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ISBN 1 86320 256 0

Typesetting and layout: Arawang Communication Group, Canberra.
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Preface

The International Conference on Rodent Biology and Management (ICRBM) was held in the Beijing Friendship Hotel on 5–9 October 1998. The conference was co-organised by the Institute of Zoology, Chinese Academy of Sciences, and CSIRO Wildlife and Ecology, Australia.

Over 140 presentations were made. The framework of the scientific program of '98 ICRBM detailed in this report was organised by Lyn Hinds, Grant Singleton, Herwig Leirs, Anita Dalakoti and Zhi-Bin Zhang, and finalised through extensive communication with the symposium chairs.

The abstracts of '98 ICRBM are listed in the order of the surname of the first author. The abstracts of participants from non-English speaking countries were modified for readability. No intentional changes to the content were made. The views of the authors of these abstracts are not necessarily those of the editors or the organising committee.

We thank all those who contributed to the successful organisation of the conference. We also thank ACIAR who has generously supported the reprinting of the full set of conference abstracts. We thank Karen Weaver for her editorial assistance.

Editors

Zhi-Bin Zhang Secretary General of '98 ICRBM
Lyn Hinds Co-chairman of '98 ICRBM
Grant Singleton Co-chairman of '98 ICRBM
Zu-Wang Wang Executive Chairman of '98 ICRBM
General Information

'98 ICRBM

The International Conference on Rodent Biology and Management (‘98 ICRBM) was held in the Friendship Hotel, 5 Bai Shi Qiao Road, Beijing 100837, China on 5–9 October 1998.

The conference was organised by:

- Institute of Zoology, Chinese Academy of Sciences
- CSIRO Wildlife and Ecology, Australia

and sponsored by:

- Australian Centre for International Agricultural Research (ACIAR)
- Chinese Academy of Sciences (CAS)
- Chinese Nature Science Foundation (CNSF)
- Cyanamid (China) Co. Ltd
- Tianjing Tianqing Chemicals Co. Ltd
- Longhua Insecticides Co. Ltd
- Zhang Jia Kou Twin Round Kikbo Pharma Co. Ltd
- Kalian Chemical Experimental Factory

with assistance from:

- Animal Ecology Committee, Chinese Ecological Society
- National Key Laboratory of Integrated Pest Management of Insects and Rodents in Agriculture, CAS
- Rodent Control Committee, Chinese Plant Protection Society.

The Organising Committee was:

- Honorary Chairmen: Charles J. Krebs (Canada) and Ru-Yong Sun (China)
- Executive Chairman: Zu-Wang Wang (China)
- Co-chairmen: Grant Singleton and Lyn Hinds (Australia)
- Secretary General: Zhi-Bin Zhang (China)
- Committee Members: Alan Buckle (U.K.), Herwig Leirs (Denmark), Valery Neronov (Russia), Dale Noite (USA), An-Guo Chen, Zhi Deng, Nai-Chang Fan, Yong Ma, Ji-Ke Liu, Hao-Quan Lu, ChengXin Wang, Wen-Qin Zhong, Wen-Yang Zhou, En-Lin Zhu (China)

The conference aimed to promote rodent management based upon biological and ecological studies. The scientific program included opening and closing ceremonies, plenary presentations, symposium presentations, specialist discussion groups and workshops, and poster sessions.
ICRBM meeting: 4 October 1998

The meeting was chaired by Zhi-Bin Zhang and Grant Singleton. The honorary chairmen, executive chairmen, symposium chairs, plenary chairs, organising committee members and discussion group chairs of ICRBM attended this small meeting.

Opening ceremony: 5 October 1998

Chairs: Grant Singleton and Zhi-Bin Zhang
Keynote speakers: Zu-Wang Wang, CAS-IOZ Director and ICRBM Executive Chairman
Grant Singleton, CSIRO–WE and ICRBM Executive Co-Chairman
Bob Clements, ACIAR Director
Jian-Ji An, Associate Director-General, Bureau of International Cooperation, Chinese Academy of Sciences.
Da-Bao Zhu, Director of Life Sciences Division of the Chinese Natural Sciences Foundation.

Closing ceremony: 9 October 1998

Chairs: Herwig Leirs and Zu-Wang Wang
Keynote speakers: Charles Krebs, ICRBM Honorary Chairman
Ru-Yong Sun, ICRBM Honorary Co-Chairman
John Copland, ACIAR Project Coordinator
Lyn Hinds, CSIRO–WE and ICRBM Executive Co-Chairman
Zhi-Bin Zhang, CAS-IOZ and ICRBM Secretary General
Scientific Program

Symposium A: Population dynamics—including forecasting and managing rodents

Plenary lectures
Charles Krebs* (Canada—invited lecture), Current paradigms of rodent population dynamics—what are we missing?
Zhi-Bin Zhang (People’s Republic of China), Rodents in China—population dynamics and management.

Oral presentations
Stenseth, N.C. Seasonality and population cycles in small rodents.
Abramson, N.I. and Nadachowski, A. Reconsideration of lemming phylogenetic history with special reference to the origin of Synaptomys.
Lushchekina, A.A. and Neronov, V.M. Specific features of the distribution of the great gerbil (Rhombomys opimus) in central Asia.
Montague, T. and Choquenot, D. The diet and dynamics of New Zealand’s forest-dwelling house mouse (Mus musculus) in the Orongorongo Valley.
Tchabovsky, A., Shilova, S., Neronov, M.V. and Alexandrov, D.Y. Rodent population dynamics under environmental change: is it an ergodic process?
Predavec, M. The role of food limitation in irruptions of Australian desert rodents.
Steen, H. and Haydon, D. Can population growth rates vary with the spatial scale at which they are measured?
Tristiani, H., and Murakami, O. Seasonal changes in the population density and reproduction of the rice field rat, Rattus argentiventer (Rodentia, Muridae), in West Java.

Poster presentations
Abramson, N.I. Variation, taxonomy and distribution patterns of the genus Lemmus in the palearctic.

* Names of paper presenters are in bold type.

Golenishchev, F.N., Aksonova, T.G. and Pavlova, N.A. Peculiarities of structure of dental system and morphometric variation in *Lasiopodomys mandarinus* and *L. brandti*.

Golenishchev, F.N. and Meyer, M.N. Distribution patterns of two chromosome forms of common vole (*Microtus arvalis* pal.) on the common border of their range.

Guo X.H., Dazhao, S. and Shuzhen, H. Study of seasonal survival rates of populations of *Microtus brandti*.


Kaetzke, P. and von Hoist, D. What stops population growth in the wild rabbit (*Oryctolagus cuniculus*)?

Liu, D.Z., Liu, N.F. and Song, Z.M. The environmental effects on the distribution of long-eared jerboas (*Euchoreutes naso*).

Tupikova, N.V., Varshavsky, A.A. and Khliap, L.A. Rodent and pika population of south of the former USSR.

Vibe-Petersen, S., Leirs, H. and van Gulck, T. Predation pressure and population dynamics in African *Mastomys* rats: possibilities for integrated pest management?


Wang, S.Q., Yang, H.F., Hao, S.S. and Zhang, Z.B. Competition between the rat-like hamster and the striped hamster.


**Symposium B: Rodent physiology and adaptation of rodents**

**Oral presentations**

Hume, I.D. Dietary and digestive adaptation of rodents.


Liu, X.T., Li, Q.F., Lin, Q.S. and Sun, R.Y. Variations in mitochondrial thermogenesis and expression of an uncoupling protein gene in brown adipose tissue from Mongolian gerbils during cold exposure.
Poster presentations


Wang, D.H. and Wang, Z.W. Metabolism and thermoregulation in root voles (Microtus oeconomus) on the Qinghai–Tibet plateau.


Symposium C: Control techniques (biological control, habitat management, ecologically based management etc.)

Plenary lecture

Grant Singleton (Australia), Rodent pest management in Southeast Asia—an ecological approach.

Oral presentations


Colvin, B.A. and Jackson, W.B. Urban rodent control programs for the 21st century.

Murakami, O. and Tristiani, H. The integrated management of the rice field rat (Rattus argentiventer) in West Java.

Leung, L. and Sudarmaji Population ecology of the rice field rat, Rattus argentiventer: implications for management.

Campbell, E. Current trends in rodent damage management for Hawaiian agriculture and conservation.


Leirs, H. Ecologically based rodent management in Africa: no quick solution for urgent problems.
Sicard, B. Chronobiology applied to rodent pest management—the case of semi-arid agriculture in sub-Saharan West Africa.
Shchipanov, N.A. Rodent pest control in relation to population organisation.
Yabe, T. Bark-stripping of tankan orange, Citrus tankan, by the roof rat, Rattus rattus.
Makundi, R.H. Towards an ecological approach for management of plague reservoirs and vectors in the western Usambara Mountains in Tanzania, East Africa.
Stuyck, J., Berwaert, K. and van Gulck, T. A promising new approach in muskrat control (Ondatra zibethicus): the introduction of eradication standards.
Khoprasert, Y., Jaekel, T., Hongnark, S. and Suasa-ard, K. Use of Sarcocystis singaporensis as a biocontrol agent against the Malayan wood rat, Rattus tiomennis in oil palm plantations in Thailand.

Poster presentations
Dou, Q., Li, F. and Mai, T. Ecological and socio-economic factors influencing integrated rodent management (IRM) in rural areas of Yunnan, China.
Douang-Boupha, B., Schiller, J.M. and Bounnaphol, O. Rodents in agriculture in the Lao PDR.
Li, J.H., Yue, M.S. and Liu, Q.Y. A field trial of integrated management of commensal rodents in the residential quarters of the urban area.
Rahmini and Sudarmaji, Age structure and breeding performance of the rice field rat in West Java.
Sudarmaji, Jumanta and Rochman. Rice as a trap crop using trap barrier system for controlling the rice field rat (Rattus argentiventer) in West Java, Indonesia.
Wu, X.D. and Fu, H.P. The primary application of classification of types of rodent damage for regional rodent control.
Symposium D: Control techniques (chemical control and resistance; physical control etc.)

Plenary lecture

Dale Nolte (United States of America), Current status of rodent management in the United States.

Oral presentations

Buckle, A.P. The management of rodent pests of agriculture—20 years on from the Paris OECD/FAO/WHO Expert Consultation.
Pelz, H.J. and Endepols, S. Development and field evaluation of a blood clotting response resistance test with rats using coumatetralyl.
Lam, Y.M. Warfarin resistance in the rice field rat, Rattus argentiventer.
Weile, P. Rat control: legislation and administration in Denmark.
Watkins, R.W., Quy, R.J., Gurney, J.E. and Cowan, D.P. Cinnamamide: a repellent for commensal and field rodents?
Dong, T.Y. Studies on resistance to anticoagulant rodenticides in China.
Liu, Q.Y., Wang, C.X. and Ma, J. Field trials with the anticoagulant ‘Stratagem’ against rodents in special environments.

Poster presentations

Brown, P.R., Jones, D.A. and Singleton, G.R. Management of mouse plagues in Australia using ecologically based pest management.
Burkart, S.E. Efficacy and value of Flocoumafen (STORM®), a second generation anti-coagulant rodenticides, in public health and agricultural rodent pest control.
Larsen, K.S., Leirs, H. and Lodal, J. Palatability and toxicity tests with a systemic insecticide bait for rat and flea control.
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Mwanjabe, P.S. Location of food sources in Mastomys natalensis Muridae, Rodentia.
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Sadao, T., Keita, M., Papillon, Y. and Sicard, B. Impact of rodents versus insects on food products stored in Mossi (Burkina Faso) and Bambara (Mali) regions.
Zhang L.S. An introduction to the anticoagulant rodenticide, diphacinone sodium salt.
Zhu, L.B., Ma, Q. and Zhu, H. Integrated rodent control measures in demolition areas in the city of Shanghai.

Symposium E: Rodent chemical communication

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Richard Brown (Canada), The olfactory world of the rodent.

Oral presentations
Johnston, R.E. Odours, scent over-marking and mate preference.
Vasilieva, N.Y. The role of conspecific and heterospecific chemical cues in population dynamics—an experimental approach.
Rozenfeld, F.M., De Jaegere, F. and Dobly, A. Social environment in relation with the reproductive success of females in two vole species.
Voznessenskaya, V.V. The role of predator cues in reproduction of Norway rats.
Heise, S., Rozenfeld, F.M. and Van Acker, A. Hierarchical structures, regulation of reproduction, odour preferences and susceptibility to diseases in groups of female common voles, Microtus arvalis.

Poster presentations
Vasilieva, N.Y., Cherepanova, E.V., Apfelbach, R. and von Holst, D. Influence of cat’s urinary chemosignals on maturation, testosterone level and meiosis in male Campbell’s hamsters (Phodopus campbelli).
Voznessenskaya, V.V. and Wysocki, C.J. Plasticity of rodent chemical communication.

Symposium F: Rodent behaviour and implication in management

Plenary lecture
David Macdonald (United Kingdom), Berdoy, M. and Mathews, F. The brown rat: Explorations of opportunism.

Oral presentations


Zhang, D.C. and Fan, N.C. A comparative analysis of behavior between two sympatric species, Ochotona daurica and C. curoniae.


Zhao, Y.J., Fang, J.M. and Sun, R.Y. Familiarity and mate choice of female and male root voles, Microtus oeconomus.

Poster presentations

German, A. Incest-avoiding behaviour of Levant’s vole (Microtus guentheri) in captivity.

Dou, F.M., Li, J.H. and Yang, X.R. A battery operated animal activity recording system with a single-chip micro-computer programmed in basic language.


Symposium G: Epidemiology of rodent diseases and their impact on rodent population and humans

Plenary lecture

James Mills (United States of America), The role of rodents in emerging human disease: Examples from the hantaviruses and arenaviruses.

Oral presentations

Ellis, B., Regnery, R., Beati, L., Marston, E. and Childs, J.E. Rodent-borne Bartonella: their importance to human health.

Machang'u, R.S., Kilonzo, B.S. and Makundi, R.H. Studies on rodent transmitted diseases in Tanzania.


Neronov, V.M., Strelkova, M.V. and Lushchekina, A.A. Interrelationship of Leishmania parasites and rodents in arid regions of Asia.

Poster presentations

Symposium H: Rodents as indicators of environmental change and their role in maintenance of ecosystem

Plenary lecture
Chris Dickman (Australia). Rodent ecosystem relationships: a review.

Oral presentations
Gliwicz, J. Rodents in disturbed forest habitats.
Ieradi, L.A. and Cristaldi, M. Rodents as monitors of environmental contamination.

Poster presentations
Cao V.S. The rodent diversity in Vietnam.
Dai, K., Yao, J. and Hu, D.F. Microhabitat preferences of desert rodents in the southern Dzungaria basin.

Special interest groups/workshop
1. Rodent damage management. Chair: D.L Nolte
4. Rodent chemical communication. Chair: N.Y. Vasilieva
Abstracts
Symposium A
Population Dynamics—Including Forecasting and Managing Rodents

INVITED LECTURE

Current paradigms of rodent population dynamics—what are we missing?

Charles J. Krebs
Department of Zoology, University of British Columbia, 6279 University Boulevard, Vancouver, B.C. V6T 1Z4, Canada

Rodent population studies have played a key role in developing our understanding of population dynamics in general and in providing a testing ground for many hypotheses about population processes. It is both a blessing and a curse that rodents are often abundant, inexpensive to investigate, and operate on a spatial scale that humans can study. The proximal stimulus to understanding rodent population dynamics is to alleviate problems of rodent pests in agriculture and disease transmission to humans. Conservation problems do not loom large in the literature on rodents.

Ideas about rodent population dynamics have gone through three phases. In the 1930s there were almost no quantitative data and population control was believed to be caused by biotic agents that operated in a density-dependent manner. By the 1950s a new paradigm of social control of numbers emerged with emphasis on physiological stress and social aggression within populations. By the 1970s a synthesis of sorts had emerged, suggesting that multiple factors caused population changes. The addition of experimental manipulation of field populations in the 1960s enlarged our outlook on the complexities of rodent populations, and the emergence of mathematical modelling and rigorous statistical analyses of survival and reproduction in the 1980s and 1990s has shown again that rodents have been the *Drosophila* of population ecology. But as precision has increased over time, generality and simplicity have declined to near extinction, and we need to reverse these trends.

What is missing and what do we need to do in the next 20 years? While we have some good short-term, experimental studies of rodent populations, we have too few long-term experimental studies. Experimentation is the key to understanding, and no study should be undertaken without a clear set of experimental predictions. The era of alpha-level descriptive population studies should be over. Second, we need large scale, extensive studies coupled with these short-term experimental studies. Rodents are good candidates for studies of spatial dynamics, a strongly emerging subdiscipline in ecology. Third, rodent management should focus on the factors limiting populations and use an experimental approach. The era of pest eradication via killing should be over and we need to be more clever in developing our management
options. The development of genetic resistance to anticoagulants and chemical poisons is a call to the ecologists of the 21st century to think more clearly about why rodent pests exist and how we might outwit them. The male penchant for killing pests should give way to the female penchant for thinking before taking the easy way in pest control. The accumulated knowledge of the physiology, behaviour, and genetics of rodents needs to be integrated into our management options. There is much to be done both to understand and to outwit these clever mammals.

