t)$, we obtained the curve of $f(t)$. (See Figure 1).

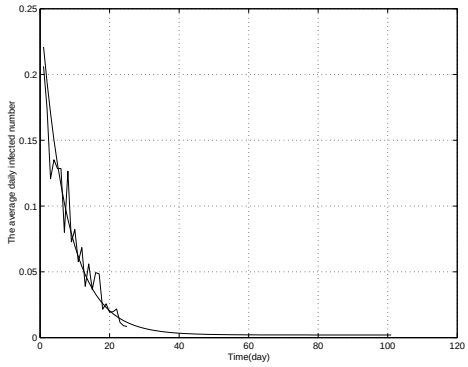

Figure 1. The daily calculation and fit of the function $f(t)$.

Substituting $f(t)$ into the above equation allowed the prediction of the evolution of the epidemic. The statistical and predicted numbers of hospitalized SARS infected are shown in Figure 2.

It is obvious that the comparison of the predicted result and statistical data after the SARS epidemic shows a quite accurate prediction.

The infection rate changes with time. Using the fact that the susceptibles form most of the total population and the change in the number of susceptibles is very small compared to the total population size, this group approximated the number

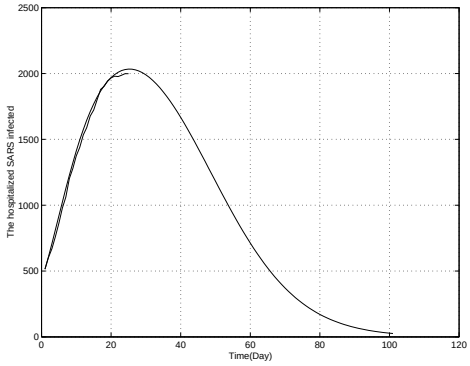

Figure 2. The statistical and predicted daily hospitalized SARS infected numbers.

of susceptibles by a constant, dropped the susceptible class, and formulated the following discrete model:

$$\begin{aligned} E(t+1) &= E(t) + \beta(t)(kE(t) + I(t)) - (\varepsilon + \lambda)E(t), \\ I(t+1) &= I(t) + \varepsilon E(t) - (\delta + \theta)I(t), \\ Q(t+1) &= Q(t) + \lambda E(t) - \sigma Q(t), \\ J(t+1) &= J(t) + \theta I(t) + \sigma Q(t) - (\delta + \gamma)J(t), \\ R(t+1) &= R(t) + \gamma J(t), \end{aligned} \tag{1}$$

where the variables $E(t)$, $I(t)$, $Q(t)$, $J(t)$ and $R(t)$ are the numbers of the individuals in exposed, infectives, quarantined, diagnosed, and recovered classes at time t, respectively.

Here δ is the SARS induced death rate, γ the recovery rate, ε the transfer rate from exposed to infective class, λ the transfer rate from exposed to quarantined class, σ the transfer rate from quarantined to diagnosed class, θ the transfer rate from infective to diagnosed class, k the infectivity fraction for the exposed individuals compared with individuals in the infective class, and $\beta(t)$ the transmission rate per day.

By using this model, Zhien's group studied the dependence of the basic reproductive number on epidemic parameters using statistical data and numerical simulations that are appropriate for the transmission process for SARS in China. The simulation results matched the empirical data well and indicated that early quarantine and high quarantine rates are crucial to the control of SARS. On the basis of these models, Zhien's group also designed the software required to implement and analyze these models. The subsequent news release on successful SARS epidemic predictions provide a powerful example of what a group of researchers with different backgrounds can do together, under the leadership of individuals like Zhien, in terms of seeking solutions to important national and global problems.

Zhien is, for most of us, not only an international figure but also a caring friend whose legendary hospitality has increased our love and admiration for China.

We are pleased to dedicate this special issue in honor of Zhien Ma's 70th birthday for his endless contributions as a great educator, outstanding purveyor of mathematics, and active and fruitful reformer of mathematics teaching in China; for the profound effect of his research on population dynamics and epidemiological modeling; and for his successful applications of mathematics to the understanding of infectious diseases.

Zhien has an impressive list of publications with more than 130 journal articles. For various reasons, many people working in mathematical biology may not be aware of many of these publications, so we provide a partial listing as follows.

GUEST EDITORS:

Fred Brauer
Carlos Castillo-Chavez
Thomas G. Hallam
Jia Li
Jianhong Wu
Yicang Zhou

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