factors governing the spread of the VVIC agent (Tyndale-Biscoe 1994). Ideally, all of these levels of specificity should be satisfied.

Public acceptability will be heavily influenced by the media's interpretation of this technology (Williams 1997) as well as by international debate and agreement on its safety (Oogjes 1997; Stohr and Meslin 1997; Williams 1997).

Apart from the issues associated with the use of a GMO, public acceptability also encompasses animal welfare issues. Although it is generally agreed by animal welfare groups that immunocontraception is a more acceptable form of control than the current lethal methods (Oogjes 1997; Singer 1997), there are other biological issues that need to be considered. For example, Guynn (1997) expressed concern over sterilised females experiencing an abnormal number of oestrous cycles and thus expending more energy. The use of long-term field trials should give some indication of behavioural changes experienced by sterilised and non-sterilised individuals. For example, Williams and Twigg (1996) found during the first year

Table 6
Risks and benefits of viral-vectored immunocontraception (VVIC).

Risks	Benefits
Public concerns about genetically modified organisms (Regal 1986; Molak and Stara 1987; Siddhanti 1987)	Environmentally benign
Possibility of non-target species infection (national) and infection of target species in another ˇountry where it may be a desirable part of the fauna (international) (Tyndale-Biscoe 1995)	More humane than conventional methods of control; supported by animal welfare groups (Oogjes 1997; Singer 1997)
Possibility of pathogens broadening their host range after genetic modification (Regal 1986; Kurtz 1987; Tiedje et al. 1989)	Species-specific
Potential for behavioural/hormonal disruptions to cause ill effects in sterilised individuals; other animal welfare/ethical issues such as potential mortality in utero (Guynn 1997)	Can be used in terrain where pest species would be inaccessible to instigate conventional control methods
Irretrievable once released	More appropriate for highly fecund pest species as it targets reproduction (Bomford 1990; Tyndale-Biscoe 1994, 1995)
Virus may infect laboratory colonies	May be active long- or short-term and therefore have the potential to be a flexible tool for population management
VVIC may select for animals with poor immune systems, therefore favouring immunodeficient animals and thus increasing their susceptibility to pathogens (Guynn 1997; Nettles 1997)	Presence of sterile individuals in the population may exert a much greater biological control pressure than if the same number of fertile animals were removed (Howard 1967)
Legal implications with respect to federal and state registration requirements (Guynn 1997).	Self-disseminating 'release and forget' strategy

of a sterility trial on wild rabbit populations that sterilised females had higher survivorship and body weights than unsterilised females.

Conclusion

Ecologically-based pest management requires the application of a suite of strategies to manage pest species. New approaches, such as fertility control, will become one of these strategies and thus must not be seen as a replacement for conventional methods of control. Where damage mitigation is the objective for population reduction, the short-term use of lethal approaches may still be appropriate. However, it is the prolonged use of such techniques that should be discouraged.

Fertility control techniques that are currently available are not logistically appropriate for wildlife populations. They are expensive and/or invasive, require repeated dosing to maintain sterility levels and often have side effects that lead to behavioural changes. They are also difficult to administer on a broad-scale. Immunocontraception, and in particular viral-vectored immunocontraception, aims to overcome many of these shortcomings by being a naturally disseminating, species-specific fertility agent. However, one disadvantage of this method is the public acceptance of the use of a GMO. Therefore, it is important that the risks of new methods of control, including GMOs, are fully assessed through experimental trials and public debate. These risks should be viewed in the context of control methods which are currently available—i.e. non-specific, fatal poisons. This may mean that these new methods will not be available for broad scale release for at least another decade. However, the potential rewards of this technology will be well worth the longer-term investment.

References

Abbott, D.H. 1988. Natural suppression of fertility. Symposium of the Zoological Society of London, 60, 7–28.

Alexander, N.J. and Bialy, G. 1994. Contraceptive vaccine development. Reproduction, Fertility and Development, 6, 273–280.

Allan, J.E. and Shellam, G.R. 1984. Genetic control of murine cytomegalovirus infection: virus titres in resistant and susceptible strains of mice. Archives of Virology, 81, 139–150.

Barlow, N.D. 1994. Predicting the effect of a novel vertebrate biocontrol agent: a model for viral-vectored immunocontraception of New Zealand possums. Journal of Applied Ecology, 31, 454–462.

Barlow, N.D., Kean, J.M. and Briggs, C.J. 1997. Modelling the relative efficacy of culling and sterilisation for controlling populations. Wildlife Research, 24, 129–142.

Baskin, M.J. 1932. Temporary sterilization by the injection of human spermatozoa. A preliminary report. American Journal of Obstetrics and Gynaecology, 24, 892–897.

Becker, S.E. and Katz, L.S. 1997. Gonadotrophin releasing hormone (GnRH) analogs or active immunization against GnRH to control fertility in wildlife. In: Kreeger, T.J., ed., Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 11–19.

Beckmann, R. 1988. Mice on the farm. Rural Research, 138, 23–27.

Bomford, M. 1990. A role for fertility control in wildlife management? Bulletin No. 7., Canberra, Bureau of Rural Resources, 50p.

Bomford, M. and O'Brien, P. 1997. Potential use of contraception for managing wildlife pests in Australia. In: Kreeger, T.J., ed. Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 205–214.

Booth ,T.W.M., Scalzo, A.A., Carello, C., Lyons, P.A., Farrell, H.E., Singleton, G.R. and Shellam, G.R. 1993. Molecular and biological characterisation of new strains of murine cytomegalovirus isolated from wild mice. Archives of Virology, 132, 209–220.

Bradley, M.P. 1994. Experimental strategies for the development of an immunocontraceptive vaccine for the European red fox, *Vulpes vulpes*. Reproduction, Fertility and Development, 6, 307–317.

Bradley, M.P., Hinds, L.A. and Bird, P.H. 1997. A bait-delivered immunocontraceptive vaccine for the European red fox (*Vulpes vulpes*) by the year 2002? Reproduction, Fertility and Development, 9, 111–116.

Braysher, M. 1993. Managing vertebrate pests: principles and strategies. Canberra, Bureau of Resource Sciences, 58p.

Caughley, G. 1977. Analysis of vertebrate populations. London, John Wiley and Sons, 234p.

Caughley, G. 1985. Harvesting of wildlife: past, present and future. In: Beasom, S.L. and Roberson, S.F., ed., Game harvest management. Kingsville, Texas, Caesar Kleberg Wildlife Research Institute, 3–14.

Caughley, G., Pech, R. and Grice, D. 1992. Effect of fertility control on a population's productivity. Wildlife Research, 19, 623–627.

Caughley, J., Monamy, V. and Heiden, K. 1994. Impact of the 1993 mouse plague. GRDC Occasional Paper Series No.7. Canberra, Grains Research and Development Corporation, 73p.

Chambers, L.K., Singleton, G.R., and Hinds, L.A. 1999. Fertility control of wild mouse populations: the effects of hormonal competence and an imposed level of sterility. Wildlife Research, 26, 579–591.

Chambers, L.K., Singleton, G.R. and Hood, G.M. 1997. Immunocontraception as a potential control method of wild rodent populations. Belgian Journal of Zoology, 127, 145–156.

Childs, J.E., Ksiazek, T.G., Rollin, P.E., Krebs, J.W., Zaki, S., Nichol, S.T., Peters, C.J. and Glass, G.E. 1994. Hantaviruses and their rodent reservoirs in the United States. In: Halverson, W.S. and Crabb, A.C., ed., Proceedings of the 16th Vertebrate Pest Conference, Santa Clara, California, 1–3 March 1994. Davis, University of California, 188–191.

Cowan, P.E. and Tyndale-Biscoe, C.H. 1997. Australian and New Zealand mammal species considered to be pests or problems. Reproduction, Fertility and Development, 9, 27–36.

Dalum, I., Jensen, M.R., Gregorius, K., Thomasen, C.M., Elsner, J.I. and Mouritsen, S. 1997. Induction of cross-reactive antibodies against a self protein by immunization with a modified self protein containing a foreign T helper epitope. Molecular Immunology, 34, 1113–1120.

Davis, S.S. 1996. Vaccine delivery systems: particulate delivery systems. Vaccine, 14, 672–80.

Dunbar, B.S. 1997. Contraception in domestic and wild animal populations using zona pellucida immunogens. In: Kreeger, T.J., ed., Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 1–9.

East, I.J., Gulyas, B.J. and Dean, J. 1985. Monoclonal antibodies to the murine zona pellucida protein with sperm receptor activity: effects on fertilization and early development. Developmental Biology, 109, 268–73.

East, I.J., Mattison, D.R. and Dean, J. 1984. Monoclonal antibodies to the major protein of murine zona pellucida: effects on fertilization and early development. Developmental Biology, 104, 49–56.

Emlen, J.T., Stokes, A.W. and Winsor, C.D. 1948. The rate of recovery of decimated populations of brown rats in nature. Ecology, 29, 133–145.

Fenner, F. and Buller, R.M.L. 1997. Mousepox. In: Nathanson, N., Ahmed, R., Gonzalez-Scarano, F., Griffin, D.E., Holmes, K., Murphy, F.A. and Robinson, H.L., ed., Viral pathogenesis. Philadelphia, Lippincott-Raven Publishers, 535–553.

Florman, H.M. and Wassarman, P.M. 1985. O-linked oligosaccharides of mouse egg ZP3 account for its sperm receptor activity. Cell, 4, 313–324.

Gao, Y. and Short, R.V. 1993. The control of rodent populations. Oxford Reviews of Reproductive Biology, 15, 265–310.

Geddes, A.M.W. 1992. The relative importance of pre-harvest crop pests in Indonesia. Chatham, UK, National Resources Institute Bulletin, 47p.

Goldberg, E. and Shelton, J. 1986. Immunosuppression of fertility by LDH-C4. In: Talwar, G.P., ed., Immunological approaches to contraception and promotion of fertility. New York, Plenum Publishing, 219p.

Gratz, N.G. 1994. Rodents as carriers of disease. In: Buckle, A.P. and Smith, R.H., ed., Rodent pests and their control. Wallingford, UK, CAB International, 85–108.