**PLENARY LECTURE**

*Rodents in China—population dynamics and management*

Zhi-Bin Zhang

National Key Laboratory of Integrated Pest Management of Insects and Rodents in Agriculture, Institute of Zoology, Chinese Academy of Sciences, 19 Zhongguanchun Lu, Haidian, Beijing 100080, China

Rodent pests are a serious problem for agricultural production in China. Over recent decades, with changes in climate patterns, heavier droughts and warmer winters, rodents are becoming more abundant. In the early 1980s, there were broad-scale outbreaks of rodents in agricultural areas in China; 24.9% of arable land and 14% of grasslands were infested annually. Since 1986, rodent management has been a key project in the national five-year-plan. The biology and management of 15 major rodent pests from six major ecosystems have been extensively studied for more than 13 years. The key project aims to collect long-term population data for major rodents, to establish short-term (3–6 months) or long-term (>6 months) forecasting models, to understand population recovery and community succession after large-scale management, to develop effective control techniques and strategies, to establish demonstration areas and to help local government to launch a large-scale rodent control campaign. The population dynamics and management strategies vary greatly and depend upon the species and its ecosystem.

In the Northern Plateau with dry farmland, the rat-like hamster (*Cricetulus triton*) and striped hamster (*C. barabensis*) are dominant species. The striped field mouse (*Apodemus agrarius*) becomes dominant in some wet areas with good irrigation. The former two hamster species showed a similar pattern of outbreaks in 1982, 1986 and 1993, and these corresponded with El Niño episodes. After ditch-irrigation was changed to a spray irrigation system, the rat-like hamster was observed to outbreak in some areas of Beijing where previously the striped field mouse was dominant. The sterilising effects of alpha-chlorohydrin have been tested effectively in the laboratory on the rat-like hamster. A multiple-capture trap with magnetic trigger was invented for catching the rat-like hamster.

In the Northwest Loess Plateau with very dry croplands, Chinese zokor (*Myospalax chinesis*), an underground dwelling rodent, and brown voles (*Microtus spp*) are major rodent species. The populations of Chinese zokors are stable. This species seldom comes above ground, and is also very cautious of rodent baits, making traditional
direct baiting ineffective. Tube-bombs with firework material have been successfully developed for controlling zokors in this region. Ecological management including use of herbicides, reducing waste land and flattening the farmland were effective in reducing damage by zokors.

In the steppe grassland of Inner Mongolia, the two major rodent pests are Brandt’s vole (M. brandti) and Mongolian gerbil (Meriones unguiculatus). Both species show irregular outbreaks every 3~5 years. Mongolian gerbils occurred mostly in the mixed areas of grassland and cropland. Over-grazing by cattle and cultivation are key factors allowing infestation by voles and gerbils. Ecological management measures, such as controlling over-grazing by setting the date of spring-grazing 10~15 days later than usual, were found to be effective.

In the Qinghai–Tibet alpine meadow ecosystem, plateau zokor (M. baileyi) and plateau pika (Ochotona curzoniae) are major pests. The population of plateau zokors, the underground species, is stable while the population of plateau pika shows irregular outbreaks. Heavy snow is difficult for pika populations but it facilitates survival of zokors in winter. Direct baiting works well for controlling pika but not zokor. A baiting machine, which puts baits in a simulated burrow system that crosses the tunnels of plateau zokor, was invented, and the efficiency of control has greatly increased. A botulin-toxin-C was found to be very effective in controlling zokors and pikas in this region. As in the steppe grassland of Inner Mongolia, over-grazing and cultivation are key factors for increasing rodent infestation. Therefore ecological management measures including over-grazing control, and planting herbs in the degenerated rangelands after chemical control are also important for sustainable integrated management.

In the rice-field region along the Yangtze River, Norway rats (R. norvegicus), striped field mouse (Apodemus agrarius) and R. nitidus are major pests. The population of rats is stable between years. Striped field mouse was negatively affected by heavy rain and flooding. Oriental voles (M. fortis) are the major pest near Dongting Lake and their reproduction and migration are affected by heavy flooding. They inhabit the beach area of Dongting Lake in the non-flooding seasons but migrate to rice-fields around the lake during the flooding season and cause serious crop damage. Blocking the migration path of voles between the rice-fields and the lake beach using a barrier system along the beach dam was very successful in reducing the huge crop damage.

In the rice-field of the Pearl River Delta, R. losea and Bandicota indica are major pests. The numbers of both species are stable between years. Baiting with rodenticides in different seasons achieved different efficiencies of control. The population of R. losea recovered quickly, within 3~6 months after baiting with rodenticide. B. indica is very cautious of physical traps and is becoming more abundant in this region due to development of industry that has changed cropland into a mosaic of waste lands.

The future studies of the national key rodent project will focus on: (1) population dynamics to understand the population outbreaks and to set up long-term forecasting models; (2) behaviour and chemical communication studies to develop effective baiting
techniques; (3) development of sustainable control techniques including fertility control and habitat management; and (4) improvement of existing anticoagulants and determination of the potential of natural and biological materials for controlling rodents.

**ORAL PRESENTATIONS**

**Populations of African rodents: models and the real world**

*Herwig Leirs*

Danish Pest Infestation Laboratory, Skovbrynet 14, DK-2800 Lyngby, Denmark.

Most field rodent pests display irregular population outbreaks during which damage to standing crops is devastating. Therefore, there has been a wish to be able to predict such outbreaks for several decades. The earliest models were based on observed correlations between outbreaks and preceding abnormal events such as unusual rainfall. At a later stage, theoretical deterministic population dynamics models were used and, more recently, models containing some degree of stochasticity and parameterised with data obtained from long-term biological studies were proposed.

The last-mentioned models combine a theoretical concept of population dynamics with empirical information. Therefore, they are useful both to better understand population dynamics as well as to simulate what happens in the real world. The first objective is reached even if the model performs very poorly, because that would at least document the gaps in our knowledge. However, the model’s practical use is highly dependent on its accuracy. Poor performance in practical simulations may lead to wrong predictions about future population development or the potentialities of new management approaches.

This is illustrated with models that were constructed for populations of *Mastomys natalensis* rats in Tanzania. Using independent data sets, the robustness of the population models is tested and their sensitivity to stochasticity or poor parameter estimation is evaluated. Suggestions for improving the existing models and the interpretation of the simulation results will be presented.

**Seasonality and population cycles in small rodents**

*Nils Chr. Stenseth*

Division of Zoology, Department of Biology, University of Oslo, P.O. Box 1050 Blindern, N-0316 Oslo, Norway.

Referring to *Clethrionomys rufocanus* in Hokkaido and in northern Finland, the seasonal component of population regulation is discussed. Based on empirical information, it is demonstrated that the degree of density-dependence is stronger during the winter than the summer. It is furthermore shown that a major cause of the observed population fluctuations may be due to this seasonal forcing. It is furthermore demon-
strated that observed non-linearities (or phase-dependencies) may primarily be due to the density-dependent structure during the winter.

The Finnish data used cover a period of 49 years, whereas the Hokkaidian data consist of 225 time series mostly covering between 20 and 30 years; in the presentation, analyses based on these two sets of data are summarised. As part of the presentation two sets of mathematical models are presented and discussed—one based on statistical time series modeling and the other based on assumptions common within the field of ecological modeling.

**The influence of high temperature and migration on reproduction of Microtus fortis calamorum in the Dongting Lake area**

Cong Guo, Mei-Wen Zhang, Yong Wang, Bo Li and An-Guo Chen

ICSC-World Laboratory Research Centre for Rodent Control, Changsha Institute of Agricultural Modernization, Chinese Academy of Sciences, Changsha, Hunan 410125, China

From early autumn to spring *Microtus fortis* live on the beach of Dongting Lake when the water level of the lake is low. As the water level rises in spring or in early summer, the area of the lake beach is narrowed, and *M.fortis* migrate across the dike into the farmland. When the lake beach re-emerges in autumn, the voles return. After 3 years of field investigations and laboratory observations, we have determined that the high temperature in summer and migration are two key factors influencing on the reproduction of *M.fortis*.

Most microtine rodents occurring at high latitudes (above 35°N) breed mainly in summer. However, in the Dongting Lake area (28°13’ 29°55’N, 111°11’–113°43’E), *M. fortis* show a different pattern of reproduction. They breed all year and the average pregnancy rate of adult females is 37.1%, although the pregnancy rate is very low in summer (June–August). In 1992, no pregnant voles were captured in summer, while in 1993 and 1994, the pregnancy rates were 15.9% and 4.5%, respectively. The pregnancy rates in winter were high, 72.3% in 1992, 50.0% in 1993 and 66.7% in 1994. The reproductive dynamics of males were similar to that of females, with some males showing small testes in the summer. In 1997, a laboratory experiment was conducted to test whether the high temperature in the summer affected the breeding potential. Voles captured on the beach were paired (n = 53 pairs) and held under natural temperature and light/dark cycle in summer (June–August) or under artificial conditions (21–23°C, 12L:12D). There was no significant difference in pregnancy rates in June and August, but in July, pregnancy rates under artificial conditions were significantly greater than under natural conditions.

In the farmland the lowest breeding rate of *M.fortis* occurred in June which was not the hottest month. Generally, migration occurred in May and the testes of the males became small in June, one month after the migration. We think this response was related to the stress of the migration during flooding. In 1992 the flood season began earlier than usual, in March. Although *M.fortis* were forced to migrate into farmland, the breeding rate of both sexes in April was still high. In 1994, some voles moved
into farmland after heavy rain in April, and also had high breeding rates. Why did both sexes retain high breeding potential after migration in March? We conclude it is because temperatures in April are still suitable for breeding. So the high summer temperature was the main factor influencing reproduction in *M. fortis*, and the stress of migration forced by the flood enhanced this effect.

Reconsideration of lemming phylogenetic history with special reference to the origin of *Synaptomys*

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True lemmings (Lemminae) at present are the most common rodents that inhabit the Arctic tundra of both Old and New World and are very well known for periodic rapid increase of population densities, sometimes followed by migrations. At the same time, despite the rather good representation in Late Cainozoic sites, the early history of the group and phylogenetic relations of the genera are confused. In order to clarify the phylogenetic and taxonomic relationships of a number of forms described from Pliocene and early Pleistocene in Eurasia and North America, comparative analyses of vast fossil lemmings material from Late Cainozoic sites in Poland, Western and Eastern Siberia and other regions have been performed. All characters used in phylogenetic analysis and taxonomic interpretations earlier were considered and revised; new ones also have been included. Analysis of variation of masticatory surface patterns in M3 (character of greatest importance in taxonomy and systematics of Lemminae) from Late Vilanyian site Zamkova Dolna Cave (Poland) clearly shows that remains earlier referred to *Synaptomys* in Eurasia actually belong to *Lemmus*. In this sample a full range of variation (total number of teeth = 87) can be observed: from teeth corresponding in the masticatory surface pattern to *Synaptomys* (Pliococtomys), 14% to recent *Lemmus* (also 14%), with all possible transitions among these extremes. The morphology of other teeth in this sample where the significant difference between the two genera is marked (M2, M1, the structure of the lower jaw), meanwhile, it is typical of *Lemmus* structure, so there is no doubt that this sample should be referred to the *Lemmus*. From the other side, comparison of teeth with the most primitive among this sample (Synaptomys-like) tooth structure with the teeth described from sites of older geological age as *Synaptomys europaeus* (Rebelice Krolewskie, Poland) and *Synaptomys mimomiformis* (Simbugino, South Ural) showed that there is no major difference in their morphology and no doubt that these teeth belong to one evolutionary line and, hence, should be referred to the *Lemmus*. This conclusion essentially changes the generally accepted viewpoint on the history and phylogenetic relationships of the genera of Lemminae. It means firstly, that the oldest remains of the group belong to the genus *Lemmus*, and, thus, it is the most ancient and primitive genus in the group. Secondly, there were no remains and no evidence of any occurrence of bog lemmings in Eurasia and the origin and evolution of the latter is therefore exclusively connected with North America. Two hypotheses of phylogenetic relationships can be formulated and tested further. According to the first one, true and bog lemmings are the sister groups, whose split occurred in the
Late Pliocene of North America, after the first migration of true lemmings (*Lemmus*) which possibly took place around 3 million years B.P. Under the other one, bog lemmings of North America are an independent line of evolution that developed in parallel, with similar teeth morphology, from different cricetid ancestors in response to the requirements of the similar food niche. Comparative analyses of the structure of lower jaw and palate of first representatives of *Synaptomys* species of North America and first species of *Lemmus* in Eurasia are needed to test these hypotheses.

**Specific features of the distribution of the great gerbil (*Rhombothyrm opimus*) in central Asia**

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Studies of the great gerbil’s range and distribution in Central Asia were analysed from published data, museum collections, natural maps and the authors’ field observations. A preliminary scheme was plotted for range regionalisation, in which three parts have been isolated or, according to a 1971 classification of Dubrovskii and Kucheruk, three regional complexes of autonomous groups of populations are distinguished: Dzungarian, Central-Gobi (or Beishan) and East-Gobi-Alashan. Five autonomous population groups have also been isolated which are to the north of the main range: Shargin-Gobi, Beger-nuur, Orok-nuur, Bulgan and Bayan-Dov. West of the main area of the great gerbil distribution, an isolated colony is in the Ili river valley, connected with the Kazakhstan portion of the range (Ili regional complex of autonomous groups of populations). Regions with favourable conditions for great gerbil colonies were also shown. Additional field observations are required for more detailed description of the great gerbil range.

**The diet and dynamics of New Zealand’s forest-dwelling house mouse (*Mus musculus*) in the Orongorongo Valley**

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Monitoring of house mice living in the mixed beech (*Nothofagus* spp.) and podocarp/hardwood forest of the Orongorongo Valley, New Zealand began 1971 with a view of examining the relationship between mouse numbers and intermittent production of beech seed. Over the 104 quarterly-trapping sessions, mouse catch rates ranged from 0 to 13.7 mice per 100 trap nights. The initial hypothesis that mouse numbers in the forest fluctuate in relation to food (beech masting and arthropod abundance) prompted us to examine the arthropod diet and breeding of mice between 1992 and 1996.

Overall 85% of the 254 stomachs examined contained some form of arthropod. Sixty-eight percent of mice had eaten spiders, 52% had eaten caterpillars, and 47% had eaten other taxa such as beetles, centipedes, amphipods, and fly larvae. Spiders
were eaten consistently throughout the year while the consumption of caterpillars varied seasonally. The consumption of beetles and other taxa was sporadic. The most commonly identified prey were the spider *Miturga* sp. and the tortricid caterpillar *Cryptaspasma querula*.

Mice caught at beech trap sites ate different arthropods to those caught at podocarp/hardwood trap sites. *Cryptaspasma querula* was most often eaten by mice caught at podocarp/hardwood trap sites while another caterpillar group *Tingena* spp. was most often eaten by mice caught at beech trap sites. Mice living in beech ate more beetles than those caught in podocarp/hardwood. Differences in food eaten were also reflected in differences in trap catch and body weights of mice. Mice caught in stands of podocarp/hardwood weighed 6% more than those caught in stands of beech and mice were always caught in stands of podocarp/hardwood while they were rarely caught for 18 months at beech trap sites. Our findings suggest that, in the Orongorongo Valley, stands of podocarp/hardwood may act as mouse donor habitat while beech is acting as mouse reception habitat. Analysis of changes in mouse catch rates since 1971 suggest that population fluctuations in both habitats are density dependent and closely related to beech seed fall. We can now predict with reasonable accuracy the timing of peaks in mouse numbers in beech habitat.

**The cohort life table of the Brandt’s vole (*Microtus brandti*) in Inner Mongolian grasslands, China**

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This work was carried out in the typical steppe of the Inner Mongolian grassland in North China from 1995 to 1996. The life data of 320 voles, *Microtus brandti*, were obtained by capture-recapture techniques and by direct observations in two field populations, a wild population (43°25', 116°41') and an enclosed population (43°37', 116°41'). The procedure, Survival Analysis, of the shareware package STATISTICA Release 4.5A, was used for data analysis.

Our data have indicated that many deaths occur in the early life stage of the Brandt’s vole. The median life is about 50% shorter than that of expected life of the same cohort. The characteristics of the survivorship curves of this species suggest a lower survival rate in the early and later life stages with a higher survival rate in the middle life stage, producing an n-shaped survival curve. The type of survivorship curve of this species is B or between types B and A. The ecological longevity of *Microtus brandti* is about 18 months.

There is no significant difference between sexes in this species. Differences in survival of each sex are often thought to be due to the species’ sexual selection and mating system. In polygynous species, males generally have lower survivorship than females during most stages in life, and a shorter lifespan. On the contrary, in many monogamous species, males have a similar or higher survival rate than females.
However, in our studies, Brandt’s vole exhibited no differences between the sexes despite its polygynous mating system. One explanation is the delay in maturation of new born males which may reduce the injury caused by the intrasexual competition and combat. As a result, the mortality rate of these sub-adult males may be reduced.

Offspring of females which over-winter have a higher survival rate than offspring of current season females. This could be due to the maternal behaviour of over-winter females which are in better physical condition and more experienced breeders than younger females born in the current season. Another explanation may contribute to inbreeding. Previous work has shown that families of Brandt’s voles re-form in the early spring with all over-winter males dispersing from their original groups, while most of the females remain. As a result, over-winter males are not closely related to over-winter females in the same group and offspring are not inbred. However, in the following breeding season, most of the voles including the adult newborn females seldom move from their original group. Therefore, father–daughter matings occur and offspring have a lower survival rate than offspring of over-winter females.