Grundy (Chalmer), J.E., Mackenzie, J.S. and Stanley, N.F. 1981. Influence of H-2 and non-H-2 genes on resistance to murine cytomegalovirus infection. Infection and Immunity, 32, 277–286.

Guynn, D.C. Jr. 1997. Contraception in wildlife managment: reality or illusion? In: Kreeger, T.J., ed., Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 241–246.

Hardy, C.M., Clarke, H.G., Nixon, B., Grigg, J.A., Hinds, L.A. and Holland, M.K. 1997. Examination of the immunocontraceptive potential of recombinant rabbit fertilin subunits in rabbit. Biology of Reproduction, 57, 879–886.

Harris, J.D., Hibler, D.W., Fontenot, G.K., Hsu, K.T., Yurewicz, E.C. and Sacco, A.G. 1994. Cloning and characterization of zona pellucida genes and cDNAs from a variety of mammalian species: the ZPA, ZPB and ZPC gene families. DNA Sequence, 4, 361–393.

Herr, J.C., Flickinger, C.J., Homyk, M. and Klotz, K.J.E. 1990a. Biochemical and morphological characteristics of the intra-acrosomal antigen SP-10 from human sperm. Biology of Reproduction, 42, 181–193.

Herr, J.C., Wright, M., John, E., Foster, J., Kays, T. and Flickinger, C.J. 1990b. Identification of human acrosomal antigen SP-10 in primates and pigs. Biology of Reproduction, 42, 377–382.

Holland, M.K., Andrews, J., Clarke, H., Walton, C. and Hinds, L.A. 1997. Selection of antigens for use in a virus-vectored immunocontraceptive vaccine: PH-20 as a case study. Reproduction, Fertility and Development, 9, 117–124.

Holland, M.K. and Jackson, R.J. 1994. Virus-vectored immunocontraception for control of wild rabbits: identification of target antigens and construction of recombinant viruses. Reproduction, Fertility and Development, 6, 631–642.

Hone, J. 1992. Rate of increase and fertility control. Journal of Applied Ecology, 29, 695–698.

Howard, W.E. 1967. Biocontrol and chemosterilants. In: Kilgore, W.W. and Doutt, R.L., ed., Pest control—biological, physical and selected chemical methods. New York, Academic Press, 343–383.

Hudson, J.B. 1994. Mouse cytomegalovirus (murid herpesvirus 1). In: Osterhaus, A.D.M.E., ed., Virus infections of rodents and lagomorphs. Amsterdam, Netherlands, Elsevier Science, 85–117.

Hutchins, M., Stevens, V. and Atkins, N. 1982. Introduced species and the issue of animal welfare. International Journal of Studies on Animal Problems, 3, 318–336.

Hutchins, M. and Wemmer, C. 1987. Wildlife conservation and animal rights: are they compatible? In: Fox, M.W.and Michley, L.D., ed., Advances in animal welfare science. Boston, Martinus Nijoff Publishers, 111–137.

Jackson, R.J., Maguire, D.J., Hinds, L.A. and Ramshaw, I.A. 1998. Infertility in mice induced by a recombinant ectromelia virus expressing mouse zona pellucida glycoprotein. Biology of Reproduction, 58, 152–159.

Jochle, W. 1997. Prolactin in canine and feline reproduction. Reproduction in Domestic Animals, 32, 183–193.

Jones, W.R. 1994. Gamete immunology. Human Reproduction, 9, 828–841.

Kearns, B. 1993. The cost of the mouse plague. Unpublished discussion paper presented to the mouse plague forum, 12 August 1993. Horsham, Victorian Institute of Dryland Agriculture.

Kennelly, J.J. and Converse, K.A. 1997. Surgical sterilization: an underutilized procedure for evaluating the merits of induced sterility. In: Kreeger, T.J., ed., Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 21–28.

Kennelly, J.J., Johns, B.E. and Garrison, M.V. 1972. Influence of sterile males on fecundity of a rat colony. Journal of Wildlife Management, 36, 161–165.

Key, G., Wilson, E. and Connor, J. 1994. Present status of *Rattus norvegicus* on Santa Cruz Island, Galapagos, Ecuador. In: Halverson, W.S. and Crabb, A.C., ed., Proceedings of the 16th Vertebrate Pest Conference, Santa Clara, California, 1–3 March 1994. Davis, University of California, 118–123.

Kirkpatrick, J.F., Liu, I.M.K., Turner, J.W. Jr, Naugle, R. and Keiper, R. 1992. Long-term effects of porcine zonae pellucidae immunocontraception on ovarian function in feral horses (*Equus caballus*). Journal of Reproduction and Fertility, 94, 437–444.

Klein, J. 1979. The major histocompatibility complex of the mouse. Science, 203, 516–521.

Knipling, E.F. and McGuire, J.U. 1972. Potential role of sterilization for suppressing rat populations: a theoretical appraisal. US Department of Agriculture, Agricultural Research Service Technical Bulletin, 1455, 1–27.

Knudsen, S., Saadbye, P., Hansen, L.H., Collier, A., Jacobsen, B.L., Schlundt, J. and Karlstreom, O.H. 1995. Development and testing of improved suicide functions for biological containment of bacteria. Applied and Environmental Microbiology, 61, 985–991.

Koffron, A.J., Mueller, K.H., Kaufman, D.B., Stuart, F.P., Patterson, B. and Abecassis, M.I. 1995. Direct evidence using *in situ* polymerase chain reaction that the endothelial cell and T-lymphocyte harbor latent murine cytomegalovirus. Scandinavian Journal of Infectious Diseases, 99, 61–62.

Kurtz, J.C. 1987. Assessing the risks associated with biotechnology: the regulatory problem. In: Lave, L.B., ed., Risk assessment and management. New York, Plenum Press, 93–98.

Leirs, H., Verhagen, R., Sabuni, C.A., Wanjabe, P.M. and Verheyen, W.N. 1997. Spatial dynamics of *Mastomys natalensis* in a field–fallow mosaic in Tanzania. Belgian Journal of Zoology, 127, 29–38.

Lou, Y., Ang, J., Thai, H., McElveen, F. and Tung, K.S.K. 1995. A zona pellucida 3 peptide vaccine induces antibodies and reversible infertility without ovarian pathology. Journal of Immunology, 155, 2715–2720.

Manning, W.C. and Mocarski, E.S. 1988. Insertional mutagenesis of the murine cytomegalovirus genome: one prominent α gene (*ie2*) is dispensable for growth. Virology, 167, 477–484.

Marks, C.A., Nijk, M., Gigliotti, F., Busana, F. and Short, R.V. 1996. Preliminary field assessment of a cabergoline baiting campaign for reproductive control of the red fox (*Vulpes vulpes*). Wildlife Research, 23, 161–168.

Marsh, R.E. 1988. Chemosterilants for rodent control. In: Prakash, I., ed., Rodent pest management. Boca Raton, Florida, CRC Press, 353–368.

Marsh, R.E. and Howard, W.E. 1973. Prospects of chemosterilants and genetic control of rodents. Bulletin of the World Health Organisation, 48, 309–316.

Meehan, A.P. 1984. Rats and mice. Their biology and control. Sussex, Rentokil Limited, 383p.

Millar, S.E., Chamow, S.M., Baur, A.W., Oliver, C., Robey, F. and Dean, J. 1989. Vaccination with a synthetic zona pellucida peptide produces long-term contraception in female mice. Science, 246, 935–938.

Molak, V. and Stara, J. 1987. Risk assessment of deliberate release of genetically engineered microorganisms. In: Lave, L.B., ed., Risk assessment and management. New York, Plenum Press, 83–91.

Moors, P.J., Atkinson, A.E. and Sherley, G.H. 1992. Reducing the rat threat to island birds. Bird Conservation International, 2, 93–114.

Nettles, V.F. 1997. Potential consequences and problems with wildlife contraceptives. Reproduction, Fertility and Development, 9, 137–143.

Oogjes, G. 1997. Ethical aspects and dilemmas of fertility control of unwanted wildlife: an animal welfarist's perspective. Reproduction, Fertility and Development, 9, 163–167.

Pennycuik, P.R., Johnston, P.G., Lidicker, W.Z. Jr and Westwood, N.H. 1978. Introduction of a male sterile allele (t^{W2}) into a population of house mice housed in a large outdoor enclosure. Australian Journal of Zoology, 26, 69–81.

Pollock, J.L., Presti, R.M., Paetzold, S. and Virgin, H.W. 1997. Latent murine cytomegalovirus infection in macrophages. Virology, 227, 168–179.

Prakash, I. 1988a. Rodent pest management. Boca Raton, Florida, CRC Press, 480p.

Prakash, I. 1988b. Bait shyness and poison aversion. In: Prakash, I., ed., Rodent pest management. Boca Raton, Florida, CRC Press, 321–329.

Primakoff, P., Lathrop, W., Woolman, L., Cowan, A. and Myles, D. 1988. Fully effective contraception in male and female guinea pigs immunized with the sperm protein PH-20. Nature, 335, 543–546.

Ramsay, A.J. and Ramshaw, I.A. 1997. Cytokine enhancement of immune responses important for immunocontraception. Reproduction, Fertility and Development, 9, 91–97.

Regal, P.J. 1986. Models of genetically engineered organisms and their ecological impact. In: Mooney, H.A. and Drake, J.A., ed., Ecology of biological invasion of North America and Hawaii. New York, Springer-Verlag, 111–129.

Rhim, S.H., Millar, S.E., Robey, F., Luo, A.M., Lou, Y.H., Yule, T., Allen, P., Dean, J., and Tung, K.S.K. 1992. Autoimmune disease of the ovary induced by a ZP3 peptide from the mouse zona pellucida. Journal of Clinical Investigations, 89, 28–35.

Rosiere, T.K. and Wassarman, P.M. 1992. Identification of a region of mouse zona pellucida glycoprotein mZP3 that possesses sperm receptor activity. Developmental Biology, 154, 309–317.

Sankai, T., Endo, T., Kanayama, K., Sakuma, Y., Umezu, M. and Masakai, J. 1991. Antiprogesterone compound RU486 administration to terminate pregnancy in dogs and cats. Journal of Veterinary Medical Science, 53, 1069–1070.

Saunders, G. and Cooper, K. 1981. Pesticide contamination of birds in association with a mouse plague. Emu, 82, 227–229.