**Rodent population dynamics under environmental change: is it an ergodic process?**

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Rodents are assumed to respond to environmental change by altering population numbers and distribution in accordance with species-typical ecological demands. When analysed in space, variation in population and community structure appears to be closely associated with varying conditions. Rules operating at spatial scale are often implied for analyses and forecasts of the population dynamics in a changing environment. This is done at a temporal scale proceeding from the assumption of its ergodicity. Here we present data on the long-term (1980–1997) dynamics of the rodent community in the semi-deserts of southern Russia (Republic of Kalmykia) under the conditions of rapid recovering succession, induced by recent dramatic reduction of live-stock pasturing and a new cycle of climate humidisation. Desert with low sparse ephemeral cover changed in the early to mid 1990s to steppe-like landscape covered with dense tall perennial grass. As a result we expected decrease in numbers and extent of distribution of the psammophyl gerbil *Meriones meridianus* and a population increase in mesophil species *M. tamariscinus, Microtus socialis, M. rossiaemeridionalis* and *Spermophilus pygmaeus*. Species abundance and distribution were estimated in various habitats within a 20 km² area in the south of Kalmykia (Chernye Zemli) in 1980–83 and in 1993–97. The surveys were carried out along transects (50 snap-traps set in lines for 3 days) and at stationary 1 ha grids by means of capture–recapture methods (100 trap stations set in squares 10 x 10 m for 2 hours during two weeks). Species status within the community was estimated through relative abundance of a particular species in the total number of rodents captured. Extent of distribution was measured as the proportion of key sites inhabited by particular...
species. Species abundance was estimated through relative trappability on snap-trap transects (ind/100 day-traps) and as local density within live-trap grids (ind/ha).

Population status of *M. meridianus* has not changed significantly despite the marked reduction of normally preferred open sandy-soil habitats with sparse vegetation. In both periods this species occurred everywhere at relatively high and stable numbers. *M. tamariscinus* avoided open and slightly covered sands, and was not abundant and occupied few habitats in the 1980s. In the 1990s this gerbil had dispersed widely, significantly increased in numbers and was equally dominant with *M. meridianus* in almost all types of habitats. Contrary to expectation, abundance and extent of distribution of *S. pygmaeus*, typical representative of the steppe fauna, decreased. There was some population growth only in 1997. *M. socialis* kept the status of rare species during the whole period of observations up to 1997, when population numbers increased by 20–40 times and the species spread everywhere dispersing in non-typical habitats. Unusually high snow cover, rather than vegetation succession, appeared to induce this peak. Single individuals of *M. rossiameridionalis* were recorded within the study area for the first time only in 1997. Thus, rapid recovering succession has not resulted in a marked response by the rodent community. The results in part contradict an assumption that the phases of temporal variation in species abundance and distribution under changing environment have analogues in space. In particular, both gerbil species sympatric on the large parts of their geographical ranges, show different habitat preferences in accordance with different ecological requirements and rarely occur together at high densities. Discrepancy between expected and observed species’ response may indicate some kind of population “inertia”, constraints being previous population state and associated social processes. Prognostic models developed on the basis of the rules operating at the spatial scale should be considered with caution since ergodicity is not likely to be an attribute of biological systems.

**Models for predicting plagues of house mouse (Mus domesticus) in Australia**

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The introduced house mouse (*Mus domesticus*) is a major pest in the grain-growing regions of southern and eastern Australia. The population dynamics of mice differs significantly between the relatively frequent outbreaks in the Darling Downs in Queensland and areas with mostly low abundance of mice and occasional eruptions to plague proportions as in the wheat-belt of New South Wales, Victoria and South Australia. The different dynamics imply that the major regulating factors are not uniform between regions.

There are at least eight models, with varying degrees of predictive ability, that describe the development of mouse plagues in Australia. They include: broad-scale regional models that rely on environmental or production data; district and small-scale models that describe in detail the processes of plague formation; and simplified
‘process’ models focusing on one or more mechanisms that might influence the rate of change of mouse abundance.

In this paper we describe recent modifications to a model for predicting the onset, magnitude and duration of mouse plagues in the cereal production areas of the Victorian mallee. A secondary aim is to assess the efficacy of viral- or bait-delivered immunocontraception for managing mouse plagues. The model is based on a 16-year data set that has tracked four major eruptions of mice. Separate numerical response functions for breeding and non-breeding seasons, and environmental indices for the onset and termination of breeding, were used to match computer simulations with the observed population trajectories. As well, the model was validated by using records of plagues for the last 100 years to test predictions of the frequency of eruptions. The structure of this computer simulation model is compared with other published models for similar climatic regions. Potential areas for future development will be discussed.

Analysis of the effects of predation and food availability on population dynamics of root voles

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This study determined the effects of interactions between nutrition, predation, and spacing behaviour on the population demography of root voles, *Microtus oeconomus*, using a factorial experimental design in enclosures in the field. The effect of predation and patterns of food availability on the population dynamics of the voles is described. The specific hypothesis tested is that the availability of high-quality food, and predation act independently and additively to limit the population densities of small rodents.

The results from four experimental treatments generally supported the hypothesis that food availability and predation have independent and additive effects on the vole populations. The predictions that the populations with supplementary food and no predation would reach the highest densities, that those with no supplementary food and no predator access (control) would show the lowest densities, and that those with a single treatment would have intermediate densities, were confirmed. A two-way ANOVA indicated that both food and predation treatments had significant effects on densities during weeks 1–20. Prevention of predator access significantly affected recruitment during weeks 4–20, but the effects of additional food on recruitment was less and only marginally significant.

The effects of both food and predation treatment on the densities and recruitment appeared to be additive (no significant interaction) and different in magnitude. Also as expected, the patterns of recruitment and the instantaneous rate of population increase under four different treatments paralleled the observed density patterns.
The role of food limitation in irruptions of Australian desert rodents

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Natural irruptions of desert rodents are generally characterised by sudden increases in numbers following rainfall. Australian desert rodents follow this same pattern and it has been suggested that the sudden increase in numbers is due to an increase in food. However, reports of irruptions in Australia tend to be anecdotal with little or no supporting evidence for causal factors. Here I report the results of a study investigating food limitation in populations of Australian desert rodents in relation to irruptions. The study was carried out in the Simpson Desert in southwestern Queensland and concentrated on two endemic species: Notomys alexis and Pseudomys hermannsburgensis.

In the natural situation, populations of both P. hermannsburgensis and N. alexis showed strong temporal fluctuations. For both species, numbers of individuals were correlated significantly with an index of rainfall with a time-lag of four months. Four months after large rainfall events, both species showed a peak in population numbers. Numbers of rodents increased primarily as a result of reproduction on both local and regional scales. All members of the population, apart from lactating females, appeared to be highly mobile, resulting in low residency time and a high turnover of individuals within the local population.

Pseudomys hermannsburgensis, which is largely granivorous, showed a positive relationship with seed availability both temporally and spatially. With declining availability of seeds in the sand, numbers of P. hermannsburgensis showed a corresponding linear decline. On a small spatial scale, numbers of P. hermannsburgensis captured per trap were correlated positively with the availability of seeds at each trap station. This spatial correlation suggests that P. hermannsburgensis can respond to spatial variation in food availability; tied in with movement patterns of individuals, it suggests that habitat selection may play a role in determining local population levels. Notomys alexis, which also include much seed in the diet, showed a non-significant temporal trend with seed availability, declining in numbers through the period of seed decline. There was no spatial relationship between numbers of N. alexis and seed availability. These data suggest strongly that rainfall and possibly rain-induced food availability trigger natural irruptions of Australian desert rodents.

A series of supplementary feeding experiments was used to directly test the hypothesis that populations of P. hermannsburgensis and N. alexis are food limited. The addition of sunflower seeds to a series of trap plots resulted in increased numbers of P. hermannsburgensis compared with control plots. The response of this species was quite specific in that animals responded only to food placed at the bottom of dunes. The density of P. hermannsburgensis was related directly to the amount of supplementary food available, and the amount of food consumed. Notomys alexis showed an increase in mean body mass as a result of supplementary feeding, but population
density did not change. Neither species showed a long-term response to the dispersion of supplementary food (clumped or spread). Supplementary feeding was not able to reverse a population decline, but it did slow the overall rate of the decline in *P. hermannsburgensis*. The combination of pattern analyses and experimental manipulations suggests that populations of *P. hermannsburgensis* are limited by availability of food, whereas populations of *N. alexis* are not.

Can population growth rates vary with the spatial scale at which they are measured?

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Cyclic small mammal populations often exhibit lower than maximum growth rates following their decline. This phenomenon is known as the extended low and is thought to be an important clue to the solution of the mystery of why the populations seem to have a slow population recovery after a population decline to very low numbers. We identify three simple sources of bias in the estimation of population growth rates that should be considered before more complex ecological hypotheses are proposed to explain this phenomenon. First, we show that the commonly used method of adding a constant to time series data to avoid problems caused by division by zero can lead to underestimation of growth rates at low densities. Second, we suggest that sampling variance around density estimation can lead to positive bias in the estimation of growth rates when populations are distributed in ephemeral patches. Third, we show that the use of trapping grids smaller than twice the characteristic range of natal dispersal to estimate population growth rates at low densities can lead to negatively biased estimates. We analyse data from growing populations of bank voles and snowshoe hares and show that robust positive correlations exist between estimates of growth rate and the spatial scale at which population density estimates were conducted. These observations are discussed in relation to our identified sources of bias.

Seasonal changes in the population density and reproduction of the rice field rat, *Rattus argentiventer* (Rodentia: Muridae) in West Java

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The purpose of the present study was to investigate the seasonal population abundance of the rice field rat in a two hectare experimental field by using the capture-recapture method and to find the major factors affecting the above estimated population fluctuations.
Field work was conducted from 1988 to 1990 at the Jatisari Forecasting Center in West Java, about 120 km east of Jakarta. The centre is an agricultural research station (2 ha) which has rice as its main crop. Population survey by the capture-recapture method was conducted on a 2 ha experimental field surrounded by a 40 ha area of local farmland. The rice in the experimental field was planted one month after the rice field in the neighbouring farmlands. This was done so data on rat populations in asynchronised fields could be collected. Single capture live-traps made of wire mesh were baited with whole grain. The traps were checked every morning for 5 days. Trapping was conducted twice monthly. The reproductive condition of males was estimated by examining the position of the testes. Females were classified as reproductively active if they were pregnant or lactating.

Fluctuations in the size of rat populations were clearly marked by two distinct peaks per year. The population began to increase during the seed ripening phase during the rainy season and during the milky stage during the dry season. In 1988, the highest population size was estimated to be 1529 per 2 ha; this population caused severe damage to the rice crop with almost no rice harvested. Peaks occurred 2–4 weeks after harvest, and gradually decreased for about 2 weeks during the rainy season and 3 weeks during the dry season. These peaks were caused by the recruitment of young rats and immigration. In the rainy season for both years, the mating season was from January to mid-February (the panicle premordia initiation to milky stage), and births occurred from mid-February to mid-April (ripening to post-harvest). In the dry season of 1988, the mating season was from mid-April to mid-June (panicle premordia initiation to booting), and births were from mid-June to mid-August (flowering to harvest). The dry season crop in 1989 was planted later: the mating season was from mid-April to mid-July and births were from mid-July to late-September. The breeding season declined with the disappearance of rice plants after harvest each year. Survival was generally low during the mating season and high during the birth season. Survival rate was lowest in the non-breeding season (during non-cultivation). In general, the ripening stage of the rice plant was the major nutritional factor affecting the population fluctuation.

Forecasting the relationship between population size of the striped hamster and ecological factors

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This paper applies the theory of the gray interrelation analysis to the forecast of the relationship between the population size of the striped hamster and ecological factors. We selected some systematic data that related to the striped hamster population and the related ecological factors from a 10-year database for the North China Plain. We regard the population size and related factors as the main factor array and relating factor array, respectively. By using the gray interrelation theory, we can get the following result:

\[
\begin{align*}
\hat{r}_{05} &= 0.880796; \quad \hat{r}_{03} = 0.879127; \quad \hat{r}_{01} = 0.873885; \quad \hat{r}_{02} = 0.871899; \\
\hat{r}_{08} &= 0.838137; \quad \hat{r}_{07} = 0.834565; \quad \hat{r}_{04} = 0.833309; \quad \hat{r}_{06} = 0.540963.
\end{align*}
\]
In this paper, $r_{01}$, $r_{02}$ to $r_{08}$ stand for the relating degree between the sex ratio, pregnancy ratio, average litter, age structure $[(\text{juvenile + subadult})/(\text{adult + old})]$, extremely high temperature and extremely low temperature, total precipitation, extremely high precipitation and the population size, respectively. According to this, we can divide these factors into four levels: (i) extremely high temperature, average litter number; (ii) sex ratio, pregnancy ratio; (iii) extremely high precipitation, total precipitation, age structure; (iv) extremely low temperature. It was found that the population size of the striped hamster was highly affected by the extremely high temperature and the average litter number. The theory of the gray interrelation analysis can be successfully used to forecast the population size of farmland rodents and can reflect the real state of the farmland ecosystem more closely.

**POSTER PRESENTATIONS**

**Variation, taxonomy and distribution patterns of the genus *Lemmus* in the palaearctic**

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Brown or true lemmings (*Lemmus*) are the most prolific rodents of the recent tundra. They have very wide distribution all over the Holarctic tundra zone, including islands of the Polar basin. However, despite their important role in the tundra’s ecosystem the taxonomic structure, distribution patterns and character of morphological variation are insufficiently known.

There are many contradictions about the rank and number of forms comprising the genus *Lemmus*. The primary aim of the current work was to examine the interpopulation variation of skull morphology and pelage colour in 13 lemming populations across the Eurasian Arctic and to elaborate on this basis any possible taxonomic interpretations. The major part of the material for this study was gathered during the Russian–Swedish Tundra Ecology Expedition during June–July 1994 in 13 sites in the Arctic tundra from Kola Peninsula on the west to Western Chukotka on the east, including the Novosibirskie Islands (I. Kotelnyi and I. Fadeyevskiy) and Wrangel Island. A complex of linear measurements and indexes (28 in total) describing the shape, proportions and sizes of the skull and mandible were taken and processed with methods of multivariate statistics. Statistical processing of data was by ANOVA, factor analysis, cluster analysis, discriminant and canonical analysis using STATISTICA version 7.0.

With the samples analysed as a whole there is a very distinct division into two large groups: island populations and mainland populations. Most of the differences between these two main clusters are explained by the significant differences in linear sizes. Lemmings from all island populations are significantly larger than those in the mainland. All mainland populations form a very close group, but despite this closeness among the mainland populations two groups could be distinguished that conditionally...
designated as west and east group. Canonical analyses have shown that despite the greater difference between the mainland and island populations, the latter group (east and west) differ in other characters which mostly reflect the proportions rather than general sizes. On the next step we excluded from the analysis the island population, considering only six mainland populations. Achalanobis distances we obtained were much smaller than in the previous case, but they are significant and typical. We can see two distinct groups along the first canonical axis, the ones we designated as east and west and each of them in its turn distinctly split on two subgroups along the axis of the second component. The boundary between west and east subdivisions lay between Eastern Taimyr and the Olenek River. The group of so-called east populations lemmings from the right shore of the Kolyma River could be distinguished on the basis of certain craniological characters. These lemmings differ karyologically from the rest of the populations studied and represent another species, *Lemmus trimicrotus*.

The same material has been used by Fedorov et al. (in press) for the study of mtDNA variation. The results obtained correspond well to the differentiation we obtained in the study of morphological variation. On the basis of synthesis of morphological, karyological and data of mtDNA variation the comprehensive taxonomical structure and probable history of distribution of the *Lemmus* are suggested.

**Growth and development of the sulfur bellied rat (*Rattus niviventer sacer*)**

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This study investigated the growth and development of the sulfur bellied rat (*Rattus niviventer sacer*) by raising several pregnant females in a laboratory during 1992 to 1995. Females were originally captured in the fields of Xixian in Shanxi, and were fed wheat, bean, sunflower, watermelon, fruit, insects and grasses. Observations were made daily to detect births of litters. Newborn litters were monitored for changes in body fat, size and developmental characteristics. Females giving birth produced a neonate about every 15 to 25 minutes, with the longest interval between pups being 2 hours 40 minutes.

The sex ratio (M:F) of newborns was 0.93 and the survival of newborns was high (96.3%). The average body weight of newborn females was $3.24 \pm 0.12$ g, and was not significantly different to the males ($3.36 \pm 0.91$ g). Initially, body weight increased quickly with average daily growth rates of body and tail lengths (relative efficiencies of 0.9938 and 0.9970) from days 0 to 25 after birth. During this period there were no obvious differences in body weight, body length and tail length between females and males. They began to grow upper incisors at about 11 days of age, opened their eyes by about 18 days and became independent after 22 days.
This information on growth and developmental characteristics of young sulfur bellied rat could be used to understand aspects of the population ecology and control of the species.