Shellam, G.R. 1994. The potential of murine cytomegalovirus as a viral vector for immunocontraception. Reproduction, Fertility and Development, 6, 401–409.

Siddhanti, S.K. 1987. Methodological approach to the study of risk policy decision-making: the case of deliberate release of genetically engineered organisms. In: Lave, L.B., ed., Risk assessment and management. New York, Plenum Press, 99–106.

Sinclair, A.R.E. 1989. Population regulation in animals. In: Cherrett, J.M., ed., Ecological concepts. Oxford, UK, Blackwell Scientific Publications, 197–241.

Sinclair, A.R.E. 1997. Fertility control of mammal pests and the conservation of endangered marsupials. Reproduction, Fertility and Development, 9, 1–16.

Sinclair, A.R.E, Olsen, P.D. and Redhead, T.D. 1990. Can predators regulate small mammal populations? Evidence from house mouse outbreaks in Australia. Oikos, 59, 382–392.

Singer, P. 1997. Neither human nor natural: ethics and feral animals. Reproduction, Fertility and Development, 9, 157–62.

Singleton, G.R. 1989. Population dynamics of an outbreak of house mice (*Mus domesticus*) in the mallee wheatlands of Australia — hypothesis of plague formation. Journal of Zoology, London, 219, 495–515.

Singleton, G.R. 1994. The prospects and associated challenges for the biological control of rodents. In: Halverson, W.S. and Crabb, A.C., ed., Proceedings of the 16th Vertebrate Pest

Conference, Santa Clara, California, 1–3 March 1994. Davis, University of California, 301–306.

Singleton, G.R. and Petch, D.A. 1994. A review of the biology and management of rodent pests in Southeast Asia. ACIAR Technical Reports No. 30. Canberra, Australian Centre for International Agricultural Research, 65p.

Singleton, G.R. and Redhead, T.D. 1989. House mouse plagues. In: Noble, J.C. and Bradstock, R.A., ed., Mediterranean landscapes in Australia: mallee ecosystems and their management. Melbourne, Commonwealth Scientific and Industrial Research Organisation (CSIRO), 418–433.

Singleton, G.R., Smith, A.L., Shellam, G.R., Fitzgerald, N. and Müller, W.J. 1993. Prevalence of viral antibodies and helminths in field populations of house mice (*Mus domesticus*) in southeastern Australia. Epidemiology and Infection, 110, 399–417.

Singleton, G.R. and Spratt, D.M. 1986. The effects of *Capillaria hepatica* (Nematoda) on natality and survival to weaning in BALB/c mice. Australian Journal of Zoology, 34, 677–681.

Skinner, S.M., Mills, T., Kirchik, H.J. and Dunbar, B.S. 1984. Immunization with zona pellucida proteins results in abnormal ovarian follicular differentiation and inhibition of gonadotropin induced steroid secretion. Endocrinology, 115, 2418–2432.

Smith, A.L., Singleton, G.R., Hansen, G.M. and Shellam, G. 1993. A serologic survey for viruses and *Mycoplasma pulmonis* among wild house mice (*Mus domesticus*) in southeastern Australia. Journal of Wildlife Diseases, 29, 219–229.

Spratt, D.M. and Singleton, G.R. 1986. Studies on the life cycle, infectivity and clinical effects of *Capillaria hepatica* (Bancroft) (Nematoda) in mice, *Mus musculus*. Australian Journal of Zoology, 34, 663–675.

Stenseth, N.C. 1981. How to control pest species: application of models from the theory of island biogeography in formulating pest control strategies. Journal of Applied Ecology, 18, 773–794.

Stohr, K. and Meslin, F.X. 1997. Zoonoses and fertility control in wildlife—requirements for vaccines. Reproduction, Fertility and Development, 9, 149–155.

Szostak M.P., Hensel, A., Eko, F.O., Klei, R., Auer, T., Mader, H., Halsberger, A., Bunka, S., Wanner, G. and Lubitz, W. 1996. Bacterial ghosts: non-living candidate vaccines. Journal of Biotechnology, 44, 161–170.

Tedin, K., Witte, A., Reisinger, G., Lubitz, W. and Bleasi, U. 1995. Evaluation of the *E. coli* ribosomal rrnB P1 promoter and phage-derived lysis genes for the use in a biological containment system: a concept study. Journal of Biotechnology, 39, 137–148.

Tiedje, J.M., Colwell, R.K., Grossman, Y.L., Hodson, R.E., Lenski, R.E., Mack, R.N. and Regal P.J. 1989. The planned introduction of genetically engineered organisms: ecological considerations and recommendations. Ecology, 70, 298–315.

Twigg, L.E., Singleton, G.R. and Kay, B.J. 1991. Evaluation of bromadiolone against house mouse (*Mus domesticus*) populations in irrigated soybean crops. I. Efficacy of control. Wildlife Research, 18, 265–274.

Tyndale-Biscoe, C.H. 1994. Virus-vectored immunocontraception of feral mammals. Reproduction, Fertility and Development, 6, 281–287.

Tyndale-Biscoe, C.H. 1995. Vermin and viruses: risks and benefits of viral-vectored immunosterilisation. Search, 26, 239–244.

Tyndale-Biscoe, C.H. 1997a. Immunosterilization for wild rabbits: the options. In: Kreeger, T.J., ed., Contraception in wildlife management. Technical Bulletin No. 1853, United States Department of Agriculture, Animal and Plant Health Inspection Service, 223–234.

Tyndale-Biscoe, C.H. 1997b. Summing up the conference. Reproduction, Fertility and Development, 9, 183–186.

Vickery, B.H., McRae, G.I., Goodpasture, J.C. and Sanders, L.M. 1989. Use of potent LHRH analogues for chronic contraception and pregnancy termination in dogs. Journal of Reproduction and Fertility Supplement, 39, 175–187.

Wace, N.M. 1986. The rat problem on oceanic islands—research is needed. Oryx, 20, 79–86.

Wasser, S.K. and Barash, D.P. 1983. Reproductive suppression among female mammals: implications for biomedicine and sexual selection theory. Quarterly Review of Biology, 58, 513–538.

Whittingham, D.G. and Wood, M.J. 1983. Reproductive physiology. In: Foster, H.L., Small, J.D. and Fox, J.G., ed., The mouse in biomedical research, volume III — normative biology, immunology and husbandry. New York, Academic Press, 137–164.

Williams, C.K. 1997. Development and use of virus-vectored immunocontraception. Reproduction, Fertility and Development, 9, 169–178.

Williams, C.K. and Twigg, L.E. 1996. Responses of wild rabbit populations to imposed sterility. In: Floyd, R.B., Sheppard, A.W. and De Barro, P.J., ed., Frontiers of population ecology. Melbourne, Commonwealth Scientific and Industrial Research Organisation (CSIRO), 547–560.

11. Urban Rodent Control Programs for the 21st Century

Bruce A. Colvin and William B. Jackson

Abstract

Urban rodent control in the 21st century must focus on a program approach that is both strategic and comprehensive (i.e. proactive rather than reactive). This includes an integrated pest management approach that incorporates long-term planning, scheduling, data management and mapping capabilities. It also must include 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, training, and understanding of the ecological and political complexities of urban environments. Greater focus on sanitation enforcement, infrastructure maintenance and construction will be essential for long-term removal of causal factors. The long-term goal must be an effective and sustainable program.

Keywords

Urban, integrated pest management (IPM), rodent control, commensal rodent, sanitation, infrastructure

INTRODUCTION

THE PRINCIPLES of urban rodent control have been well researched and described in this century. However, substantial problems continue to persist and grow in many metropolitan areas, as well as in small municipalities. Although the science and technology have been established (Jackson 1982; Frantz and Davis 1991), the failure appears most evident at the point of implementation. Success is not predicated on a control tool, but rather on coordinated efforts supported by technical leadership at the local level.

Telle (1969) in Germany and Myllymäki (1969) in Finland described the principle of establishing a 'rat-free town'. The goal was to have less than 1% of the premises showing signs of rat activity. Drummond (1970) in England stressed the idea and importance of a program approach for managing urban rat populations (Drummond et al. 1972, 1977; Drummond 1985). Examples of successful and coordinated programs are few, but include Budapest, Hungary (Gacs et al. 1977; Bajomi and Sasvari 1986), Kuwait (Al Sanei et al. 1986), and Denmark (P. Weile 1998, pers. comm.). All of these have included an emphasis on sanitation and environmental management.

The primary difference between urban and agricultural rodent control is that the urban environment is relatively diverse and stable, requiring consistent application of control measures, since food and structural resources are consistently available. On the other hand, in open agricultural settings, the environment is relatively homogeneous and subject to disruptions, and resources used by rodents and control efforts tend to be seasonally timed. Habitat manipulation is readily feasible in urban areas for limiting growth of rodent populations and to prevent over-dependency on rodenticide. In contrast, with agricultural situations there may be limited opportunity for habitat manipulation and thus greater emphasis frequently is given to trapping and rodenticide use. The basic ecological and organisational principles of rodent control programs, however, are transferable between urban and agricultural environments.

Urban rodent control in the United States (US) typically is implemented in a limited or disjointed fashion, rather than being comprehensive or coordinated. Programs commonly are reactive rather than proactive. Reasons for this include limited funding, training, political and technical support, and organisation (Howard 1984). The political and scientific interest in urban rodent control in the US currently is low, although the need appears to be great.

Commensal rodents are those described literally as 'feeding at our table'. They include species such as Norway rat (*Rattus norvegicus*), roof rat (*Rattus rattus*), and house mouse (*Mus musculus*). In Asia, they also can include species such as the lesser bandicoot rat (*Bandicota bengalensis*) and Polynesian rat (*Rattus exulans*). Commensal rodents have been associated with a variety of diseases, contamination and destruction of stored foods, structural damage, and other aspects of environmental deterioration (Gratz 1994; Lund 1994). They frequently display remarkable adaptive behaviour in urban environments.

Urban infrastructure is ageing, congestion is increasing, and urban habitat is expanding worldwide. These factors accentuate the growing need for effective rodent control programs, for public health, economic and aesthetic reasons. Additionally, expectations of urban residents and businesses for quality-of-life improvements and effective public health management will continue to grow. The result will be more sanitation problems to be managed in more densely populated urban centres, and these urban environments will increasingly require re-design and construction to support human population levels and business economies.