Peculiarities of structure of dental system and morphometric variation in *Lasiopodomys mandarinus* and *L. brandti*

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At present the genus *Lasiopodomys* Lataste, 1887 is divided into two monotypic subgenera-nominative and *Lemmimicrotus* Tokuda, 1941 with the species *Lasiopodomys brandti* Radde, 1861 and *Lemmimicrotus mandarinus* Milne-Edwards, 1871. Recently in the same genus, the species *L. fuscus* Buchner, 1888 has been included that earlier was referred to the subgenus *Neodon* Hodgson, 1849. The voles of this genus inhabit the territories of Mongolia, China, Korea and Russia where the range of *L. brandti* and *L. mandarinus* is limited by the territories of Southern Transbaikal. Few studies have been conducted on the structure of the skull and morphotype variation of dental system.

One hundred and seventy specimens of *L. mandarinus*, 70 specimens of *L. brandti* and 8 specimens of *L. fuscus* from different geographical regions of Transbaikal, Mongolia and China deposited in the collections of Zoological Institute RAS, St Petersburg University and the Zoological Museum of Moscow University were examined. Twenty-four characters in the structure of the skull and dental system were involved in the analysis of seven samples of *L. brandti* populations performed using principal component analysis. Discriminant function analysis was used to distinguish subspecies forms. All three species are well identified by the interorbital ridge, sizes of auditory bullae, and proodont incisors. Within the species *L. mandarinus* two populations from Transbaikal and Mongolia belonging to one species essentially differ in the sizes of auditory bullae and proodont incisors.

Within the species *L. mandarinus* two populations from Transbaikal and Mongolia belonging to one species essentially differ in the sizes of auditory bullae, interorbital width, paraconid part of the first lower molar (E/1). Subspecies *L. b. hangaiicus* Bannicov, 1948 can be identified on the combination of 7 characters with the 100% exactness. The highest morphotype variability was marked for the molars of *L. mandarinus*. The first lower molar of *L. mandarinus* is represented by 6 morphotypes with the prevalence in 84% of specimens of morphotype 5/4, 7 (in nominator: the number of salient angles on the inner part of the tooth, in denominator the number of salient angles on the outer part of the tooth, after the comma the number of closed dentine spaces). The third upper molar (M3) is represented by 9 morphotypes, the dominating ones are morphotypes 3/3, 4 (44%) and 3/2, 4 (27%). In *L. brandti* M1 is represented by five morphotypes, the morphotype 5/3, 7 is meeting more often than others (52.5% specimens). Among the seven morphotypes of M3, the dominant is the morphotype 3/3, 5 (52.5%). In both species the dominant morphotypes in the different populations of Transbaikal and Mongolia are retained. For the *L. fuscus* the three
morphotypes of M1 and M3 have been distinguished, there with the extinct voles of the genus *Allophajomys*. The third upper molar more often meets in the form of 3/3, 4 as in *L. mandarinus*, but differs by more expressed talonid. It should be that *L. fuscus* has significantly less quantity of cement. Taking in account significant morphological differences of *L. fuscus* from other voles of genus, it may be given the taxonomical rank of subgenus.

**Distribution patterns of two chromosome forms of common vole** *(Microtus arvalis* Pallas) **on the common border of their range**

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On the territory of the former USSR, the study of common vole (*Microtus arvalis* Pallas, 1779) karyotypes has shown that there are two forms of this species that have the same chromosome number (2n = 46) and morphology of macrochromosomes but differ in morphology of small autosome and sex Y-chromosome. It has been established that on the vast range of *M. arvalis* the chromosome forms ‘arvalis’ and ‘obscurus’ geographically replace each other. The form with the European distribution was designated as ‘arvalis’, and with Euroasiatic as ‘obscurus’. The hybrids of two forms obtained in the laboratory are fertile. The eastern boundary of the range of the form ‘arvalis’ and western boundary of the range of the form ‘obscurus’ are in the European part of Russia and in Ukraine. The major part of the boundary occurs in the country between the rivers Dnieper and Volga.

The main aims of the current work were: clarification of the boundary of distribution of two chromosome forms of *Microtus arvalis*, and study of their distribution in Vladimir and Nizhegorodskaya regions. This territory was chosen because the distance between the extreme known records of the forms ‘arvalis’ and ‘obscurus’ comprised only 350 km and the absence of essential geographical obstructions may allow us to find out the possible zone of sympathy.

Within the Vladimirskaya region two forms of common vole that replace each other on the right shore of the river Klyas’ma have been found. On the left shore of this river only one form, namely ‘arvalis’, was found. The distance between the different forms on the right shore of the river decreased to 12 km in the absence of essential geographical obstacles, and the direct contact between two forms in the Vladimirskaya region seems possible. Preliminary data of experimental hybridisation allow us to propose that the hybridisation of forms ‘arvalis’ and ‘obscurus’ in natural conditions is not excluded. However, among the 43 animals analysed we have found no hybrids. Two problems therefore arise: (1) Why do both chromosome forms nowhere meet together? (2) What is the taxonomical status of these forms? We suppose that such distribution is determined by the ethological isolation between these forms. Such isolation between the close species is known, for example sibling species *M. arvalis* inhabiting one territory and even one biotope occupy different microsites in correspondence with the peculiarities of their biology. Seemingly the form ‘obscurus’ is younger in an evolutionary sense but is essentially biologically similar to the
form 'arvalis'. Furthermore, what prevents them from occupying the same ecological niches? In this case the recognition of individuals of own population from the foreign population is of primary importance and when dispersion is taking place, one form does not let the other form enter its territory. If that is so, the hypothesis should be confirmed that the form 'obscurus' be given species rank.

**Study of seasonal survival rates of populations of Microtus brandti**

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In Zhengxiangbai Banner and Tipus Banner, Inner Mongolia, from 1990 to 1996, seasonal survival rates of two populations of Brandt’s vole (*Microtus brandti*) were estimated using capture-recapture methods. Feeding data were derived in the laboratory. During periods when the populations were increasing or decreasing, survival was lowest in winter (mean 0.2473 ± 0.0748) and highest (mean 0.6870 ± 0.1137) in autumn. The number of voles in a burrow system was related to seasonal survival rate, especially in winter.

**Migration of rodent species in agricultural landscapes in the Vietnam–Cambodian border region**

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In recent years, Vietnamese people living in the border region of Vietnam–Cambodia (Kien Giang, Long An, Dong Thap, An Giang provinces) reported that rats from Cambodia migrated each year to Vietnam around the lunar new year. A study was conducted in the Ha Tien district, Kien Giang province, over two time intervals: from September 1996 to March 1997, and December 1997 to March 1998. A 1.5 km plastic fence (0.8 m high) was established at the Vietnam–Cambodian border. A live-multiple-capture cage trap made of wire (600 x 300 x 300 mm) was placed every 30 m along the base of the fence, flush with an opening to a hole. The live-capture traps were faced alternately towards Vietnam or Cambodia. The traps were checked each day. Rats caught only in the central 1 km of the fence (n = 35 traps) were included in the analyses.

In 1996, rats moved from Vietnam to Cambodia (*emigration*) before floodwaters reaching the border region (from the middle of October to the beginning of November). Movement of rats in the other direction (*immigration*) occurred from the middle of February to the beginning of March. In 1998, a similar pattern of rat movements was observed, although the immigration of rats from Cambodia to Vietnam was one month earlier than in 1997 and the peak in immigration occurred in early February.
Almost all the rats were adults. The sex ratio of immigrating and emigrating rats was male biased. The most marked imbalance of females to males occurred in 1998, when twice as many males immigrated than females. The proportion of adult females in breeding condition was generally high. The species composition of rats immigrating and emigrating was markedly different. In 1996–97, 60% of the emigrating rats were Rattus argentiventer, 20% were R. losea and 20% were a combination of other species, whereas 69% of the immigrating rats were R. losea, 20% were R. argentiventer and 11% were other species. In 1997–98, 46% of the emigrating rats were Rattus argentiventer, 29% were R. losea and 25% were a combination of other species. Again there was a switch in species composition for the immigrating rats: 56% were R. losea, 28% were R. argentiventer and 16% were other species.

We propose that the patterns of migration of rats in the border region of Vietnam–Cambodia are influenced primarily by seasonal flooding of the Mekong Delta and different timing in the cropping patterns on either side of the border. Cropping land in Cambodia is at a higher elevation than in Vietnam, and Cambodian farmers plant only one crop per year. This is a traditional rice variety that takes 6 months to mature. In Vietnam there are two rice crops grown each year, generally they use varieties that mature in 3–4 months. In July–August, the summer–autumn rice crop in Vietnam is harvested when the water level in the delta is gradually rising, forcing rats to move to higher ground. In August–September, rice plants are at the booting to flowering stage in Cambodia. This is a most attractive stage of crop development for rats. In January–February, Cambodian farmers harvest rice then burn the rice straw. In Vietnam, the floodwaters have receded and most of rice crops are at the tillering to booting stages. So again the rats would be attracted to the maturing crops. Why there are seasonal changes in species composition of the migrating rats is not clear. Ecological studies of rat populations on either side of the border are required to understand this conundrum.

What stops population growth in the wild rabbit (Oryctolagus cuniculus)?

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Predation, food shortage and disease are thought to be mechanisms responsible for population regulation of the wild rabbit. However, it is unknown whether fluctuations in rabbit density within a habitat can be produced by social processes involving dominance and aggressive behaviour. During a 12-year study, alternative hypotheses of self-regulation of a population within a habitat were tested.

In an enclosure of 22 000 m², a rabbit population stabilised at around 50 adult individuals despite a yearly production of about 400–1200 offspring. From approximately a thousand observation hours, physiological data such as glucocorticoid concentrations, immune-parameters and parasite loads were determined for each individual during their life time. Furthermore, kinship was determined by tagging every individual from the first day of their life within burrows. In addition, paternity was determined by DNA-fingerprinting.
There was evidence of density-dependent suppression of reproduction in females. However, this alone was not sufficient to regulate the population. The survival rate of offspring was related to a density-delayed mortality rate of multi-annual adults. Multi-annual adults were not replaced continuously but in intervals of two or three years.

Wild rabbits lived in small groups of 1–3 males and 1–7 females which were defended against neighbours. Within the groups, there was rank ordering amongst males and females. Social processes like territory extension, formation of subgroups, emigration and immigration of individuals determined the composition and size of a group. The emigration of both sexes probably served as incest-avoidance within the population.

Males regulated and stabilised group size while population size was decreasing by: a) dominant males extending their territories; b) subdominant males replacing deceased dominant males or integrating into groups with many females; and c) males generally guarding their females to prevent dispersal. Females regulated and stabilised group size by: a) emigrating from large groups into smaller groups; and b) maintaining their small group size by becoming territorial.

Group composition related to sex-specific competition and conspecific bonds which acted as a feedback mechanism regulating population density.

Social dominance increased with age, as indicated by a decrease in corticosteroid concentration. Social processes like territory extension, establishment of subgroups and the elevation in life expectancy confirm this hypothesis. Social processes reduced the integration of yearlings, leading to a decrease in population density.

The environmental effects on the distribution of long-eared jerboas (Euchoreutes naso)

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The effects of environmental factors on the distribution of long-eared jerboa (Euchoreutes naso) were studied in Anxi County, Gansu Province, north-west China, from March to October 1990. Seven sample plots were chosen according to the types of landscape, and were investigated for 5318 trap nights. The population number was calculated by the percent-capture rate. The relationships between the population of long-eared jerboa and environmental factors were analysed using stepwise regression and correlation methods.

The results show that the population of long-eared jerboas is correlated significantly and positively with the total population number of other rodents in the community, and is negatively correlated with the vegetation cover in spring. The optimal standard
regression equation is $Y = 0.314 + 0.345Tc - 0.028D$, $R_t = 0.9845$, $(P < 0.00001)$; $R_d = 0.9943$ $(P < 0.00001)$. In summer, environmental factors do not significantly affect the population number of long-eared jerboa. However, the population number is correlated positively with the total population number of other rodents in the community. The optimal standard regressive equation is $Y = 0.0941 + 0.0765Tc$ $(R = 0.6992$, $P < 0.05)$. It is concluded that the vegetation cover might be the factor determining the distribution of jerboas in super-arid desert areas in Anxi County. The rodents' utilisation of the limited and patchy food resources may be one of the reasons for aggregated distribution of rodents in this area. It is suggested that niche separation in foraging time, food type and size might permit their coexistence.

**Rodent and pika populations of south of the former USSR**

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Terrestrial animal populations are defined by authors as the total of all animal species inhabiting certain territory. Population maps of terrestrial animals are similar to vegetation maps that reflect distribution of plant communities. Only a few such maps have been published and all of them were for limited regions of the former USSR. Maps compiled by us show modern (1950s–1990s) primary and secondary (appeared on anthropogenically transformed territories) rodent and pika populations of steppe and desert zones and adjacent mountains. The scale of the map is 1:4 000 000. Each community is characterised in the legend by 4–5 indices such as numbers of species, their domination, habitats (predominant and secondary) and some others. A computer variant of the map will be in MAPINFO format and will consist of vector layers with spatial data and databases attached to them. Attached to the contour net of this map there are two tables—a table with a list of species and their numbers and characteristics, and a table with the list of principal and secondary habitats. Included is a map of sites where the material was collected, a table with list of species in each site, geographical coordinates of sites, and bibliographical citations describing these data. The latter enables us to consider the map as the cadastre of communities and species that have been registered within limits of mapped territory.

**Predation pressure and population dynamics in African Mastomys rats: possibilities for integrated pest management?**

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The multimammate rat, *Mastomys natalensis*, is a common and important agricultural pest species in sub-Saharan Africa. The present rodent control relies mainly on the ad hoc use of rodenticides but attempts to design and evaluate alternative
methods are needed. Earlier observations suggest that predation is a major mortality factor in this rodent. In order to investigate the importance of predation for the species' population dynamics and its possible application in biological control strategies, a 3-year study has been set up in February 1998 Morogoro, Tanzania.

The experimental set-up consists of monthly capture-recapture studies of the rodent population in different plots, and monitoring of predator presence by direct observations, trapping and collection of owl pellets. The 0.5 ha field plots are cultivated as maize fields, and subjected to three different treatments (all replicated):
1. excluding predators by fencing and netting the area;
2. attracting predators by improving hunting conditions using perch poles and nest boxes; and
3. allowing predators in unmanipulated situations (control).

A six-month pilot experiment in 1996–97 has shown that perches affect raptors' hunting behaviour and that survival is higher under netted areas but the effect on rodent densities may be obscured by compensating migration effects. To investigate these effects of dispersal the present predation manipulations are repeated both in populations exposed to dispersal (open populations) and in populations without dispersal (enclosed populations).

Seasonal reproductive patterns of the Mongolian gerbil in Inner Mongolia, China

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This study was conducted in Taipus Qi, Inner Mongolia from March to October in 1997. Small mammals were captured at monthly intervals using shaped traps placed in crop fields showing similar environmental characteristics. Gerbil reproductive status was assessed by autopsy.

The breeding peak occurred during March and April. The mass of the testes was greatest in March and April, decreased rapidly in May ($t = 11.35, p < 0.001$) and showed no obvious changes thereafter. The epididymis showed similar changes. Seminal vesicle size was greatest in March, and decreased significantly at monthly intervals from March until May ($p < 0.05$ and $p < 0.01$, respectively). No further changes were observed in the remaining months.

The ventral scent gland is an important organ influencing sexual activity. Its length and width are good indicators of testis weight ($p < 0.001$). Body weight also has a high correlation with testes weight ($p < 0.001$).

Ovarian weights of females decreased from March to June. Uterine and vaginal weights increased from March to April, decreased from April to June, then remained
this size. Pregnancies were observed from March to August; 53.5% of females were pregnant in March, 37.5% in April, and about 10% from May to August. The average litter size was 5.88 ± 1.14 (SD).

The Mongolian gerbil shows seasonality in its reproductive pattern with reproduction being concentrated in spring in this region.

**Competition between the rat-like hamster and the striped hamster**

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The rat-like hamster (*Cricetulus triton*) and striped hamster (*Cricetulus barabensis*) are the two most common species of rodents in farmland in northern China. Competition between the two species was investigated in farmland in Raoyang County, Hebei Province, China. Relative abundance was assessed using more than 440 000 snap-trap-nights from 1983 to 1989. Activity ranges were studied with mark-recapture techniques. Food preference was analysed by examining the contents of cheek pouches of both species.

The results indicated that strong competition exists between the two species. They preferred very similar food items in laboratory tests although food items differed in the field. The rat-like hamster with a larger body mass takes more food (e.g. peanuts, wheat and corn), while the striped hamster with a small body mass prefers the smaller seeds of weeds. This could reduce competition and allow coexistence in farmland. It appears that their niches differ temporally. The striped hamster reproduces in early spring, and reaches peak numbers in spring, while the rat-like hamster reaches peak numbers in autumn. When individuals of the two species fight, the rat-like hamster defeats and often kills the striped hamster.

**Population fluctuations of *Microtus fortis* in Dongting Lake area, Hunan, China**

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*Microtus fortis* is one of the main pest rodents in the Dongting lake area. The animals live on the beach of the lake from early fall to next spring. The population increases gradually while the animals live on the beach. In the summer, when the beach becomes flooded, the animals move into the farmland. Usually the animals cause great damage to the crops in the farmland.

The population fluctuations of the animal are different between the beach and the farmland. The key factors influencing the fluctuations are also different.
1. The population fluctuation of the animals on the beach of the lake. The lake beach was the most suitable habitat for the animal. When the lake beach emerged in autumn, the animals moved back onto the beach. The main breeding season was from October to May when the animals inhabited the beach. The population density increased gradually. The duration of the period from when the beach emerged until it again became flooded determined the population size and therefore the number of animals that moved into farmland.