The purpose of this chapter is to describe strategies and issues for implementing urban rodent control programs, while considering both ecological and administrative components. This includes a historic US perspective with transition to future opportunities worldwide.

Historical Background

The 'Modern Rodent Control Era' began with the advent of World War II, as urban destruction and concern for food supplies (both quality and quantity) forced attention to rodent control. This included the need for more effective rodenticides and better understanding of rodent biology. (The term 'ecology' had not yet been applied to this issue.) Federal funds in the US supported related research and development projects.

Initial efforts focused at the School of Hygiene and Public Health of the Johns Hopkins University in Baltimore, Maryland. The rodenticide ANTU was brought forth there, and Compound 1080 resulted from a massive synthesis and evaluation program by the federal government. These rodenticide baits were far more effective than the arsenic and phosphorus baits in use at that time. (It was not until the next decade that warfarin would leap into the marketplace as a 'miracle' rodenticide, following the 'miracle' insecticide, DDT.)

The 1940s and early 1950s at Johns Hopkins University were times of active research on basic elements of rat behaviour, later serving as the foundation of control approaches and future urban programs worldwide. Calhoun (1948, 1963) performed detailed studies of the sociology of the Norway rat, providing new research approaches for studying the social behavior of semi-confined rodent populations. Basic studies of Norway rats in the residential blocks of Baltimore followed by Davis and others (Davis et al. 1948; Emlen et al. 1948, 1949; Davis and Fales 1949, 1950; Davis 1953). Those studies documented for the first time the reproduction, movement, and many other life history components (now referenced as 'ecology') of urban rat populations. Parallel studies on aspects of commensal rodent biology also occurred in the United Kingdom during the same time era (Chitty and Southern 1954).

From the fundamental studies at Johns Hopkins University came the notion of relating a logistical growth curve (sigmoid curve) to changes in rodent populations (Figure 1). Such a mathematical expression could then be used to predict population growth and as a tool for understanding how to strategically manage rodent populations. By lowering the carrying capacity of the environment, the rate of population increase could be dampened and population declines achieved (Davis and Jackson 1981).

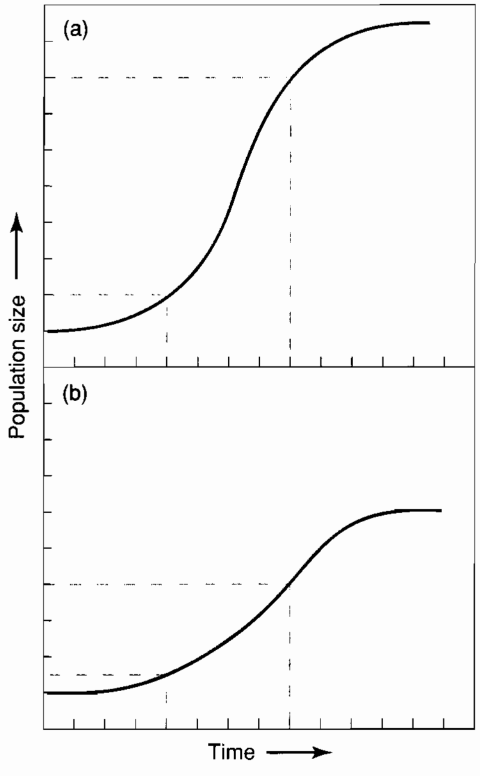

Figure 1.
Sigmoid curves depicting the rate of change and growth of rodent populations over time, (a) without environmental (sanitation) management and (b) with environmental management to reduce carrying capacity. The two dashed lines on each graph show the passing of the same amount of time on the horizontal axis, while on the vertical axis there is a dramatic increase in the population size during the second time period. The most economic and effective strategy is to manage populations at the low end of the sigmoid curve under reduced carrying capacity (b).

Populations then could be more effectively 'managed' at the low end of the population growth curve. Baltimore officials cooperated and set up a demonstration area in which no rodenticides would be used, but intensive enforcement of environmental standards would be substituted. Specific regulations were passed and sanitation police were hired. Outdoor toilets, board fences, old cars and other rubbish were removed. Proper storage and handling of refuse was enforced. With this regimen, the outside rat population was virtually eliminated from this residential area. However, the program was not maintained because of the need for intensive (i.e. expensive) site management and the lack of political and personal will to maintain environmental standards. Yet, the logistical model as a management tool had been demonstrated successfully and, to one degree or another, became the basis of future management efforts in the US and elsewhere (Figure 2).

During World War II, the US Public Health Service set up programs in the Communicable Disease Center (CDC) in Atlanta, Georgia, for training personnel in the control of various disease vectors met in military activities. In post-war years, such training programs expanded to include state and municipal personnel. Equipment was provided for state agencies as well. Handbooks covering a wide variety of vector and sanitation topics were developed, and many remain as the prime resource documents available today (Pratt and Johnson 1975; Pratt and Brown 1976; Pratt et al. 1976; Scott and Borom 1976; Davis et al. 1977). However, the involvement of CDC in technical support for urban rodent control programs faded by the early 1980s and personnel once active have retired.

Universities were slow to pick up the challenge of urban rodent ecology and control. The Johns Hopkins program faded when the core staff left by the late 1950s.

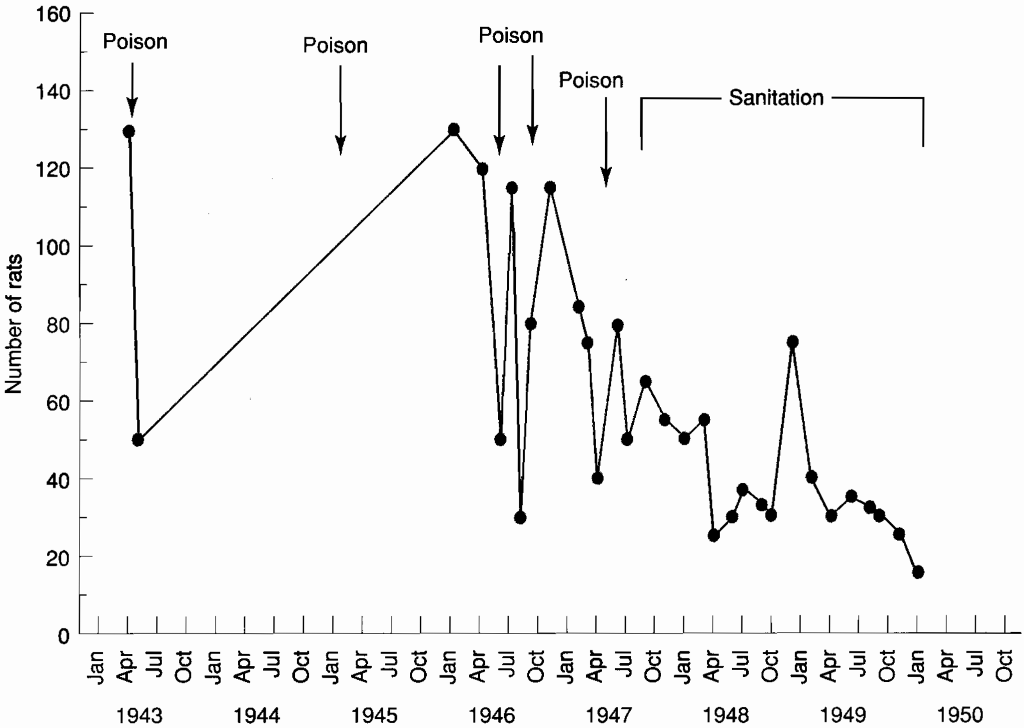

Figure 2.
Changes in Norway rat abundance in Baltimore following poisoning and sanitation improvements (Jackson 1998). The population increase during late 1948 was attributable to a strike by garbage collectors that temporarily increased food resources (carrying capacity) for rats.

Most mammalian researchers considered urban pest rodents not 'worthy' of basic research and the urban environment a distasteful setting for studying mammalian ecology. This left entomologists as the source of much information for pest control curricula, and they commonly did not want to bother with rodents or approached them as 'furry cockroaches'.

Two universities, Bowling Green State University in Ohio and the University of California at Davis, developed effective vertebrate pest curricula in the 1960s and 1970s. This included undergraduate and graduate instruction and research programs. Designations such as 'economic biology' were typical, and research continued the kinds of efforts first begun at Johns Hopkins University. This included basic behaviour but also, by the 1970s and 1980s, a focus on genetic resistance to anticoagulant rodenticide, secondary poisoning hazards, and development of new rodenticides, traps and bait stations. Many personnel currently providing leadership on vertebrate pest management in the US came from these two university programs. However, by the late 1980s these programs also began to fade and ended as faculty retired.

The Federal government, through the US Public Health Service, supported research on genetic resistance to warfarin (first-generation anticoagulant rodenticide) during the 1970s (Jackson et al. 1988). During that same era and into the early 1980s, $12.8 to $15.0 million dollars annually were provided for state and local efforts specifically for implementing urban rodent control programs. These programs involved a standardised approach of environmental management, including target areas, systematic surveys, education, sanitation improvements and baiting. The goal was to progressively shift blocks of premises to a maintenance condition with subsequent monitoring for re-infestation. This federal program assisted more than 100 communities (Jackson 1984, 1998). However, in the early 1980s, specific designation of federal funding for urban rodent control ended, and subsequently many local programs were greatly reduced and eventually became less structured.

The US Fish and Wildlife Service, through regional and state programs in the 1960s–1980s, stimulated and supported efforts at universities as related to vertebrate pests. This included some technical support on urban rodents, although most of their effort was directed at predators, birds and field rodents. In the mid 1980s, these programs were transferred by the US Congress to the US Department of Agriculture (USDA). With that change, control of urban rodents was specifically excluded from the USDA scope of services, although rodent infestation of stored grain and croplands remain within their area of concern.

Today in the US, technical support for urban rodent control is very limited. Active research programs do not exist on the federal, state or university level. Most States and municipalities have limited knowledge and skill in urban rodent control, resulting in limited effectiveness when programs are implemented. Urban (and suburban) rodent control could be described as a composite of work by householders, licensed pest control operators and municipal agencies (Kaukeinen 1994), but without defined coordination. Most efforts by local health departments are reactive, in response to citizen complaints about infestations or rat bites. Their efforts typically involve use of anticoagulant baits within a limited area (e.g. at the site of a complaint or perhaps a few city blocks).

The Boston Model

The basic research of the 1940s–1950s, the program approaches described in the 1960s–1970s, and the technical advances of the 1970s–1980s were combined in 1990 in Boston, Massachusetts. The unique opportunity to establish a truly comprehensive and properly designed rodent control program had arisen from the start of an 11-billion-dollar highway construction project funded by the Federal Highway Administration (Colvin et al. 1990). This involved reconstruction of the urban infrastructure along a seven-mile route, including utility systems and an 8–10 lane highway to be built underground.

Key to the program design was a centralised approach with well-defined responsibilities and firm accountability. The primary management function was performed by personnel (biologists) skilled in technical aspects of rodent control, yet also with contract management, public relations, engineering, scheduling, and computer-based mapping and data management skills. The second component of the program was the municipal functions, performed by the Inspectional Services Department, the Code Enforcement Police, the Water and Sewer Commission, and the Public Works Department. The third component involved pest control contractors who performed poison baiting, trapping and monitoring. The fourth component was public participation, championed by community leaders and organisations. These various components were integrated to maximise the skills and participation of each group within the total program.

Work tasks assigned to each municipal agency were based on their existing scope of services. For example, the Inspectional Services Department was assigned standardised surveys of premises, enforcement of State Sanitary Code and public education. The Code Enforcement Police dealt with violations of City sanitation ordinances. The Water and Sewer Commission assisted by cleaning catch basins and providing access to sewer manholes. The Public Works Department helped by making infrastructure repairs and maintaining trash receptacles in public areas. Most of these municipal tasks focused on environmental change to reduce rodent habitat.

The program was an integrated pest management (IPM) approach covering about a seven-square-mile area. It was tailored to the need of each neighborhood based on surveys of sanitary conditions and rodent activity at surface and subsurface levels. Where problems were chronic, IPM methods and monitoring were applied more intensely. The program included an extensive public outreach and education campaign involving community meetings, diverse literature, videos, door-to-door contact and school presentations. The education campaign recognised cultural differences among neighbourhoods, and literature was prepared in multiple languages.

Sanitation was given heightened attention on more than 10,000 premises in the project area. The Code Enforcement Police performed ticketing daily, and the Inspectional Services Department cited property owners to hearings and court for chronic sanitary code violations. In locations highly susceptible to infestation, residents and businesses were given refuse containers after signing a contract to maintain and use them. Property owners and businesses were held responsible for maintaining their property in an acceptable condition, including hiring their own pest control contractor if needed. City personnel conducted baseline and periodic surveys on private properties, and these surveys helped ensure maintenance of environmental improvements. The objectives were to reduce the environmental carrying capacity for rodents and also to prevent their dispersal.

Trapping and poisoning were performed on both surface and subsurface levels in all public areas, and as a supportive measure on some private properties. Engineering drawings and information were used to 'three-dimensionally' dissect the infrastructure. About 1,500 sewer and other types of utility manholes were baited using pulsed-baiting methods on a seasonal basis (Colvin et al. 1998). Census and monitoring tools were used extensively to detect and closely monitor for low levels of activity (non-toxic census baits, tracking tiles, night-time visual surveys and tracking with snow cover). Night-time observations were essential for targeting control resources and identifying sanitary problems that only appeared after dark (e.g. plastic rubbish bags left out on sidewalks).

Administrative elements were emphasised as part of the IPM program. Contract specifications for both pest control contractors and municipal agencies were developed (Colvin et al. 1992). This provided a basis for accountability and performance. Program elements were centrally scheduled, to maximise timing and geographical distribution of resources. Data management and mapping using a geographic information system was important for efficiency of operations (Von Wahlde and Colvin 1994); this included tracking of events over the entire project area, historic patterns of problems and poison placements in utility systems. Standardised data sheets were used to collect information for program planning and analysis. Data sheets also helped ensure that personnel were performing their assigned tasks. Cost containment was predicated on maintaining a proactive rather than haphazard or reactive approach.

An important administrative element that characterised the dynamics of the program was a referral system. All members of the program team were cross-trained to identify program issues, even though the particular issue might involve a task assigned to another team member (agency or contractor). If a pest control contractor observed a sanitary problem on private property, the contractor could refer that observation through the centralised program office to the city agency responsible for enforcement. Similarly, observations by a city agency of a rat infestation needing treatment could be referred to a pest control contractor assigned to the particular geographic region. All referrals were tracked on a database to ensure they were followed through.

The program also entailed habitat modification beyond basic rodent-proofing of structures (i.e. sealing of holes and entry points). Landscaping within the project area was evaluated and factors conducive to rodent activity were identified (Colvin et al. 1996). Rodent-proofing principles were then incorporated into design specifications for final surface restoration and landscaping. For example, rat abundance in landscaped areas was associated with the amount of coverage by shrubbery. Plots with massed needled evergreens were most susceptible to infestation, in contrast to plots with broad-leafed evergreens and deciduous shrubs. Numerous property owners and businesses re-designed their existing landscaping, reducing densely planted needled-evergreens and giving greater emphasis to stone mulch, shrubbery spacing, refuse containers, maintenance, and trees and shrubs that did not produce excessive fruit. Varieties that grow in vase-like, rather than mounded, shapes provided more openness within landscaped areas.

Results of the control program can be characterised in several ways. Brick sewers with pipe diameter <61 cm in residential areas had the highest subsurface rat activity;

up to 38% of those manholes were active at the program start (baseline). Bait consumption and the number of active sewer holes were 96% and 87% below baseline, respectively, when seasonal baiting was last initiated in 1997. The Code Enforcement Police in 1996 were issuing 67% fewer tickets for sanitation violations than in 1991, even with intensified efforts. About 375 properties were identified with rat activity during baseline surveys; by 1997, control efforts were needed on about ten of those properties (<4% of those originally identified). Another 25–30 properties required close monitoring to detect potential re-infestation. Referrals by the program's pest control contractors to the City for resolution of sanitary problems and rat activity on private property declined from a high of 153 in 1993 to 13 in 1995 and 20 in 1996 (87% reduction). Visual night-time surveys for rat activity declined from a localised average event of 104 sightings per hour (range 19–500) to incidental observations within the project area (>99% reduction). These 'real world' statistics collectively demonstrated that the program approach was effective.

Throughout the program, phone calls from the public concerning complaints about rodents and sanitation remained relatively constant, independent of the obviously positive environmental changes that were occurring. However, the magnitude of problems identified by the public grew less as the program continued. The relatively constant input from the public was a positive event, since it demonstrated sustained participation by the communities. This was achieved through the consistent presence of program staff in the neighbourhoods, timely and effective response to public concerns, involvement of community leaders, and repetitive positive feedback to political entities by program managers and the public. Neighbourhood 'cleanup days' evolved with the participation of residents and businesses, and awards and recognition were given. The pattern of success, involvement, and commitment broke the public scepticism that commonly degrades the opportunity to sustain an urban rodent control program.

The Boston model had several elements that proved crucial for success. Foremost was a true partnership among City agencies, community groups, and contracted management and pest control firms. The model demonstrated that a blend of municipal and privatised functions worked well and could succeed, but only with technical leadership, open sharing of information, consistent communication among team members, and trust. It had to be one team focused on an IPM strategy, with excellent diversity of skills and accountability on the part of each team member. Weekly meetings within various program groups and quarterly team meetings enhanced training and communication.

Future Opportunities

The future of urban rodent control is not limited by science and technology; it is limited by politics and bureaucracies. Personnel management, budgets, contracts, news media, legal proceedings and political agendas were not factored together when Davis and others performed the original ecological research in Baltimore, but they must be today for the science of rodent control to be implemented. When Davis (1972) summarised rodent control in context of future strategies, he expressed frustration with the political impedance of urban rat control and use of short-term solutions. He reaffirmed the need to focus on basic biological principles (i.e. reducing carrying capacity) and the need for competent administrators.

Urban programs need to be consistently and strategically managed rather than politically cyclic in their implementation and focus. Lethal measures need to be intensive rather than simply cropping populations and spurring higher reproductive rates that occur with lower competition. In other words, many urban programs function today on the steep slope of the sigmoid growth curve (Figure 1). A temporary lowering of the number of animals is achieved by a punctuated control effort, but subsequently a sudden population rebound occurs. This sudden perturbation of rodents often is misinterpreted as a 'new' population of colonists. Whereas in reality, the population may never have been effectively controlled to start with and has simply responded reproductively as the sigmoid curve predicts.

There must be a commitment to long-term management of the urban environment and an organisational structure to achieve closure of issues day-by-day. This type of preventative approach is actually a more cost-effective (economical) approach long-term than chronically reacting to crises and public complaints. Of course, any program also must have the capability to respond quickly to sudden problems and emergencies (e.g. disease, rat bites or localised outbreaks).

Rats need to be viewed as an 'indicator species' of environmental quality (or degradation), and programs need to focus on causal factors for species success rather than simply being reactive and poison dependent. The goal must be to manage populations at the low end of the sigmoid growth curve by reducing carrying capacity and giving greater emphasis to surveillance monitoring and sanitation controls. A behavioural shift from rat hunting to environmental management and monitoring is needed. This represents an ecologically-based strategy.

The kind of organisational management and IPM methods demonstrated in the 1990s in Boston should become the foundation of program implementation in the 21st century. An effective program will include centralised leadership, partnerships among participants, sound definition of work scope, assigned responsibilities, mapping and data management capabilities, and education of policy makers. A program approach should be comprehensive in scope and structure, and inclusive in terms of participants (Figure 3).