2. The population fluctuation of the animals on the farmland. Farmland was not suitable habitat for the animal. Because of low breeding potential, high mortality and dispersal, the population density decreased during this period. The density of the population in farmland dropped dramatically when the lake beach emerged. The population density on the farmland was very low during winter.

A stochastic model of the responses of farm populations of the Norway rat to anticoagulant use

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In the field every farm appears unique because of the variety of factors that interact to determine the outcome of rodenticide treatments. One approach to such complexity is mathematical simulation. Such a mathematical model has potential to assist with evaluating rodenticide efficacy data and predicting the outcome of treatments which use different materials against populations with varying resistance status.

A model has been developed based on our understanding of rat feeding behaviour, under both controlled conditions in the laboratory and in the field. The core of the model treats as a two-stage process the way animals overcome their initial wariness or 'neophobia' towards rodenticide bait. Firstly, there is the latency for them to first feed on a rodenticide bait. Secondly, there is the subsequent increase in their bait consumption up to an asymptotic value. The size of this asymptote reflects the nature of the alternative food supply; for instance, in a stable environment with abundant alternative food, such as a farm grain store, the asymptote will be low while in an unstable environment with relatively poor quality and limited alternative food, such as a farm refuse dump, the asymptote will be high.

The model has been subject to extensive validation against data collected from the field. The model performs particularly well at simulating the consumption of unpoisoned and anticoagulant baits across a range of farm types and in relation to resistance status. Although the model suggests that more animals are 'killed' during simulations than in the real world this discrepancy is explicable in terms of some factors not included in the model. That the model can make realistic predictions of subtle changes in the resistance status of Hampshire rat populations suggests that it is a robust simulation of the real world.
Population fluctuation of a rodent pest in Yunnan, China

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Mus caroli is an important rodent pest of crops in central Yunnan, China. Among 1027 captures, Mus caroli accounted for 76%.

Trapping was conducted monthly in cultivated land in the Tonghai County, Yunnan Province from late 1989 to September 1993. The common abundance index (number/WO trap-days) was determined by using the snap-trap method. Trapping lines were 20 m apart and baited traps were placed at 5 m intervals. The local climate and the development of crops were recorded. All captured rodents were autopsied.

There were significant differences between the average monthly population abundance between different years from 1990 to 1993. The population fluctuation usually peaked twice a year, during May to June and in November. The density fluctuations seemed to be related to the developmental stages of crops and also to the reproductive activities of the rodents.

Two linear and one multiple linear regressions were run to estimate the population abundance in May of the year.

- \[ Y(M5) = 1.96x + 0.20, \text{ } r = 0.93 \]
  where \( M5 \) = population abundance in May; \( x \) = population abundance in January.

- \[ Y(M5) = 2.14x^2 - 21.42, \text{ } r = 0.92 \]
  where \( x \) = average of monthly mean temperature during February to March

- \[ Y(M5) = 1.172x(I) + 1.1572x(II) - 12.4848, \text{ } r = 0.990 \text{ } (p<0.05) \]
  where \( x(I) \), same as formula (I); \( x(II) \), same as formula (II).

The population abundance in May of 1994 showed the regressions mentioned above were reliable.

Reproductive characteristics, growth and development of the rat-like hamsters (Cricetulus triton)

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Variations in reproduction of rat-like hamsters (Cricetulus trion) the most important pest of the cultivated fields, were investigated in Raoyang County, Hebei Province, North China. It was found that reproductive parameters such as length of the breeding season, sexual maturity rate, pregnancy rate, litter size, ratio of resorbing embryos and sex ratio changed as density increased and decreased. Some of the
parameters were inversely related to population densities. During high densities, reduced recruitment, shortened length of breeding season and delayed rates of maturation of the first generation (spring-born) were observed. When population density was at a peak, the rate of growth and sexual maturity were asynchronous. Populations of *C. triton* showed evidence of a strong density-dependent suppression of sexual maturation and a significant negative feedback regulation mechanism. The phenomenon of pregnancy failure in sub-adult females was observed in different seasons during both peak and non-peak years. Sex ratio favoured males over females and was more likely to occur in breeding seasons. It was related to activity and mortality differences between juvenile males and females. The variations of reproduction in relation to air temperature, precipitation, soil type, food supply in different seasons and years were also examined. It is concluded that several reproductive parameters are useful for prediction of population trends.

The growth and development of rat-like hamsters were studied in laboratory conditions. Mean gestation was $21.57 \pm 0.69$ days and post-partum oestrus occurred by the fifth day. Increases in growth rate were analysed using measurements of weight and linear dimensions. The instantaneous growth rates (IGR) at various ages (from the day of birth to 100 days) showed that the growth was most rapid in the first 10 days. The IGR values at 5–10 days were highest for mass and lowest for body length. From then until 100 days, mass maintained the highest IGR, whereas IGR for hind foot and tail length decreased to very low levels. Sexual dimorphism was not obvious. The morphological and behavioural development of young hamsters was also observed. Weaning occurred at $26.86 \pm 1.13$ days. Hamsters became sexually mature at the age of 1.5–2 months. Females reached sexual maturity slightly earlier than males. Females had a 3–4 day oestrous cycle. The sex ratio (male/female = 1.71) in captivity favoured males, a result of a higher mortality in infantile females. Development was divided into four periods: infantile period (from the day of birth to 20 days), juvenile period (20–30 days), sub-adult period (30–60 days) and adult period (from 60 days on). Seasonal changes of growth rate were also studied.

**Survey of rodents living around Beijing Capital airport**

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Beijing Capital Airport is situated in the north-eastern part of Beijing. A survey of rodent species, population densities, habitats and seasonal abundance was carried out using rat traps. For more than 10 years (1984–1994), *Citeilus dauricus* has been investigated by checking holes in the grassland in nearby runways in the area of Beijing Capital Airport. The survey was conducted in three stages. Stage one was the initial survey combined with integrated rodent control (IRC) from 1984–1985. The 2nd and 3rd stages were carried out from 1986–1988 and 1993–1994, respectively. Seven species of rodents belonging to three families were recorded: *Rattus norvegicus, Mus musculus, Apodemus agrarius, Cricetulus triton, C. barabensis, Myospalax fantanieri,* and *Citeilus dauricus.* The house mouse (*Mus musculus*) is widely distrib-
uted in the area and is the dominant species making up 62.8%. *A. agrarius*, *C. arabensis* and *C. triton* comprise 17%, 15% and 6%, respectively. The rodent population peaks in September or October every year.

The most effective strategy to reduce rodent infestations is integrated rodent control using poison bait traps, gassing treatments and environmental management. This has reduced numbers from 5.6 to 0.6 rodents per 100 traps, which is less than the infestation threshold level. The average elimination rate was 89% from 1984 to 1985. Environmental factors may also have affected the rodent densities temporarily. However, re-infestation was observed in the area during the 3rd stage of the survey. The infestations increased to 6.0 rodents per 100 traps.

More research is needed to develop methods to effectively and rapidly reduce rodent populations so that their numbers remain below threshold levels.
Symposium B
Rodent Physiology and Adaptation of Rodents

ORAL PRESENTATIONS

Dietary and digestive adaptations of rodents

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Amongst the Mammalia, the rodents are the most diversified order and include the greatest number of species and individuals. Their phenomenal success worldwide can be explained in terms of their generally small size and conservative body plan, their highly adaptable reproductive strategies, and their great dietary flexibility. This paper explores the evolution of rodents from the primitive adaptation of a mandibulo-dental apparatus for an omnivorous diet to more modern forms which include greater specialisation in dietary strategies that include not only omnivory but also strict carnivory (e.g. the Australian water rat Hydromys) and strict herbivory (e.g. the Caviomorpha). Four basic characteristics of rodent teeth are rootless, continuously growing incisors with enamel restricted to the anterior face, a large diastema between the incisors and the cheek teeth, the ability to occlude only the incisors or only the cheek teeth, and folds of skin that push inward through the diastema so that the incisors occlude outside the mouth. Because of these features, rodents can efficiently shear vertebrate flesh; stab and seize invertebrate prey; manipulate small seeds; remove bark; and clip off and grind plant stems, leaves and buds.

Evolutionary trends among the rodents as adaptations for herbivory include an increase in the number of transverse ridges on the cheek teeth, hypsodonty, and appearance of continuously growing cheek teeth that develop roots only late in life or not at all; and strengthening of the masticatory musculature; as well as several changes to the gastrointestinal tract. These include an increase in total tract capacity, replacement of unilocular (undivided) with bilocular stomachs; reduction in the proportion of the stomach lined by glandular mucosa and an increase in the area of squamous, non-glandular epithelium; reduction in the relative length of the small intestine; increase in the relative size and complexity of the caecum and proximal colon; and development of a colonic separation mechanism that results in selective retention in the caecum of fluid and small particulate digesta (including bacteria) and in facilitated passage through the colon of large intractable food particles (insect cuticles and plant fibre).

Physiological studies show that rodents can also greatly expand total digestive tract capacity, and rapidly modulate small intestinal hydrolytic activity and nutrient transport capacity in response to peak seasonal energetic demands and changes in food quality. Although functional studies need to be extended across a greater number of
rodent species from a wider range of nutritional niches, it is clear that the great structural diversity in rodent dental and gastrointestinal features is matched by an impressive flexibility in digestive performance. All these features guarantee ecological success and an ability to rapidly utilise new food resources as they become available.

Energetics and thermoregulation of small mammals on the Qinghai–Tibetan plateau

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Energetics and thermoregulation of small alpine herbivores were studied for more than 20 years at a research site located in Qinghai Province, in the northwest of China, about 3200–3500 m above sea level. The climate shows marked temperature differences between day and night but little fluctuation year round. There is a long cold season and a short plant growth period. The species studied were the plateau pika (*Ochotona curzoniae*), Gansu pika (*Ochotona cansus*), plateau zokor (*Myospalax baileyi*) and root vole (*Microtus oeconomus*). The plateau pika and plateau zokor are endemic species, the Gansu pika is distributed in most areas of northwest China, while the root vole has a wide geographical range. The plateau zokor is fossorial, while the others are burrowing species.

1. Basal ecophysiological properties and seasonal variations in metabolism (basal metabolic rate, BMR, resting metabolism, RMR, and average daily metabolic rate, ADMR) were measured.

2. Seasonal variations in non-shivering thermogenesis (NST) capacity were determined and changes in weight, structure, function and chemical composition of brown adipose tissue (BAT) were measured for above-ground active animals. Thermogenic capacities increased during the cold winter.

3. Maximum metabolic rates (MMR) of the plateau pika and root vole were measured and the relationship between MMR and NST, MMR and BMR was analysed.

4. Behavioural thermoregulation of the root vole was investigated. Huddling and nest building are very important for reducing heat loss in root voles.

5. BMR and NST were determined during different reproductive stages.

6. Energetic characteristics during postnatal growth and development were studied in the root vole.

7. Seasonal changes in digestibility and assimilation of natural food were measured, except for the Gansu pika.

8. Cold-induced maximum energy acclimation rate, maximum assimilated energy during peak lactation and the effect of litter size were determined in the root vole.

9. Seasonal variations in digestive tract morphology were observed in four species of small mammals.
10. Effects of photoperiod and temperature on metabolism, NST capacity, MMR, cytochrome oxidase activity of BAT mitochondria, and gut morphology during acclimation were determined.

11. Energy flow through the plateau pika, root vole and plateau zoker populations has been studied. The survival strategies and evolutionary adaptations of alpine small mammals are discussed.

Variations in mitochondrial thermogenesis and expression of an uncoupling protein gene in brown adipose tissue from Mongolian gerbils during cold exposure

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Brown adipose tissue (BAT) is the major site of cold-adaptive thermogenesis in small mammals, and uncoupling protein (UCP) in the inner membrane of BAT mitochondria is the key molecule regulating and limiting thermogenesis. Thus, BAT is very important for small rodents inhabiting the north of China where marked seasonal changes in climate occur. In our study, Mongolian gerbils (Meriones unguiculatus) inhabiting northern China, have been selected and raised in the laboratory. Adult gerbils were used in experiments to investigate thermogenic activity and UCP expression of BAT mitochondria during cold exposure.

In adult Mongolian gerbils observed during from 1 day to 4 weeks of cold exposure, firstly the GTP-binding capacity of BAT mitochondria (i.e. indicating thermogenic activity of BAT) increased gradually, and reached its maximum after three weeks. Secondly, there was only one species of UCP mRNA with a length of about 1.5 kb. The UCP mRNA was significantly upregulated after only 1 day, and reached maximum levels after 1 week, then remained at a relatively high level but tending to slowly decrease. Not until 4 weeks was an obvious decline of UCP mRNA content observed. In addition, the specific activity of T45'-deiodinase in BAT also increased gradually. The results indicated that, even during acute cold exposure, the UCP mRNA had been upregulated. Such rapid upregulation of UCP mRNA may be necessary for BAT to synthesise new UCP and to finally acquire its optimal function of thermogenesis. The activation of T45'-deiodinase may be important for the upregulation of UCP mRNA and the recruitment of BAT. Furthermore, the basal GTP-binding capacity of BAT mitochondria is higher in Mongolian gerbils than in rats kept in the same or similar warm environment temperature, indicating higher basal thermogenic activity of BAT. This would be the physiological basis of the high capacity of non-shivering thermogenesis (NST) in Mongolian gerbils. It may be an adaptive strategy of the Mongolian gerbil to large oscillations in daily temperature in its habitat.
Seasonal changes of non-shivering thermogenesis in small mammals from an inland semi-arid region on the Ordos Plateau, Inner Mongolia

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Environmental temperatures in the Ordos semi-arid area change dramatically between seasons. It is hot in summer (up to 35°C), and cold in winter (the minimum temperature is -25°C). Temperatures are also low in spring and autumn. To survive these fluctuations in environmental temperature, small mammals may utilise non-shivering thermogenesis (NST) to enhance their tolerance of cold. This study aimed to reveal seasonal adaptations of NST in four species of rodents in the Ordos arid region. The species were the northern three-toed jerboa (Dipus sagitta), desert hamster (Phodopus roborovskii), striped hamster (Cricetulus barabensis) and mid-day gerbil (Meriones meridianus).

Injection of a mass-dependent dose of norepinephrine induced NST at 27°C. NST increased significantly in autumn compared with summer values for the four species (P < 0.05). In jerboas (a hibernating species) the maximum NST increased 83%, the regulatory NST (NST-RMR) increased 4 times, and the expected NST (NST%) based on body size (28.9Wb-0.49) changed from 40% in summer to 73% in autumn. The NST max also showed a 29% increase in gerbils in autumn and the regulatory NST rose 82%.

Desert hamsters showed the greatest variation in NST between seasons. The NST max not only increased 52% in autumn from that of summer, but also was 48% above the summer value in spring. The NST% was 113% and 90% in autumn and spring, respectively, and only 66.1% in summer. The regulatory NST was 2.5 and 2.3 fold higher in autumn and spring than in summer.

In the striped hamster the NST also showed an increase in autumn. The NST max was 53% higher than that of summer and the NST% was 118% in autumn. This species had a high NST in summer, the NST% was 87% and the regulatory NST was 12% higher than the spring value.

A high NST capacity would allow individual jerboas greater tolerance of a cold autumn and be advantageous for accumulation of body fat by reducing maintenance energy expenditure before entering torpor. The small sized desert hamster (15 g) had a high NST both in autumn and spring to tolerate cold temperatures possibly because its micro-habitat is in broad semi-mobile sand dunes where temperatures fluctuate greatly between day and night. The striped hamster, a non-desert species, had a high NST to adapt to the cool habitat, the farmland and the stabilised sand dunes.
Seasonal variation in the digestive tract morphology of four species of rodent in the Ordos semi-arid region, Inner Mongolia

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To understand the strategies used by small mammals for survival in inland arid environments where major changes in temperatures and food resources occur, seasonal variations in the gastrointestinal morphology were studied in four sympatric species of rodents from the Ordos semi-arid region of Inner Mongolia. The animals were the northern three-toed jerboa (*Dipus sagitta*), desert hamster (*Phodopus roborovskii*), striped hamster (*Cricetulus barabensis*) and mid-day gerbil (*Meriones meridianus*). The digestive tracts were measured from snap-trapped specimens.

The results showed that the ratios of wet stomach weight to body mass (SW/BM) in jerboas were 14% and 25% larger in spring and summer than that of autumn, respectively (P < 0.05). Similarly the SW/BM were 29% and 47% larger in summer than in autumn in desert hamsters and striped hamsters, respectively (P < 0.05). The dry stomach weights (DSW/BM) showed no seasonal changes in jerboas and desert hamsters, but were 41% heavier in summer than in autumn in striped hamsters (P < 0.05). The SW/BM and DSW/BM in gerbils did not change with seasons. The ratio of small intestine length to body length (SIL/BL) showed no seasonal changes in the four species. In jerboas, the wet and dry weight of the small intestine (SIW/BM and DSIW/BM) increased 55% and 74% in autumn compared with summer values (P < 0.05). In desert hamsters, the SIW/BM also showed the same trend and was 70% heavier in autumn than that in summer. No significant differences were detected in SIW/BM and DSIW/BM in striped hamsters and gerbils between seasons. The ratios of caecum length to body length (CL/BL) were 48% and 64% bigger in spring and summer than that in autumn, respectively, in jerboas (P < 0.05). The wet caecum weight did not change with seasons, but the dry caecum weight increased 127% in autumn in comparison with summer values (P < 0.05). The CL/BL, CW/BM and DCW/BM showed no statistical differences in desert hamsters between seasons. The CL/BL in striped hamsters was 34% and 21% larger in spring and summer, respectively, than that in autumn (P < 0.05), but the CW/BM and DCW/BM did not change between seasons. These three indices of the caecum were not different between seasons in gerbils. There were no seasonal variations in the large intestine for the four species.