An emphasis on the engineering and structural maintenance of urban environments, to reduce pest habitat and permanently lower carrying capacity, is critically needed as part of public health management. Rodent control should be incorporated into both urban planning (design) and urban maintenance if a truly proactive program is desired. Municipalities also should require rodent control for major construction projects, since by their nature they create rodent habitat during the

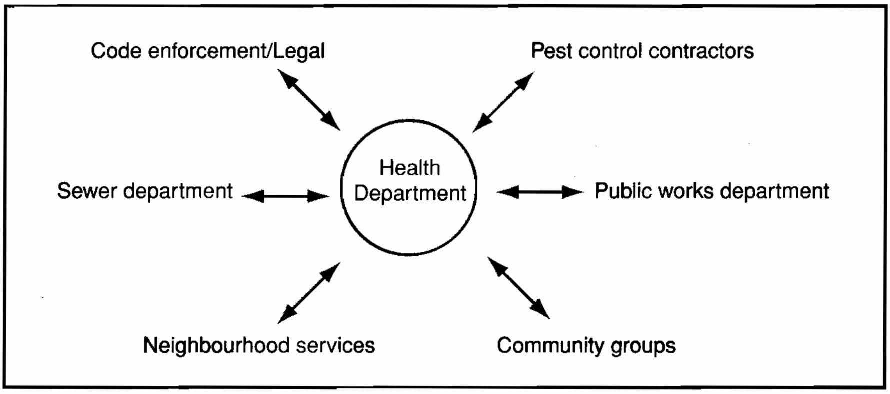

Figure 3.
A flow chart that illustrates a centralised, inclusive and organised approach to managing an urban rodent control program.

construction phase. Biologists need to become more familiar with design engineering and urban infrastructure, and work with engineers and architects.

Basic research and stewardship on the use of refuse containers, recycling programs, and refuse management and containment should be a priority. A shift from focusing primarily on rodenticide and traps (reactive approach) to sanitation management (proactive approach) is needed in urban environments. This includes use of rodent-proof containers (rubbish bins, dumpsters, refuse compactors and grease containers), public education campaigns, reduction of refuse volume, and uniform refuse containers and pickup times. Foremost, there must be effective and enforceable sanitation laws and practices established. For example, keeping lids securely closed on containers, not using plastic bags alone for refuse storage, avoiding placement of refuse outside overnight the day before collection, and timing necessary night-time collections to minimise the number of hours that refuse is exposed.

Inclusion of subsurface environments (sewers), currently ignored by most municipalities, must become a fundamental part of urban rodent control programs (Figure 4). Subsurface populations function as reservoirs that can chronically re-infest surface areas and 'elevate' disease organisms. Effective training on subsurface baiting and control is needed worldwide and will have to be incorporated into comprehensive training necessary for the success of any program.

Use of rodenticide in the future will have to be more carefully planned and implemented than typically occurs in most cities today. The spread of genetic resistance, including the recent involvement of second-generation anticoagulant compounds (MacNicoll et al. 1996), presents a significant concern for the future of urban rodent control and public health management. Rodenticide, rather than habitat management, too often is the primary approach used today by municipalities. This provides short-term resolution but may result in long-term problems.

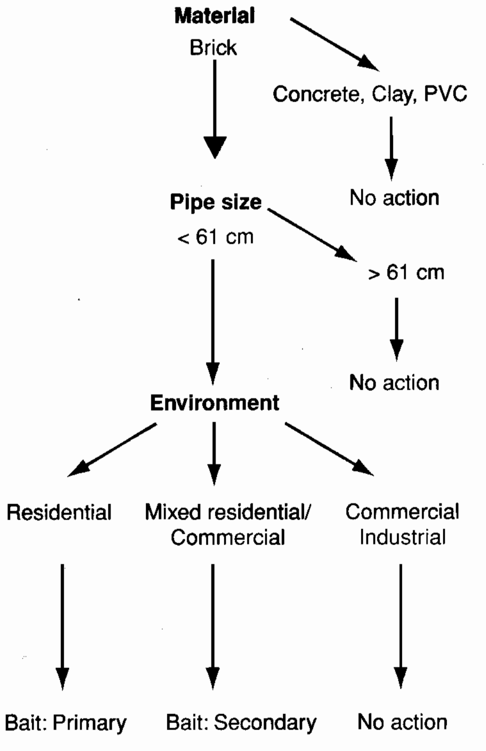

Figure 4.
An example of how to strategically implement and prioritise a sewer baiting campaign (Colvin et al. 1998).

Excessive use of rodenticide, while allowing sanitary problems to remain, presents a condition for rapid reproduction by survivors and the perpetuation of genetic qualities favourable to resistance. The strategy for lowering the potential for resistance must be to focus on environmental management and the wise use of rodenticide.

Diversity of skills should be sought when establishing a rodent control team. For example, a creative approach for public education may require the involvement of public relations and marketing experts. Teachers, lawyers, engineers, contract administrators, computer scientists, property managers, architects and social workers must be made part of the immediate or extended team to maximise program effectiveness.

A rodent control program should have an 'action plan' that defines program elements and implementation. The action plan should describe: program organisation, staff responsibilities, training, legal requirements and enforcement capabilities, contracted services, schedules, sanitation management, infrastructure design and maintenance, mapping and data management, lethal measures (including subsurface), public education and outreach, community organising, surveys and monitoring, and administrative elements.

Whether in a developed or developing nation, the ecological and organisational principles associated with urban rodent control are largely the same. The difference may be the extent of program resources available; however, it can not be assumed today that a developed nation automatically has an advantage regarding program implementation. Large, developed cities can provide more habitat, have greater bureaucracy, but have no better technical knowledge than found in smaller cities or cities in developing nations. The beginning point for all is the establishment of qualified staffing and training, political and budgetary commitment, enforceable sanitation laws, and defined responsibilities and program goals. Implementation of the IPM plan follows, encompassing surveys, public education, sanitation programs, baiting/trapping, structural improvements, community involvement, scheduling and monitoring.

Technical leadership is a serious constraint for urban rodent control today, and this needs to be overcome through involvement of universities and federal and state agencies. Field personnel on the municipal level need to base their efforts on facts rather than myths. To assist them, they need technical support that is accessible, knowledgeable and practical. In that regard, research biologists must help resolve any technical gaps concerning control methods and local ecological factors. They also must learn to partner directly with municipal personnel and translate the science of rodent control for the 'real world', so programs can be better designed, implemented and sustained.

The history of urban rodent control and the 'lessons learned' in recent years present a 'road map' for future success. However, without political support and effective administration, implementation of urban rodent control programs will continue to be limited and public health and economic impacts will result. The ecological and political arenas of the urban environment are complex and interrelated, and urban rodent control programs can only be implemented effectively when both of those subjects are mastered.

References

Al Senei, K.S., Zaghhloul, T. and Balba, M. 1986. Organisation of the rodent control project in Kuwait. In: Richards, C.G.J. and Ku, T.Y., ed., Control of mammal pests. London, Taylor and Francis, 143–150.

Bajomi, D. and Sasvari, K. 1986. Results of eight years' examination of the habitats of residual urban rat populations after eradication. In: Salmon, T.P., ed., Proceedings of the 12th Vertebrate Pest Conference. Davis, University of California, 66–74.

Calhoun, J.B. 1948. Mortality and movement of brown rats (*Rattus norvegicus*) in artificially super-saturated populations. Journal of Wildlife Management, 12, 167–172.

Calhoun, J.B. 1963. The ecology and sociology of the Norway rat. Publ. No. 0-676-768. Dept. of Health, Education and Welfare. Bethesda, Maryland, US Public Health Service, 288p.

Chitty, D. and Southern, H.N. 1954. Control of rats and mice. Volumes 1 and 2—rats, 532p.; Volume 3—mice, 225p. Oxford, Clarendon Press.

Colvin, B.A., Ashton, A.D., McCartney, W.C. and Jackson, W.B. 1990. Planning rodent control for Boston's Central Artery/Tunnel Project. In: Davis, L.R. and Marsh, R.E., ed., Proceedings of the 14th Vertebrate Pest Conference. Davis, University of California, 65–69.

Colvin, B.A., De Gregorio, R. and Fleetwood, C. 1996. Norway rat infestation of urban landscaping and preventative design criteria. In: Timm, R.M. and Crabb, A.C., ed., Proceedings of the 17th Vertebrate Pest Conference. Davis, University of California, 165–171.

Colvin, B.A., Meininger, C.A. and Grealy, M.J. 1992. Administrative procedures and contracts for vertebrate pest programs. In: Borrecco, J.E. and Marsh, R.E., ed., Proceedings of the 15th Vertebrate Pest Conference. Davis, University of California, 236–240.

Colvin, B.A., Swift, T.B. and Fothergill, F.E. 1998. Control of Norway rats in sewer and utility systems using pulsed baiting methods. In: Baker, R.O. and Crabb, A.C., ed., Proceedings of the 18th Vertebrate Pest Conference. Davis, University of California, 247–253.

Davis, D.E. 1953. The characteristics of rat populations. Quarterly Review of Biology, 28, 373–401.

Davis, D.E. 1972. Rodent control strategy. Pest control strategies for the future. Division of Biology and Agriculture, National Research Council, National Academy of Sciences, Washington, D.C., 157–171.

Davis, D.E., Emlen, J.T. and Stoke, A.W. 1948. Studies on home range of the brown rat. Journal of Mammalogy, 29, 207–225.

Davis, D.E. and Fales, W.T. 1949. The distribution of rats in Baltimore. American Journal of Hygiene, 49, 247–254.

Davis, D.E. and Fales, W.T. 1950. The rat population of Baltimore, 1949. American Journal of Hygiene, 52, 143–146.

Davis, D.E. and Jackson, W.B. 1981. Rat control. In: Coaker, T.H., ed., Advances in applied biology, Vol. 6. New York, Academic Press, 221–277.

Davis, H., Casta, A. and Schatz, G. 1977. Urban rat surveys. Publ. No. 77–8344. Dept. Health, Education, and Welfare. Atlanta, US Public Health Service, 22p.

Drummond, D.C. 1970. Rat free towns: the strategy of area control. Royal Society of Health, 90, 131–134.

Drummond, D.C. 1985. Developing and monitoring urban rodent control programmes. Acta Zoologica Fennica, 173, 145–148.

Drummond, D.C., Taylor, E.J. and Bond, M. 1977. Urban rat control: further experimental studies at Folkstone. Environmental Health, 85, 265–267.

Drummond, D.C., Taylor, E.J., Bond, M. and Greaves, J.H. 1972. Urban rodent control: an experimental study. Monograph Series. London, Association of Public Health Inspectors, 34p.