These results indicated that the stomach and caecum volume tended to be larger with the additional dietary fibre content in spring and summer.
Energy metabolism and thermoregulation in the desert hamster (Phodopus roborovskii) in the Ordos semi-arid region, Inner Mongolia

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The desert hamster (Phodopus roborovskii), a small, granivorous rodent (body weight = 15.4 g), was used to study regulation of energy metabolism and body temperature in an inland arid environment. This experiment was conducted in summer (July) 1997 in the Kubuqi semi-desert area of the Ordos plateau. The average air temperature in the shade was 25.3°C, the maximum was 30.6°C, and the minimum was 24.7°C.

Normal body temperature (Tb) was 36.2°C ± 0.85°C. At ambient temperatures (Ta) of 15–30°C, the Tb gradually decreased to its lowest of 36.5°C ± 0.86°C at the Ta of 30°C. The equation is Tb = 38.49 - 0.074Ta. Above 30°C, Tb increased and reached 40.2°C at Ta = 36°C. The resting metabolic rate (RMR) showed a linear relationship with Ta between 14–28°C and can be described by the equation, RMR = 9.73 - 0.228Ta. The thermoneutral zone (TNZ) was 28–35°C and the minimum metabolism (Mm) was 2.98±0.65 mL O₂/g.h, which is 164% of the predicted value based on body mass (3.8Wb-0.27). Below 25°C, thermal conductance was 0.321 ± 0.09 mL O₂/g.h and this changed with Ta in an exponential way. The highest thermal conductance was 2.0 mL O₂/g.h at 36°C.

The high Mm in desert hamsters is different from the general view that desert rodents have a low metabolism to adapt to the heat and shortage of food and water resources in an arid environment. This divergence may be due to stable periods of perennial plant growth and abundant food. Further, a high metabolism is advantageous to animals intolerant of low burrow and environmental temperatures (burrow temperature was 24.3°C at a depth of 58 cm in summer). Increasing metabolism may decrease the lower critical limit of the TNZ and reduce the maintenance energy expenditure. Feeding time and frequency were reduced and this decreased the threat from predators. Below temperatures of 30°C, metabolism decreased, thermal conductance increased and then body temperature decreased gradually. At 30°C, the lowest metabolic rate and body temperature were attained. Between 30 and 35°C, thermal conductance and body temperature increased, whereas the metabolic rate was stable within TNZ. This suggests that the adaptive strategy of desert hamsters in summer, at high ambient temperatures was to increase heat loss to reduce metabolic heat production and enhance heat tolerance. This small, slow-moving rodent has become well adapted to survival in the broad sand-dune microhabitat.
Metabolism and thermoregulation in the Mongolian gerbil, *Meriones unguiculatus*

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The Mongolian gerbil, *Meriones unguiculatus*, is a small cricetid rodent native to the desert and semi-arid regions of Mongolia and northern China. Although there have been extensive studies on thermoregulation of this species, most of the studies were performed on laboratory-raised animals. Marked differences may exist in the eco-physiological characteristics between field and laboratory populations. Therefore, in this experiment we used field-trapped *M. unguiculatus*. Animals were live-trapped in Xilinhot grassland, Inner Mongolia, China, in April 1998. The research site has a broad temperature range between day and night. The rates of oxygen consumption were measured using the Kalabukhov-Skovortsov closed circuit respirometer at a temperature range from 0°C to 40°C. This is the first measurement of metabolic rates over such a wide range of ambient temperatures for live-trapped gerbils.

The lowest mean metabolic rate (BMR) was 2.127 ± 0.140 mL O₂/g.h, which is 173% and 163% of two earlier published estimates, based on body mass. The thermal neutral zone (TNZ) was 26°C to 38°C. Mean body temperature was 37.3 ± 0.5°C. Thermal conductance below the TNZ was 0.169 ± 0.037 mL O₂/g.h, which is 137% and 133% of that predicted by two earlier studies, based on body mass.

Generally, the typical characteristics for desert small mammals are (1) a relatively low BMR, (2) a steep thermoregulatory curve, (3) a narrow thermoneutral zone, and (4) a poor tolerance for high ambient temperature. Our results suggest that the energy characteristics of Mongolian gerbils are very different from those found in arid adapted small mammals.

Metabolism and thermoregulation in root voles (*Microtus oeconomus*) on the Qinghai–Tibetan plateau

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Ecophysiological properties, such as the level of energy metabolism, will constrain animal distribution and abundance as well as many other aspects of their ecology. Many studies have been concerned with the ecophysiology of microtine rodent species and have shown that high metabolic rates are a significant characteristic of these animals. However, there is no available information for the species that live at high altitudes. Root voles live in the *Potentilla fruticosa* shrub of alpine meadows on the Qinghai–Tibet Plateau. They are a herbivorous, burrowing, winter-active mammal, and face the double environmental stresses of cold and hypoxia. Therefore we postulated that this species should show even higher metabolic levels than other
similar microtine species. Metabolic rates, thermal conductance, and the role of evaporative water loss in thermoregulation were measured in this study.

Animals were live-trapped in the alpine meadow ecosystem, Qinghai Province (37°29′-37°45′N, 101°12′-101°33′E), at an altitude of 3200 m above sea level. The metabolic rates were measured using open-flow respirometry with a Beckman OM-14 oxygen analyser over the temperature range 15–37.5°C. The minimum thermal conductance was $0.30 \pm 0.03$ mL O$_2$/g/h°C, 46% and 52% higher than the values predicted from the allometric equations of two earlier research groups. The width of the thermal neutral zone (TNZ) was 28°C–32.5°C. The minimum resting metabolic rate was 3.29 mL O$_2$/g/h, 213% and 189% of the values predicted by two earlier studies. Evaporative water loss (EWL) was relatively stable below the TNZ, with an average value of 5.48 mg H$_2$O/g/h. Within and above the TNZ, EWL increased with $T_a$, and reached a peak of 13.80 mg H$_2$O/g/h at 35°C. The contribution of EWL to total thermal conductance was 16% below the TNZ, 28% within the TNZ, 27% above the TNZ, and peaked at 32.5°C at 38%.

These characteristics may have been of adaptive significance for the root vole allowing it to cope with extreme environments where there are large day–night temperature differences, even though average daily temperatures fluctuate little year round. They also suggest that low temperatures may have been a major selective force during the evolution of the root vole on the Qinghai–Tibet Plateau.

**Maximum metabolic rate of root vole and plateau pika from the Qinghai–Tibet plateau**

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This paper reports studies of seasonal changes in cold-induced maximum metabolic rate (MMR), and its relationships with non-shivering thermogenesis (NST) and basal metabolic rate (BMR) in plateau pikas and root voles.

Plateau pika (*Ochotona curzoniae*, Lagomorpha: Ochotonidae) and root vole (*Microtus oeconomus*, Rodentia: Microtinae) inhabit alpine meadows in Qinghai–Tibetan Plateau. The former is endemic to the area, and the latter has a very wide geographical range in the northern part of Euro–Asiatic continent (Wang and Wang, 1996). Both of the animals are typical small herbivorous mammals.

Winter-acclimatised individuals achieved greater MMR and NST than summer ones, while BMR decreased from summer to winter in plateau pikas and root voles. These results for MMR are reported for the first time. The results of NST and BMR are consistent with results reported previously. The ranges of all metabolic rates are greater in root voles than in plateau pikas. The MMR is 105–111% of expected values in plateau pikas and 137–170% in root voles. Both changes are less than that found in related species from other areas.
There are no seasonal changes in non-shivering thermogenesis (NST) of plateau pika and vole, and this is similar to animals from other regions. NST is very important in MMR, and the increase of MMR in winter results from the increase in NST. The factorial aerobic scope (MMR/BMR) and aerobic reserve (MMR–BMR) in both of the animals are greater in winter than in summer. MMR and BMR for individuals within plateau pika populations in summer and winter were not correlated. However MMR and BMR for root vole were correlated for both winter and summer (P < 0.05).

The results provide limited support for the ‘aerobic capacity model’ for the evolution of endothermy. There is intra-specific variation in MMR and BMR of the two animals. From the metabolic characteristics of small mammals inhabiting the Qinghai-Tibetan Plateau, two life history evolutionary strategies for individuals of these species are proposed as ‘increasing MMR’ strategy (i-strategy) and ‘decreasing BMR’ strategy (d-strategy). Individuals with the first strategy have higher MMR, and can survive in much colder environments. Both animals do not store food like related species from Inner Mongolia. Individuals with the d-strategy have lower BMR, and will consume less energy. When the snow is accumulated for several days, which may happen every few years, these individuals will be at an advantage. The i-strategy and d-strategy are the two extremes of evolutionary strategies, which are on a continuum.

Trade-off between reproduction and litter size in root voles

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In this paper, the relationship between energy cost and reproduction of different litter sizes in root voles was studied, and the trade-off between them is discussed.

Total cost (TC), lactation cost (LC) and cost per offspring (OC) are affected significantly (P < 0.01) by litter size. TC and LC increased with litter size, and OC decreased with litter size. Total digestion (TD) and total assimilation (TA) increased with litter size (P<0.01), but the total digestibility rate (TDR) and total assimilation rate (TAR) generally remained unchanged. Litter mass at birth and weaning increased with litter size (P < 0.01), but mass per offspring at birth remained unchanged and the mass at weaning decreased with litter size.

Offspring production (OP) and offspring production efficiency (OPE) increased with litter size, and production per offspring (POP) and relative energy growth rate of offspring (REGR) decreased with litter size. If the best maternal strategy is to maximise reproduction with the lowest cost, the optimum litter size is the one with largest offspring production per unit cost of offspring. The optimum litter size in root voles inhabiting Qinghai–Tibetan Plateau is five or six.
Effect of photoperiod and temperature on metabolic rates in plateau pikas and root voles

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Seasonal variations exist in maximum metabolic rates (MMR), non-shivering thermogenesis (NST) and basal metabolic rates (BMR) of root voles and plateau pika. Two important physiological factors, temperature and photoperiod, were examined. Root voles and plateau pikas were raised under different environments (temperature: 23°C and 5°C; photoperiod: 16L:8D and 8L:16D hours) with food and water ad libitum.

The effect of photoperiod on metabolic rates. In plateau pikas acclimatised to long or short photoperiods, maximum metabolic rates (MMR), non-shivering thermogenesis (NST) and basal metabolic rates (BMR) remained unchanged. However, in root voles acclimatised to a short photoperiod, MMR, NST and BMR increased significantly (P < 0.01) from those acclimatised to long photoperiod.

The effect of ambient temperature on metabolic rates. In plateau pikas and root voles acclimatised to low ambient temperature (5°C), maximum metabolic rates (MMR), non-shivering thermogenesis (NST) and basal metabolic rates (BMR) increased significantly (P < 0.001) compared to those acclimatised to warm ambient temperature (23°C).

These results suggest that cold temperature, not short photoperiod, is essential to stimulate the changes in metabolic rates of plateau pikas, but photoperiod and ambient temperature interact to trigger changes in metabolic rates of root voles. The results of root voles support an earlier hypothesis concerning *Peromyscus maniculatus*.

The MMR, NST and BMR of plateau pikas and root voles changed consistently in all acclimatised individuals and between different acclimatised groups. MMR correlated with NST and BMR (P < 0.05). The correlation between MMR and BMR support the 'aerobic capacity model' for evolution of endothermy, and this suggest that food plays an important role in the MMR and BMR of animals.
Symposium C

Control Techniques (Biological Control, Habitat Management, Ecologically Based Management, etc.)

PLENARY LECTURE

Rodent pest management in Southeast Asia—an ecological approach

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In Southeast Asia, rodents, insects and weeds are thought to cause similar levels of preharvest losses to rice crops. However, the research effort and basic ecological knowledge on rodent pests lags far behind those of insect pests and weeds. As an indication of their impact, rodents are the greatest agricultural problem in Indonesia, causing annual losses to rice production of 17%. If we could reduce these losses by half, then there would be enough rice to feed an extra 17.6 million people for a year—providing 70% of their energy requirements.

The Australian Centre for International Agricultural Research (ACIAR) is currently funding two projects on the management of rodent pests in rice fields of Southeast Asia. One study is located in West Java, Indonesia (began 1995), the other in the Mekong and Red River deltas of Vietnam (began August 1996). The main objectives are to understand processes leading to increases in rat populations in rice fields, examine how rats use the landscape in these rice ecosystems, and assess the efficacy of using traditional and new methods of rat control. The outputs of the ecologically-based studies are comparable because standard field techniques are being used across these markedly different rice agro-ecosystems.

Currently, chemical control is the primary driver of ‘Integrated Pest Management’ (IPM) for rodents. This generally provides effective control in the short term, regardless of the rodent species. However, Asian governments are concerned about the affordability and misuse of chemicals, especially when they are striving to provide ‘clean and green’ food products for their domestic and export markets. The challenge is to build on past efforts of rodent IPM through a better understanding of the ecology of the pest species. This will enable adoption of management actions which are more environmentally sound, sustainable (environmentally and culturally), and likely to be integrated with current IPM programs that are in place for insects, weeds and plant diseases in particular agricultural systems.

This paper will present case studies of current and proposed research to highlight progress and challenges for ecologically-based pest management. One emerging and promising method of control is a trap-barrier system (TBS) for protecting rice crops.
The TBS consists of a rectangular fence with multiple-capture traps inserted at intervals near its base, plus a crop within the fence to attract rats. This crop is 3 weeks more advanced than the surrounding rice crops. It works on the principle that rats enter the water at the edge of the flood-irrigated crop, but cannot gain access to the more advanced crop except by entering a trap. Results will be presented from replicated, control studies that assessed the benefit–cost and optimal size of a TBS.

The TBS plus ‘trap-crop’ is one of a range of management actions that have been proposed for implementation of EBPM of rodents in Indonesia and Vietnam. These studies will be conducted at the village level and are planned to begin in 1999.

**ORAL PRESENTATIONS**

**Development of fertility control through viral or oral delivery of immunocontraceptive agents: relevance for rodent management**

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Management of wildlife pest populations currently relies on methods which increase mortality (e.g. poisoning, disease, trapping, hunting). Fertility control through immunocontraception has been proposed as an additional method which could reduce population size over time. Potentially it could target populations on a large scale, be more humane, and be cost-effective. Such an immunocontraceptive agent could be delivered using either a genetically modified virus or bacterium as the vector, or be delivered in a bait.

We have tested the concept that viral-vectored immunocontraception (VVIC) can be achieved. A laboratory-restricted mousepox virus (ectromelia virus), has been engineered to express an oocyte-specific antigen, the mouse zona pellucida 3 (ZP3) glycoprotein. Female mice (BALB/c strain) infected with the recombinant ectromelia virus produced antibodies against ZP3 and were infertile for 5–9 months. In about half of the animals, infertility was associated with disruption of early follicular development in the ovary, but with no evidence of inflammation (oophoritis) in ovarian tissue. For the remaining animals, antibodies coating mature oocytes could have prevented fertilisation by inhibiting sperm binding to ovulated eggs or penetration of sperm through the zona. Mice became fertile as ZP3 antibody levels in the serum decreased. Reinfection of the mice with the recombinant virus boosted the anti-ZP3 response and also restored infertility.

Recently, we have also achieved similar results using another mouse-specific virus, mouse cytomegalovirus (MCMV), which occurs naturally in the Australian environment. Currently this virus is considered to be the best candidate for eventual field use of VVIC. MCMV has also been engineered to carry the mouse ZP3 gene. Female BALB/c mice infected with recombinant MCMV-ZP3 (MCMV-ZP3) have remained
infertile for at least 170 days and have high serum levels of anti-ZP3 antibodies. The immunocontraceptive effect has been also demonstrated in A/J mice and a partial effect seen in the outbred ARC/s strain and C57BL/6 mice. In addition, mice infected with parental virus become infertile when subsequently infected with the MCMV-ZP3. This suggests that pre-existing immunity to MCMV does not preclude reinfec­tion with MCMV-ZP3 and this is able to result in subsequent immunocontraception in BALB/c mice. The mechanisms of MCMV-ZP3 induced immunocontraception are currently being investigated.

We are also developing bait-delivered vaccines for foxes in Australia and this approach may be suitable for strategic management of rodent populations.

**Viral-vectored immuno-contraception as a potential control strategy for house mice in Australia**

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The house mouse (*Mus domesticus*) is a significant problem in the grain-growing regions of eastern and southern Australia because of its ability to rapidly increase to densities of around 1000 mice per hectare. These mouse ‘plagues’ cause economic and social hardship in rural communities, ultimately resulting in impacts which are felt nationally. Current methods for managing mice in Australia include the use of poisons and modifications to farming practices. However, on their own, these management strategies are often not sufficient to halt increases in mouse numbers. Furthermore, some of these techniques have potential impacts on the environment that preclude them from being used as long-term control strategies.

An alternative and more appropriate approach is to reduce the reproductive potential of mice. House mice are prolific breeders, with one pair theoretically capable of producing 500 mice in 21 weeks. One way of achieving a reduction in fertility, is by using a method called viral-vectored immunocontraception (VVIC). This approach relies on inducing an immune response in the pest animal against species-specific reproductive proteins, thus blocking fertilisation. The sterilising protein is delivered using a species-specific virus which would disseminate through a wild population causing infertility in infected mice.

Experiments simulating the effect of immunocontraception on mouse populations indicate that a level of 67% sterility amongst females is sufficient to significantly reduce population size. These simulations were achieved by surgically sterilising females in mouse populations housed in near-natural outdoor enclosures. Results suggest that it is important to maintain this sterility level over more than two generations. It would be easier to maintain or pass on sterility to each generation using a disseminating system such as VVIC, rather than by using repeated baiting with a non-disseminating immunocontraceptive bait.
The ability to predict the likely behaviour of a sterilising virus in field populations relies on an understanding of the epidemiology of the vector virus in wild mice. The virus that we propose to use is murine cytomegalovirus or MCMV. This herpes-type virus is mouse-specific and is already present in wild house mice in Australia. It is spread by close contact and produces a persistent, non-lethal infection. Multiple infections with more than one strain of the virus are known to occur in a single mouse. Therefore, MCMV is an ideal candidate for a viral vector. However, there is still much to learn about this virus in wild mouse populations and this is the focus of new research. The key population-scale questions to be addressed are:

1. What is the transmission rate of wild and recombinant strains (including a sterilising strain) of MCMV in wild mouse populations? What population parameters influence transmission rate?

2. Can a recombinant strain of MCMV establish and generate an immune response in a mouse population which has already been infected with wild-type MCMV? Is the order of infection important?

We will also obtain some information on the dynamics of MCMV infection in wild mice, the importance of sexual transmission, the likely persistence and infectiveness of MCMV in the environment and the threshold population size required to maintain MCMV infection.

**Urban rodent control programs for the 21st century**

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Urban rodent control in the U.S. historically has been implemented in a limited or disjointed fashion rather than comprehensively, and programs commonly have been reactive rather than proactive. Reasons for this have included limited funding, training, and political and technical support. As urban infrastructure ages and congestion increases, the need for effective rodent control programs will become even more important for both public health and economic reasons. Additionally, expectations of urban residents and businesses for quality-of-life improvements will continue to grow.

Urban rodent control for the 21st century must focus on a program approach that is both strategic and comprehensive. This must include effective long-term planning, scheduling, data management, and mapping capabilities. It also must focus on greater partnership among municipal agencies, private pest control companies, and community groups. Central to program success will be coordination, communication, and accountability among all program participants. Cost-effectiveness will be achievable, but predicated on effective administrative management and training. Greater focus on infrastructure maintenance and construction will be essential for long-term removal of factors that enhance pest problems.
A comprehensive program in Boston, Massachusetts over the past 10 years has demonstrated many elements needed as part of future urban rodent control programs. This has included pest control companies with well-defined contract specifications, city agencies with well-coordinated roles, involvement of residents and businesses, and program managers with technical and administrative training. Through an intensive initial effort, followed by a maintenance program, Norway rat (Rattus norvegicus) populations in both surface and subsurface (utility) environments were dramatically reduced and consistently managed.

Key program elements in Boston included neighbourhood organising and education, improved regulatory enforcement of sanitation codes, improved refuse containment, strategic use of rodenticide, an effective sewer baiting program using brodifacoum, alteration of urban landscaping, infrastructure repairs, use of monitoring tools such as census bait, and review of future infrastructure designs to incorporate rodent control principles. A team approach was the program’s foundation, ensuring that all aspects of rodent control were centrally coordinated, and that problem resolution was comprehensive and efficient.

**Integrated management of the rice field rat (Rattus argentiventer) in West Java**

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This paper discusses the concept of integrated pest management (IPM) and considers the progress that has been made towards effective implementation of IPM for rodent pests in agricultural systems in Jatisari, West Java.

Integrated management of the rice field rat was conducted during planting time in 1990–1991 at the Jatisari Forecasting Center in West Java, on a 40 ha area of local farmland including the Jatisari experimental field. Habitat management in the form of synchronous planting of rice and elimination of rat refuges was conducted initially. Fumigation, chemical control by rodenticide, and a combination of plastic fences and multi-capture traps (hereafter referred to as PMT) were subsequently used to control rats. The total number of rats killed by these methods reached 3981 (3546 rats by PMT, 31 by single-capture traps, 94 by fumigation and 310 by chemical control/rodenticide). Rat damage in the field was reduced by over 99% (down to 0.2% damage).

Effective methods for controlling the rice field rat population before planting time were to synchronise planting, eliminate refuges for rats and to burn straw after harvesting. During the planting season PMT was used in the seedbed and the trapping crop area (an area planted one month earlier) to control the rice field rat population. PMT was also used for preventing the immigration of rats from surrounding areas during the generative stage of rice growth.
Effective methods for controlling rat populations during land preparation, ripening stage and after harvest were to fumigate and dig out burrow systems of rats on the dikes. The efficacy of fumigation and digging burrows is about 60% during peak population density. The application of rodenticide was effective from tillering to the end of maximum tillering under certain conditions.

Overall, PMT was found to be the most effective method for controlling the rice field rat population in paddy fields.

**Population ecology of the rice field rat, *Rattus argentiventer*: implications for management**

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The rice field rat, *Rattus argentiventer*, is one of the most important preharvest pests of rice crops in Southeast Asia, accounting for an annual loss of 17% in Indonesia. We recently conducted a capture–mark–recapture study to identify important factors limiting populations of this rodent. This knowledge will be used as a basis for designing management strategies for the pest.

The study site was located in irrigated lowland rice fields in Sukamandi, West Java, Indonesia. Two rice crops were grown each year: the wet season crop from mid-October to February; a short fallow in March; the dry season crop from April to July; and a long fallow from August to early October. The main crop growth stages are tillering (55 days), reproductive (35) and ripening (30).

Trapping was conducted using eight trap lines once every three weeks from April 1996 to April 1998. At each trap line, eight multiple-capture cage traps were set 20 m apart along a drift fence for three consecutive nights. Captured animals were individually identified, sexed, weighed, breeding condition assessed, and body dimensions measured, before being released at the point of capture. Newly-captured animals were marked by a uniquely numbered ear-tag. Crop stage and other factors were recorded at each census.

A total of 3660 rats over 8688 trap-nights was captured. Recapture rates within and between censuses were low. The number of rats captured per trap line was used as a measure of population abundance.

Mean abundance was significantly lower in the middle of paddies than in paddy margins at most crop stages, indicating that populations are limited by the availability of nest sites. Rats only nested in burrows in levee banks when rice fields were flooded. Mean abundance and body condition of rats were lowest at the mid-tillering stage after a 3-month fallow in the dry season. These declines are possibly due to the reduced food supply during the fallow.
Based on the dates when pregnancies and new born litters were detected, we deduced that mating begins as early as the late tillering stage allowing up to three litters per female over the nutritious ripening stage of crops. Mean population abundance was increased through the subsequent influx of juveniles and sub-adults during the late ripening and early fallow stages. This coincidence indicates that reproduction and population growth may be limited by high-quality food supply.

We recommend the following management strategies for critical trials: (1) minimise the number/size of levee banks and maintain/retain the long fallow to limit populations; (2) synchronise crops to minimise breeding period; and (3) time application of mortality control at the mid-tillering stage when populations are low and least capable of compensation.

Current trends in rodent damage management for Hawaiian agriculture and conservation

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Introduced rodents have caused, and continue to cause, substantial economic and ecological damage to the Hawaiian Islands. Due to the impact of these species, significant effort is being expended to understand their biology and control. Four species of commensal rodents are currently found in urban, agricultural, and natural habitats in the islands. These species are the roof rat (Rattus rattus), the Polynesian rat (Rattus exulans), the Norway rat (Rattus norvegicus), and the house mouse (Mus musculus).

In Hawaii, interest in rodent control in Hawaii historically was associated with human health issues (bubonic plague) and the need to reduce crop losses to rats in sugarcane. In recent years substantial research efforts have been devoted to development of techniques to manage rodent damage in macadamia (Macadamia integrifolia) orchards and in conservation situations. As land-use patterns change in Hawaii other problems with rodent depredations, for example in agroforestry, may emerge.

Roof rats (Rattus rattus) damage an estimated 5 to 10% of the developing nut crop in Hawaiian macadamia orchards. Aspects of roof rat biology in macadamia orchards are studied with the ultimate goal of developing an ecologically sound and cost-effective integrated pest management plan. I will present data which suggest that: 1) roof rats are the primary rodent pest species of concern for macadamia producers; 2) broadcast baiting of rodenticides on the ground in macadamia orchards without interior vegetation is ineffective for roof rat control; and 3) macadamia trees can compensate for rodent damage early in the crop cycle. Efforts are being made to obtain a state registration for anticoagulant rodenticide use in bait boxes in macadamia trees.
Rodent control is considered a high priority for many species and ecosystem restoration plans in Hawaii. Broadcast rodenticides have been used successfully to control introduced rodents for species conservation in New Zealand and could potentially be used in Hawaii. This apparent success caused biologists in Hawaii to seek regulatory approval for the use of similar techniques in this State. In 1995, a State registration for the use of 0.005% diphacinone bait blocks in bait stations to reduce rat depredation in native Hawaiian ecosystems gained approval. At present, wildlife management agencies in Hawaii are gathering the appropriate information for similar registrations for the aerial broadcast of rodenticides in Hawaiian conservation areas.

Rodent management in Vietnam

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Rodent pests are an increasing problem in agro-ecosystems in Vietnam. However, little is known about which rodent species are responsible for losses in crop production, let alone how best to manage their impact. This paper will report on a 2-year ecological study of the rice field rat, Rattus argentiventer, in the Mekong River Delta of Vietnam. Rats were live-trapped (capture-mark-release) in a range of representative habitats based in and around the rice growing region of Tra Vinh Province. Traps were set in rice crops (two or three rice crops per year), main channel banks, vegetable plots, banana and coconut plantations, melaleuca forest and undisturbed grassland. Supplementary kill-trapping was conducted to determine the breeding status (per cent adult females breeding, litter size and development) of the rats and to confirm their taxonomy.

In the Tra Vinh rice ecosystems, the dominant rodent species were R. argentiventer (60%) and the lesser rice field rat, R. losea (15%). Eleven other species made up 25% of the population—each was considered a minor component of the population and unlikely to cause significant damage to preharvest rice. We report on the breeding patterns of the two main rodent species during the wet and dry seasons, and the relative dynamics of rodent populations in the different habitats during these seasons.

Our focus on the ecology of the key rodent pest species has helped to define a range of potential management practices that should be environmentally sustainable, economically feasible and socially acceptable. The challenge ahead is whether these actions will be readily adopted at the village and/or district level. Concurrent implementation of management activities is an essential requirement for mobile species such as rodents, which can readily reinvade small areas following a reduction in rodent densities.
Preliminary study assessing integrated rodent management strategies for soybean crops in Thailand

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In the most regions of Thailand, soybean crops grown in the dry season (January–April) experience rodent damage. Most farmers address these problems by using large quantities of pesticides, which can also have major impacts on non-target species. Farmers use bow traps to reduce their use of rodenticides but the effectiveness of these traps as part of an integrated rodent control is untested.

The objective of this study was to assess proposed integrated strategies for control of rodents by testing the effectiveness of a combination of the use of bow traps and the acute rodenticide, zinc phosphide. The experiment was conducted in 10 study plots of soybean grown at the end of December 1997 and harvested in April 1998. Each plot (about 0.6 ha) was located in Nhong Wua So district, Udon Thani province, about 550 km northeast of Bangkok.

Five experimental treatments were undertaken, each replicated twice. These were: (1) bow traps alone; (2) 1% zinc phosphide bait alone; (3) bow traps and 1% zinc phosphide bait; (4) normal farmer practices of rodent control; and (5) no rodent control. During one crop season, each treatment was applied at three different crop stages: soil preparation before planting; flowering (= 40–50 days after sowing); and young pod stage (70–80 days after sowing). Before each period of treatment, the populations of rodents were measured using a footprint index and bait consumption.

Counts from the footprint index and the number of rodent carcasses in the bow traps showed that the most abundant species throughout the crop season were the fawn-colored mouse (Mus cervicolor), the Ryukyu mouse (Mus caroli) and the lesser rice field rat (Rattus losea). The great bandicoot (Bandicota indica) was observed (footprint index) to be more abundant during the flowering stage through to harvest.

The weight of seed damaged by rodents in three of the treatments (bow trap alone, zinc phosphide alone or the combined treatment) were at a similar level (91.6–134.1 kg/ha) but were quite different from farmers’ plots (197.5 kg/ha) and the no-rodent-control plots (730.6 kg/ha). Results were analysed using analysis of variance and Duncan’s New Multiple Range Test.

It is concluded that bow traps could be a suitable alternative method for controlling rodents in soybean fields where M. cervicolor, M. caroli and R. losea are abundant. This could reduce rodenticide use for rodent management in soybean crops in the dry season.
Rodent management in Qinghai–Tibet alpine meadow ecosystem

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In Qinghai–Tibet Plateau there are about 1.5 billion ha natural grasslands which are widely distributed in the east of the plateau and on high mountain ranges. Alpine meadow, which covers 49% of the total grasslands area (16 million ha) in Qinghai Province, is an important area for animal production, but is seriously damaged by rodent pests. The dominant pest species are the plateau pika (*Ochotona curzoniae*) and plateau zokor (*Myospalax baileyi*). Their foraging and burrowing activities increase degeneration of the grasslands and secondary bare areas are formed. Many scientists are studying rodent biology and ecology to develop better management of rodents in the alpine meadow ecosystem.

With increasing population densities of both species from spring to autumn, damage to the grassland is aggravated and there is a significant decline in the yield and coverage of good foraging grass. A significant correlation has been found between rodent numbers and the damage to vegetation and so an economic threshold for controlling rodents can be established according to the degree of overgrazing and degeneration. Currently, a vicious circle occurs in the grasslands with overgrazing leading to degeneration, then increased rodent numbers leading to further degeneration. However, if the densities of the pest rodents can be constrained and the ratio of excellent forage grass increased so that the density, coverage and height of vegetation increases, then this is effective for controlling plateau pika.

Since the 1960s, many rodenticides have been used in Qinghai Province. From their intensive studies on ecology, behavioural ecology and behaviour of the rodents, Institute scientists have developed a simulated burrowing poisoning machine that takes advantage of the invading behaviour of zokor. A major response was achieved after a single poisoning with the number of the pika and zokor reduced to less than an economic damaging level. Integrated control was demonstrated on 800 ha of secondary bare area using a series of treatments including chemical control with the machine, seeding, fencing, grazing and weed control. Within 3 years the vegetation recovered and productivity increased with 2000 t of dried forage grasses produced in the treated area.

Ecological management of Brandt’s vole in Inner Mongolian grassland, China

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Brandt’s vole (*Microtus brandti*) is a pest in the grasslands of Inner Mongolia where it populations accelerate degeneration of these grasslands. Control of this pest through ecological management is an urgent problem.
Brandt’s vole avoids habitat where vegetation is higher than 16 cm. Most of its food is from dicotyledons which are also stored as a main food source for winter. May is an important month for grass growth. The custom in this region is to fence alternative areas in late May for autumn harvest or winter grazing.

We sowed *Aneurolepidium chinense* seeds in spring to increase the proportion of monocotyledons in plant communities and to decrease the preferred food of Brandt’s vole. Degenerated grass areas were fenced in early May, two weeks earlier than the custom in the region. This resulted in a high cover of vegetation, and increased the proportions of monocotyledons in the plant community. These conditions reduced social and living conditions for Brandt’s vole.

Through these ecological measures we achieved high quality grass for livestock and controlled Brandt’s vole density at low levels for an extended time. To avoid pollution in the environment no chemicals were used.

**Ecological management of voles (Microtus brandti) and pikas (Ochotona daurica) in Inner Mongolian grasslands**

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Changes in the communities of rodents correlates with degeneration of grassland. The pika occurs when there is slight degeneration of grassland, while vole outbreaks occur during intermediate degeneration of grassland. By fencing in early May to protect the vegetation from grazing, the improved vegetation suppressed the density of voles, but increased the pika population.

Observations indicated that pikas harvest plants for winter food in autumn, and press the plants into store-piles beside the holes. This storing activity begins in the middle of autumn and continues until the first snow falls. The study showed that pikas would not store food after the first snow falls even though the food stored was insufficient for the length of the winter. The main components of the food and store-piles were dicotyledons. The storing activity therefore strongly influences the survival of the pikas.

Fencing degenerated areas of grassland from early May, sowing *Aneurolepidium chinense* and *Agropyron cristatum* seeds in spring, and harvesting grassland before the beginning of pika storing activities, eliminated the store-piles beside the pika holes just before the first snow falls. After these treatments, we increased the harvesting of the grass and, by increasing the proportion of monocotyledons in the plant communities, decreased the capacity of pika and vole populations to increase simultaneously. Both populations were controlled over a long period. This management regime achieved both the suppression of the populations of the two rodent pests and improved the grass harvest for livestock. This result showed high economical efficiency without any contamination with rodenticides.
Ecologically based rodent management in Africa: no quick solutions for urgent problems

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Rodent management in Africa is generally organised ad hoc for control of acute problems. Nearly always, the approach is based on rodenticides, with the choice of poisons being dictated by availability rather than efficacy. Alternative strategies are used locally on a trial and error basis but the biological basis for these approaches is usually rather poor and controlled experimental designs are not commonly applied.