Emlen, J.T., Stokes, A.W. and Davis D.E. 1949. Methods for estimating populations of brown rats in urban habitats. Ecology, 30, 430–441.

Emlen, J.T., Stokes, A.W. and Winsor, C.P. 1948. The rate of recovery of decimated populations of brown rats in nature. Ecology, 29, 133–145.

Frantz, S.C. and Davis, D.E. 1991. Bionomics and integrated pest management of commensal rodents. In: Gorham, J.R., ed., Ecology and management of food industry pests (FDA Tech. Bull. 4). Arlington, VA, Association of Official Analytical Chemists, 243–313.

Gacs, F., Herczeg, T., Papacsi, L. and Elek, S. 1977. Methods of monitoring rat infestations, and approval schemes for city-wide deratization operations. EPPO (European Plant Protection Organization) Bulletin, 7, 533–539.

Gratz, N.G. 1994. Rodents as carriers of disease. In: Buckle, A.P and Smith, A.H., ed., Rodent pests and their control. Wallingford, UK, CAB International, 85–108.

Howard, W.E. 1984. An effective organisation is essential for successful rodent control. In: Dubock, A.C., ed., Proceedings of a conference on Organisation and Practice of Vertebrate Pest Control. Hampshire, UK, ICI, 437–442.

Jackson, W.B. 1982. Norway rats and allies. In: Chapman, J.A. and Feldhamer, G.A., ed., Wild mammals of North America: biology, management, economics. Baltimore, MD, The Johns Hopkins University Press, 1077–1088.

Jackson, W.B. 1984. Urban rodent control in the United States. In: Dubock, A.C., ed., Proceedings of a conference on Organisation and Practice of Vertebrate Pest Control. Hampshire, UK, ICI, 61–71.

Jackson, W.B. 1998. Ecology of pest rodents in the urban environment. In: Ambasht, R.S., ed., Modern trends in ecology and environment. Leiden, The Netherlands, Backhuys Publishers, 101–113.

Jackson, W.B., Ashton, A.D. and Delventhal, K. 1988. Overview of anticoagulant usage and resistance. In: Suttie, J.W., ed., Current advances in vitamin K research. Amsterdam, The Netherlands, Elsevier Science Publishing, 381–388.

Kaukeinen, D. 1994. Rodent control in practice: householders, pest control operators and municipal authorities. In: Buckle, A.P. and Smith, A.H., ed., Rodent pests and their control. Wallingford, UK, CAB International, 249–271.

Lund, M. 1994. Commensal rodents. In: Buckle, A.P. and Smith, A.H., ed., Rodent pests and their control. Wallingford, UK, CAB International, 23–43.

MacNicoll, A.D., Kerins, G.M., Dennis, N.J. and Gill, J.E. 1996. The distribution and significance of anticoagulant-resistant Norway rats (*Rattus norvegicus*) in England and Wales, 1988–95. In: Timm, R.M. and Crabb, A.C., ed., Proceedings of the 17th Vertebrate Pest Conference. Davis, University of California, 179–185.

Myllymäki, A. 1969. An early approach to a rat-free town in Finland. Schriftenreihe des Vereins für Wasser-Boden und Lufthygiene, Berlin-Dahlem, 32, 161–166.

Pratt, H.D., Bjornson, B.F. and Littig, K.S. 1976. Control of domestic rats and mice. Publ. No. 76–8141. Dept. Health, Education, and Welfare. Atlanta, US Public Health Service, 47p.

Pratt, H.D. and Brown, R.Z. 1976. Biological factors in domestic rodent control. Publ. No. 76–8144. Dept. Health, Education, and Welfare. Atlanta, US Public Health Service, 30p.

Pratt, H.D. and Johnson, W.H. 1975. Sanitation in the control of insects and rodents of public health importance. Publ. No. 76–8138. Dept. of Health, Education, and Welfare. Atlanta, US Public Health Service, 42p.

Scott, H.G. and Borom, M.R. 1976. Rodent-borne disease control through rodent stoppage. Publ. No. 97-537. Dept. Health, Education, and Welfare. Atlanta, US Public health Service, 33p.

Telle, H.J. 1969. 12-Jahre grossraumige Ratten-bekampfung in Niedersachsen-kritischer Ruck-und Ausblick. Schriftenreihe des Vereins für Wasser-Boden und Lufthygiene, Berlin-Dahlem, 32, 131–143.

Von Wahlde, M. and Colvin, B.A. 1994. Using geographic information systems for tracking an urban rodent control program. In: Halverston, W.S. and Crabb, A.C., ed., Proceedings of the 16th Vertebrate Pest Conference. Davis, University of California, 327–334.

Section 3

Case Studies in Asia and Africa




12. Rodent Pest Management in Agricultural Ecosystems in China

Zhibin Zhang, Anguo Chen, Zhendong Ning and Xiuqing Huang

Abstract

Rodent pests are a serious problem of agricultural production in China. Abnormal climate patterns of recent decades, with more severe droughts and warmer winters, have allowed rodents to become increasingly abundant. In the early 1980s, there was a widespread outbreak of rodents in the agricultural areas of China. Since 1986, rodent management has been listed three successive times as a national five-year-plan key project (1986–1990; 1991–1995; 1996–2000). These key projects aim to (1) collect long-term population data on major rodents and establish forecasting models, (2) understand population recovery and community succession after large scale management, (3) develop effective control techniques and strategies, and (4) set up demonstration areas to assist local governments to launch a large-scale rodent control campaign. In this paper, a brief introduction to the results of our national key projects in four agricultural regions is given. The agricultural regions and their main pest species are (i) the North China Plain, rat-like hamster (*Cricetulus triton*), (ii) the Northwest Loess Plateau, Chinese zokor (*Myospalax fontanieri*), (iii) the Dongting Lake region along the Yangtze River, oriental vole (*Microtus fortis*) and (iv) the Pearl River Delta, *Rattus rattoides*. The problems and future challenges of rodent pest management in agricultural ecosystems are also discussed.

Keywords

Rodent pest management, agricultural ecosystem, China

INTRODUCTION

On the world scale, China has the largest population (1.2 billion people), but one of the smallest average family holding of arable land (less than 0.4 ha). Grain production is listed as the top priority by the central government in China. In most areas of the countryside, farmers not only depend on grain for food, but also for earning money by selling grain to the market or to the government.

There are four key regions of grain production in China (Figure 1). The first is the North China Plain, which belongs to the middle and lower regions of the Yellow River and regions of the Huai-He and Hai-He Rivers. Wheat, corn, peanuts and green beans are the major crops. The second is the South China Plain, located in the middle and lower regions of the Yangtze and Pearl Rivers. Rice is the major crop in this region. The third is the Northeast China Plain, which is formed by the flood plains of the Hei-Long-Jiang River, Nen-Jiang River, Song-Hua-Jiang River and Liao-He River. Corn, wheat and soybean are the major crops in this region. The fourth is the Northwest Loess Plateau, located in the upper reaches of the Yellow River, where corn and wheat are the major crops.

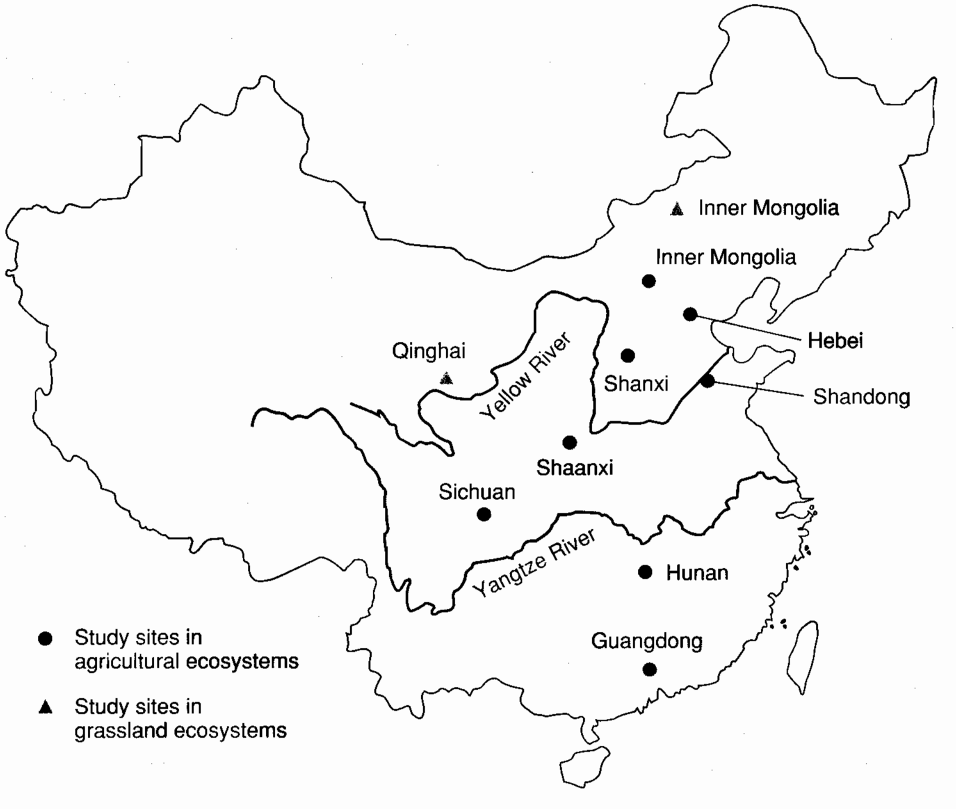

Figure 1.
Long term study sites for rodent ecology and management in China.

Although the annual grain production in China is now greater than 500 million t, in the remote areas there are still several million people who are short of grain. The government is planning to increase production by 25 million t every year during 1996–2000 by introducing new agricultural technologies. Plant protection, through management of diseases, insects, weeds and rodents is listed as the top priority in realising this goal. Since the 1980s, rodent problems have become more and more serious. Changes in climate nationally have resulted in more severe droughts and warmer winters (Wang and Ye 1992) which are two important factors influencing rodent abundance. In 1997, the Yellow River, called the mother-river of China, was without water flow for more than 100 days. Usually the river flows continually. This is indicative of the severity of the droughts that China (especially North China) is facing.