In this paper, I present several possible field rodent management strategies and discuss how well their application is supported by the available ecological information. For most examples, I will use data that were collected in a population of Mastomys natalensis in Tanzania. The use of population models as a formalised way of using the available knowledge will be illustrated.

The focus is on:
- symptomatic lethal control
- periphery baiting with rodenticides
- prophylactic lethal control (avoiding damage to crops)
- preventive lethal control (avoiding build-up of rodent populations)
- environmental control by weeding, burning etc.
- trap crops, social fences
- biological control with predators
- contraception.

Unfortunately, the available ecological information does not allow for much optimism with most of these approaches. In order to test new strategies, specifically designed experiments are proposed. However, each of these will require considerable amounts of field work and solutions are not to be expected very soon.

Chronobiology applied to rodent pest management—the case of semi-arid agriculture in sub-Saharan West Africa

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Chronobiology studies the mechanisms which allow species to react and adapt to the variations of their environment. In mammals, daily and seasonal variations of certain environmental factors called synchronisers (e.g. day–night alternation, photoperiod, temperature, relative humidity, food resources, chemical signals, pheromones and rodents density), are perceived by certain structures of the brain (e.g. suprachiasmatic
nucleus and pineal gland). Thus informed on the progress of days and seasons, the brain is then able to integrate environmental factors with:

- day-night alternation, to influence a great number of daily behaviours (locomotor, food, exploratory, etc.);
- seasons, to influence a great number of seasonal physiological functions (reproduction, mobility, metabolism, etc.).

I present our methodological approach, which comprises three stages (correlative study, causal study and modelling), and some cases studied in Burkina Faso and Mali (on *Arvicanthis niloticus* in stable wet habitats or in flooding habitat; *Taterillus gracilis* in semi-arid habitats and *Gerbillus nigeriae* in arid habitats). These results show that daily behavioural rhythms and seasonal vital functions are specific and allow species to anticipate (at the behavioural and physiological levels) the arrival of daily and/or seasonal ‘favourable’ and ‘unfavourable’ periods. Knowing these daily and seasonal rhythms/cycles is very useful for rodent pest control, because it determines, for example, if periods are favourable or unfavourable for use of anticoagulants, which in turn influences the risk of developing resistance. Knowledge of the mechanisms which determine daily rhythms and seasonal cycles is also essential for identifying the climatic and/or trophic situations which perturb the internal mechanisms of regulation of rodent populations such as reproduction and mobility. These can lead to demographic collapse or to reproduction-dependent and/or mobility-dependent outbreaks. The chronobiological approach is therefore complementary to the ecological approach, and allows us to find specific spatial and temporal strategies for rodent pest control.

**Rodent pest control in relation to population organisation**

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The population structure of rodents may significantly influence the effectiveness of pest control activities and the success in decreasing the natural foci of rodent-borne diseases. We studied population reactions of 16 species of small mammals in relation to this problem. Experiments were conducted to examine the organisation of natural populations and the response of populations after control was applied. Also, we collected data on the population reactions under natural catastrophes (for several species). The parameters studied were: space use; social behaviour; dispersion; breeding; and rate of re-establishing.

Using the ratio of the term of re-establishing to the period of recruitment by breeding (mating – dispersion of young animals) we can divide all species into ‘fast’ and ‘slow’ re-establishing species. The species that were ‘fast re-establishers had their rate of re-establishing overlapping the rate of breeding. It is obvious that such re-establishing can be provided by immigration only. We studied population organisation in ‘fast re-established species and found that a high rate of dispersion in populations was related
to different population structures. It is more useful then, to analyse not the definite population structures but the mode of function. Several population traits were correlated with function. For the ‘fast’ re-establishing species: high rates of change in casts (over 30% for 60 days) and high ratio of dispersers in daily capture (over 30%). For the ‘slow re-established species they were: high stability of the cast (less than 8% of changed individuals) and low ratio of dispersers (less than 5.5%). Among species with ‘fast’’ re-establishment there were animals that provided only one mode of function and those which provided the mode of function in relation to the conditions. In order to analyse them, we introduced the terms ‘re-establish function’ (rf) for the metapopulations provided fast re-establishing, and ‘control function’ (cf) for those that provided slow re-establishing (in the last case provided self regulation of density). Thus, three groups of animals could be distinguished, based on differences in the functional organisation of populations. The first group consists of animals which can provide both rf and cf. They change the mode of function and increase their dispersion activity after changes to their environment (e.g. pest control procedure). It leads on one hand to a decrease in pest control effectiveness, and on the other to an increase in the probability of contacts with sick animals. The second group of species provide only rf animals. They did not achieve a high density as a rule, but they are resistant to pest control and may be a significant factor in dispersion of natural foci of diseases. The third group of species provided only cf animals. They are numerous in the natural environment but they are the most sensitive to pest control.

Bark-stripping of tankan orange, *Citrus tankan*, by the roof rat, *Rattus rattus*

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Roof rats, *Rattus rattus*, damage the bark of tankan orange, *Citrus tankan* Hayata, over a wide area of Amami Oshima Island, in the Nansei Islands in southern Japan. Farmers have been engaged in tankan cultivation for about 30 years. This study examined the food habits of the roof rat to determine whether they are responsible for early bark stripping of the tankan trees.

Amami Oshima (28°10'-30°N, 129°10'-45'E) is an island situated in the subtropical climate zone with an area of 712 km². The climate is warm and humid, with an annual rainfall of 2871 mm. In mid-September 1997, I carried out a study at a tankan orchard.

I confirmed that the tankan trees were attacked by roof rats based on their tooth marks on trees and their hairs in faeces dropped under trees. Most of the damaged trees were completely girdled. Some 21 rats were collected by 90 snap-trap nights around the tankan orchard.

Phloem of tankan, which was identified by the characteristic sieve areas of the tissue, was found in 2 (11%) of 18 stomachs of the rats examined. However, no trace of outer bark was found in those stomachs. Clearly, the rats chewed the phloem con-
tained in the bark chips, because there were tooth marks on the inside of bark chips as well as on the tree surface. The rats seemed to have digested the phloem incompletely and absorbed only the sap because their faeces were filled with the phloem fibres. Seeds and fruits, including 6.4% of an immature tankan fruit, accounted for 30% of the stomach contents in volume, whereas the phloem accounted for only 9%. These results show that the primary vegetable foods of the roof rats were seeds and fruits and that the phloem was not a substitute food source. I conclude that roof rats stripped the bark of the tankan orange to obtain the sap in the phloem, although the reason for this activity remains uncertain.

Towards an ecological approach for management of plague reservoirs and vectors in the western Usambara Mountains in Tanzania, East Africa

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Outbreaks of human plague in the Western Usambara Mountains in Tanzania are strictly seasonal, occurring between October and June each year since 1980. Studies have been carried out in the past to elucidate the breeding patterns of rodents, population densities and the species involved as reservoirs and vectors of the disease organism. The studies have involved removal trapping of animals and determination of rat population densities and flea abundance on rodents. In the current study, a review of the data collected in the past was carried out to establish the appropriate ecological approaches for management of both reservoirs and vectors of plague.

A hypothesis is provided to explain the increase in numbers of plague cases between October and June. The studies suggest that favourable temperatures (22–26°C) and humid conditions between November and March favour rapid multiplication of fleas, thus increasing their abundance on rodent hosts. This period coincides with increasing numbers of wild, peri-domestic and house rodents. The chance of house-infesting rodents, mainly *Rattus rattus* and peri-domestic species (predominantly *Mastomys natalensis*), picking up infection from sylvatic species increases several fold. This enables the disease to be transferred from wild rodents to man. The onset of the heavy rains (March–April) and the cold and dry conditions (May–September) lowers the flea abundance and arrests the spread of the disease during this period.

An ecological approach on an area-wide basis to control both vectors and reservoirs of the disease to supplement the conventional techniques using rodenticides and insecticides has not been attempted. A comprehensive management strategy should involve habitat management approaches, enforcement of environmental sanitation to remove sources of food and reducing potential areas for rodent harbourage and breeding, especially for *Arvicanthis niloticus* and *M. natalensis*. Sanitary improvements and cleanliness in houses to reduce house-infesting fleas and populations of *R. rattus* are necessary.
Finally, a better understanding of the ecology of reservoirs and vectors of plague through continuing studies is mandatory for their successful management.

**A promising new approach in muskrat control (Ondatra zibethicus): the introduction of eradication standards**

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The muskrat, *Ondatra zibethicus*, can cause substantial damage to banks of watercourses and crops by its gnawing and burrowing behaviour. Eradication of this exotic animal was legislated in 1938. A general reporting and elimination duty still exists in Belgium. Regional, provincial and municipal authorities organise muskrat eradication programs along the watercourses which fall within their jurisdiction. The total costs for muskrat destruction in Flanders (North Belgium—area 13 522 km²) can be estimated annually at US$15–20 million. One of the aims of this research is to reduce eradication costs by optimising muskrat control.

A closer look into the practice of elimination of the muskrat, in which several hypotheses were experimentally checked, reveals that a properly conducted eradication program results in a very thorough rattering of an area or watercourse. On the other hand it appears sometimes that for one reason or another small areas remained unprocessed. In some cases densities of muskrat exceed 150/km².

We demonstrated in a field experiment that local residual populations were able, within a short time, to re-colonise the surrounding areas. The main problem appeared to be the thoroughness with which potential refuges were localised, rather than inefficient use of rodenticide (chlorophacinon) or of the different types of mechanical traps.

The following quality standard for a successful muskrat control was therefore formulated: no residual populations with a density exceeding a pre-set number of animals may be found within a processed area (i.e. may be localised during an inspection). The standard limit was fixed at 5 MR/km² (January–March), 10 MR/km² (April–June), 15 MR/km² (July–September) and 10 MR/km² (October–December).

Our research was closely monitored by the Department of Water of the Flemish Government and in 1996 a long-term experiment on muskrat eradication was organised in five areas (total area 2633 km²) in which the new quality standard (eradication goal) formed the core of the experiment. In addition, a supervision and evaluation system was devised in connection with the eradication programs. This new approach has already resulted in promising eradication figures of muskrats.
Use of *Sarcocystis singaporensis* as a biocontrol agent against the Malayan wood rat, *Rattus tiomanicus* in oil palm plantations in Thailand

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The coccidian protozoan, *Sarcocystis singaporensis*, naturally occurs in skeletal muscles of the Malayan wood rat, *Rattus tiomanicus*, which is a chronic pest in oil palm plantations in Thailand. Previous tests on the pathogenicity of this parasite performed by the Agricultural Zoology Research Group, Department of Agriculture, showed that sporocyst doses of >1 × 10⁵ were lethal to rats within 11–19 days. The purpose of the present study was to test the effectiveness of *S. singaporensis* against the Malayan wood rat under field conditions.

The experiment was conducted in oil palm plantations in the southern part of Thailand. Four fields were randomly allocated to two treated and two control plots. Each plot consisted of 20 × 20 palm trees (3.24 ha). Baits containing 4 × 10⁵ sporocysts/pellet or placebo-pellets were offered in 2 rounds, 15 days apart. Three pellets were placed at the base of each tree during the first round; two pellets per tree were applied in the second round. In core areas comprising 10 × 10 palm trees, rat numbers and rat activity were recorded before and after treatment with parasites and placebos. Rat numbers were determined in three traps nights with 100 live-traps per night. Footprints were counted by tracking plates marked with black ink and evaluated by using a transparent grid of 16 squares. A total of 150 plates was used in each plot. The core areas were extensively examined for presence of dead rats 13–15 days after each application of parasites.

At 11–17 days after the Malayan wood rats had consumed parasite-pellets, their numbers were significantly decreased by 71% compared with the control groups (x² = 35.3, df = 3, P < 0.001). Activity inside the parasite-treated plots was also significantly reduced compared with controls (x² = 24.8, df = 3, P < 0.001). We conclude that Malayan wood rats can be effectively controlled by artificial infection with *S. singaporensis* in Thailand.
Integrated rodent management (IRM) was adopted in 1985 in several counties of Yunnan Province. After 10 years, there have been significant successes in some places, but there are still many problems with IRM in most parts of Yunnan. Many socioeconomic factors affect the success of IRM. Data were collected from 100 farmers, 6 villages and 3 townships in Tonhai County and from 200 farmers, 1 village and 1 township in Qijin County. All data have been analysed using descriptive statistics, statistical t-tests and benefit–cost analysis.

This study has defined seven important ecological, socioeconomic factors that influence IRM in rural Yunnan.

1. The government needs to provide more assistance in overseeing the organisation of IRM by providing more financial input and training courses for farmers.
2. Although the Chinese Government organises rodent control campaigns on a large scale, including research projects for rodent control, all five levels of government should be involved. If not, each level will deny some of its responsibility for IRM.
3. Farmers need assistance to understand and adopt IRM fully and correctly. Farmers and government officers require more knowledge of the ecological control of rodents.
4. Correct estimations of the benefit/cost ratio for effective IRM must be made so that both the government and the farmers make informed decisions when undertaking IRM.
5. More training courses on IRM are needed, especially for female members of farming families. Females play an important role in the practice of IRM.
6. Inspections for rodent impacts (damage, loss of food, possible diseases) and of the practice and success of IRM need to be done jointly by the government officers and the farmers.
7. The natural enemies of rodents should be protected and there should be careful application of rodenticides to protect the environment.
for about 70% of the area and 78% of production. Rainfed upland rice accounts for about 25% and 15% of the area and production, respectively.

Smallholder producers in the main rainfed lowland rice growing areas of the Mekong River Valley generally do not rate rodents as a major pest problem and consistently rank rodents very low among potential production constraints. Conventional trapping techniques are generally capable of giving satisfactory control.

In the upland environment, smallholder producers regard rodents as their most important pest, and rank rodents second only to weeds as the overall most important constraint to production. It is also the production constraint over which they have least control. The severity of the problem varies with locality and between seasons. Complete loss of upland rice crops on a localised basis is not unusual. Conventional trapping techniques do not give adequate control in the uplands. Often areas of lowland cultivation in the narrow valleys in the more mountainous regions are also devastated by the movement of rodents from adjacent upland areas. Official policy is to actively discourage the use of rodenticides as a means of rodent control in both the upland and lowland environments. Little is currently known about the species and ecology of rodents in the Lao PDR.

Ecological characteristics and integrated management techniques for *Rattus rattoides*

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In the rice fields of the Pearl River Delta, the main pest rodents are *Rattus rattoides* and *Bandicota indica*. Studies on the ecology and management of *Rattus rattoides* have been conducted since 1987. The fluctuations in the reproductive capacity of *Rattus rattoides* between years and in different seasons were studied, as were the population dynamics and rates of recovery of the population after use of chemical pesticides.

The ecological factors affecting *Rattus rattoides* population density were analysed. Several factors, including crop structure, vegetation stage and the height of the ditch banks in the fields directly affected the conditions of habitat and food supply. These factors also greatly affected the spatial distribution of the population in the habitat. When different crops were simultaneously cultivated in the area, pest rodents shifted from one crop to another causing damage.

The frequency of rice damage and the spatial distribution of types of rice damaged by rats were measured. The relationship between the rodent density and rice yield-loss was simulated in a mathematical model and the economic thresholds for *Rattus rattoides* and for multiple-species were calculated.
The sampling techniques for estimating population density of *Rattus rattoides* are presented. The model for forecasting *Rattus rattoides* population numbers was set up using a triple exponential smoothing model combined with a seasonal adjustment model based on the regular seasonal and annual changes in the rat density. The accuracy rate of forecasting was 83%.

Two synergistic rodenticides (chronic rodenticide + synergist) were screened. The dose of chronic rodenticides was markedly decreased if synergistic rodenticides were used. The band-broadcast technique, a high efficiency baiting method for killing rodents, was developed and required coordinated application of acute and chronic rodenticides to reduce the dose in the bait.

The population density of *Rattus rattoides* was managed using integrated management techniques, involving ecological and chemical control. In demonstration tests the highest density of *Rattus rattoides* was reduced from 36% to 9%, and crop damage was decreased from 5–10% to below 0.5%.

**A field trial of integrated management of commensal rodents in the residential quarters of the urban area**

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A field trial lasting for 2 years was carried out in Tianmen, Hubei to explore methods for management of commensal rodents in residential quarters of urban areas. Three areas were used in the trials: a control area; an area where rodenticides only were applied; and a third area where integrated management including ecological measures was applied. The results show that applying integrated management with ecological measures playing a leading role can achieve a similar or even better effect than using rodenticides alone against commensal rodents. Integrated management not only brings the rodent problem under control, but also reduces or avoids the side-effects of other methods. The side-effects of rodenticides include environmental pollution, accidental poisoning, secondary poisoning, short-term effects, rodenticide tolerance and resistance, and extra consumption of manpower, money and material resources.

**The pest characteristics and control of rodents in Tulufan agricultural area**

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The ecological habitat characteristics, pests and control of rodents in the Tulufan agricultural area were studied from October 1997 to June 1998. There were six