In 1982, large-scale eruptions of rodent populations occurred in the farmlands of China. The area of infested arable land was greater than 27 million ha, about 27% of the total arable land in China. The annual grain loss caused by rodents was over 15 million t. In one year, over 140,000 people contracted rodent-borne diseases (mostly epidemic haemorrhagic fever, leptospirosis and endemic typhus) (Wang 1996).

In 1983, the State Council of the Chinese Central Government issued an urgent document calling for local governments to launch a movement on rodent control in farmland and grassland. Rodent control was listed in the top three priorities for the plant protection program. Consequently, the governments of different levels put much effort and resources into rodent control. About 44% of infested areas were treated using rodenticides, and grain losses were reduced by approximately 7.5 million t (Table 1). However, since early 1993, input by governments on rodent control has been much reduced due to changes in government infrastructure and policy. Farmers have become responsible for their own rodent control with much less coordination by government.

Table 1.
The area of arable land infested by, and treated for, rodents in China from 1980 to 1993 (from Zhao 1996).

Year	Infested area (million ha)	Treated area (million ha)
1980	3.3	1.3
1981	6.7	3.3
1982	20.0	2.5
1983	21.5	9.9
1984	24.0	8.7
1985	24.8	14.5
1986	33.9	17.5
1987	39.3	17.3
1988	26.7	11.7
1989	21.3	14.7
1990	21.3	6.7
1991	20.3	13.9
1992	21.5	13.3
1993	33.3	5.0
Total	**317.9**	**140.3**

Note: data for 1980–82 were based on surveys in 18 provinces; data for 1983–87 in 20–24 provinces; data for 1988–1991 in 27 provinces; data for 1992 in 26 provinces; data for 1993 in 22 provinces.

The magnitude of the rodent outbreaks in the arable land of China in the early 1980s also led to an increased effort in rodent research. Since 1985, rodent control has been listed in three successive national five-year-plan projects (1985–1990; 1991–1995; 1996–2000) by the central government. There are approximately 100 scientists with the Chinese Academy of Sciences, Ministry of Agriculture and universities working on rodent control. Long-term study sites located in key regions of grain production were selected (Figure 1) according to level of the rodent infestation. Table 2 gives details of the locations of the study sites and the major rodent pest species in each. No sites were on the Northeast China Plain. Two study sites within the grassland ecosystem (Figure 1) were selected and the findings from research conducted at these sites are reported elsewhere in this book (Fan et al, Chapter 13; Zhong et al., Chapter 9). In 1986, another study site, which does not belong to the key regions of grain production but with local heavy rodent infestation, was selected in the south part of the Inner Mongolia Plateau. This region is a mixture of cropland and grassland. Mongolian gerbils (*Meriones unguiculatus*) cause huge damage to crops (mostly cereals and potato) in this region.

Since 1985, population surveys, assessment of rodent damage, and control techniques and strategies, have been extensively studied by well-trained scientists. Scientific staff at each of the study sites provide technical extension and advice for instigating local rodent control campaigns. In this chapter, case studies are described from four major agricultural regions, focusing on the achievements of rodent control based on biological and ecological knowledge of the target rodent pests.

Table 2.
Long-term study sites of the three successive national five-year-plan projects on rodent ecology and management in key regions in China.

Key regions	Study sites	Major pest species
North China Plain	Hebei Province Shandong Province	*Cricetulus triton* *Cricetulus barabensis*
Northwest Loess Plateau	Shanxi Province	*Myospalax fontanieri*
		Citellus dauricus
	Shaanxi Province	*Microtus mandarinus*
		Cricetulus triton
South China Plain (Yangtze River Region)	Hunan Province (Dongting Lake Region)	*Rattus norvegicus* *Microtus fortis*
	Sichuan Province	*Rattus nitidus* *Rattus norvegicus*
South China Plain (Pearl River Delta)	Guandong Province	*Rattus rattoides* *Bandicota indica*
Inner Mongolian Plateau	Inner Mongolia	*Meriones unguiculatus*

Case Studies of Rodent Management in the Major Agricultural Regions

Hamster management in the North China Plain

Agricultural systems and environments

In the North China Plain, wheat is planted in autumn (October) and harvested the next summer in June. Summer corn is planted immediately after the wheat harvest and is harvested in October. Small areas of the arable land are not planted in October. Instead, they are planted the next spring with crops such as cotton, peanuts, soybean and spring corn. Therefore there are three sowing seasons (April, June and October) as well as two harvest seasons (June and October).

The climate in this region belongs to the warm–temperate zone. It is very cold in winter and very hot in summer. The annual rainfall is approximately 400–500 mm, with 80% of the annual rainfall occurring in summer (June, July and August).

Ploughing and irrigation are two major agricultural activities in the sowing seasons. Other common activities in the fields include spreading of chemical insecticides and fertilisers, and the clearing of weeds. Most of these activities have a negative effect on rodent populations in this region. Ploughing and irrigation destroy their burrow systems, and sometimes kill the juveniles directly. The spatial distribution of burrow holes of the rat-like hamster is clearly affected by periods of intensive agricultural activities; most of the burrows are constructed in the banks or in non-irrigated or non-ploughed wastelands (small patches of trees and grasses) during this time (Zhang et al. 1997c).

In 1986 in Raoyang County, Hebei Province, the impact of winter irrigation on the habitat and distribution of the burrows of the rat-like hamster (*Cricetulus triton*) was examined. The density of burrows of the hamster in the wasteland was 67.7 holes/ha, while the density in irrigated farmland was 35.6 holes/ha (Zhang et al. 1997c). Winter irrigation of wheat is therefore crucial in reducing the over-wintering hamster population.

Reproduction patterns and population dynamics

The climate, crop plantation system and agricultural activities determine the seasonal reproduction and population dynamics of rat-like hamsters. Rat-like hamsters usually begin to reproduce in early March and finish breeding by the end of August or early September. The adult female hamsters that survive the winter produce three litters and their young of that season may in turn produce 1–2 litters. Females born in early autumn do not breed until the next spring. The litter size of the rat-like hamster ranges from 2–22 with an average of 9 or 10. The reproductive performance of hamsters is considerably affected by population density. In the peak year of 1996 (average trap success 7.7%) the average litter size of the rat-like hamster was 9.1 with a pregnancy rate of 24.8%. In the trough year of 1998 (average trap success of 1.2%), the average litter size was 9.9, with a pregnancy rate of 39.2% (Zhang et al. 1998).

For the rat-like hamster, there are two periods of high density within a year; one in spring and one in autumn. The autumn peak (e.g. in 1986) is usually larger than the spring peak (Figure 2). Heavy rains and high temperatures in summer cause low population densities by increasing the mortality rate of the hamsters. In 1986, the monthly mortality rates of rat-like hamsters were 0.19, 0.14 and 0.42 in spring, autumn and summer, respectively (Zhang et al. 1992). The high summer temperatures (possibly together with the interaction of heavy rain or changes in the photoperiod) result in a 10-day longer mean interval between pregnancies for hamsters compared to spring (Zhang et al. 1991).

Since the early 1980s, the winter has become warmer in the North China Plain and the seasonal population patterns have begun to change, with the magnitude of the spring peak similar to, or higher than, the autumn peak. Taking 1986 and 1994 as examples, the average air temperature in January in 1986 and 1994 was –3.66°C and –2.1°C, respectively; the hamster population density in January was 0.07% and 3.01%, respectively; and the mortality from the previous October to April was 0.83 and 0.56, respectively. This resulted in a higher spring peak than autumn peak in 1994 (Figure 2).

Damage and assessment

The rat-like hamster has a mean body mass of 120 g and is principally a seed-eater; 70% of the food carried in its cheek pouches is composed of crop seeds, 15% stems, roots, flowers and leaves of crops, and 15% insects (Wang et al. 1991). The main damage caused

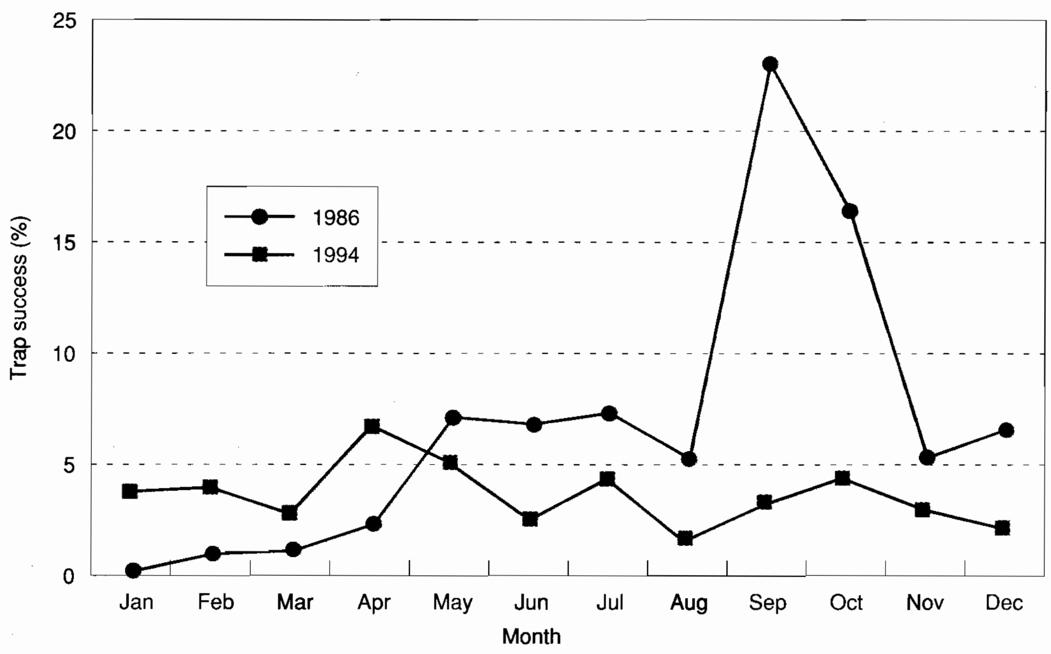

Figure 2.
Seasonal dynamics of the rat-like hamster population in 1986 and 1994 in Raoyang County, Hebei Province (from Zhang et al. 1998).