Invasive Rodent Ecology, Impacts, and Management with an Emphasis on the United States

Gary W. Witmer
USDA APHIS National Wildlife Research Center, Fort Collins, Colorado
William C. Pitt
USDA APHIS National Wildlife Research Center, Hilo Hawaii
Gregg Howald
Island Conservation, Kelowna, British Columbia, Canada

ABSTRACT: Many invasive rodent species have become established in the United States and its territories, both on the mainland and on islands. While most were introduced accidently, some were introduced for food or fur. These rodents have caused serious impacts to native flora and fauna, agriculture, and other resources. They have caused the extinction of many species of birds in insular ecosystems. Although many methods are used to control or eradicate introduced rodents, rodenticides and traps are the main tools. Since the early 1990s, agencies have been eradicating rodents from various islands, primarily for conservation purposes. There have been numerous eradication attempts in the United States and most have been successful. We review introduced rodent impacts and eradications, both successful and unsuccessful, which have occurred, with an emphasis on the United States. Finally, we consider some research needs and some remaining challenges in invasive rodent management and eradication in the United States, including the use of toxicants, land access, public attitudes, resource availability, and monitoring difficulties.

KEY WORDS: eradication, invasive species, management, rodent control, rodents, United States, wildlife damage

Proc. 26th Vertebr. Pest Conf. (R. M. Timm and J. M. O'Brien, Eds.)
Published at Univ. of Calif., Davis. 2014. Pp. 15-20.

INTRODUCTION

Many species of plants, microbes, and animals have been introduced around the world. Species are considered "alien" or "invasive" when they are not native to an area, but become established and cause, or are likely to cause, economic or environmental harm or harm to human health (NISC 2008). Pimentel (2011) compiled information on the economic and environmental costs of introduced species around the world. Some vertebrate species were introduced purposefully, while others were introduced inadvertently or by escaping captivity. Purposeful introductions include animals used for food, fur, as work animals, or as companion animals. In some cases, they were introduced as a means of biological control (e.g., mongoose introduced to control rats). Game animals (including birds, mammals, and fish) have been widely introduced outside their native ranges to provide sporting opportunities and a source of game meat. Larger mammals, such as pigs and goats, were often introduced to islands by early explorers so that a supply of meat would be available to ships stopping on their long voyages. Those same ships were infested with rats and mice which, as a result, have colonized much of the world (Drake and Hunt 2009). Many species of terrestrial vertebrates have been introduced into parts of the United States and its territories (Witmer and Fuller 2011), as has happened worldwide (Long 2003, Lever 2005, Kraus 2009).

The most common vertebrate introductions are the commensal rodents, which have been widely introduced around the world (Long 2003) both on mainland settings and islands. However, it should be noted that many native rodent species occur worldwide. Approximately 40% of all mammalian species are rodents; this amounts to about 2,277 species (Wilson and Reeder 2005). Native rodents have ecological, scientific, social, and economic values (Witmer et al. 1995, Witmer and Singleton 2011). Rodents are important in seed and spore dispersal; pollination; seed predation; energy and nutrient cycling; the modification of plant succession and species composition; and as prey for many predators. Additionally, some species provide food and fur for human uses. Rodents are also used extensively in medical research.

As invasive species, however, rodents are particularly problematic because they have many characteristics that make them very effective invaders. Rodent species have adapted to all life-styles: terrestrial, aquatic, arboreal, and fossorial (underground living). Most rodent species are small, secretive, nocturnal, adaptable, and have keen senses of touch, taste, and smell. In contrast to the normally small-bodied rodent, the capybara (*Hydrochaeris hydrochaeris*) of South America can reach 70 kg in mass. Rodents have excellent abilities to jump, climb, swim, and squeeze through small openings (Timm 1994, Pitt et al. 2011a). For most species of rodents, the incisors continually grow throughout their lifespan, requiring constant gnawing to keep the incisors sharp and at an appropriate length. Additionally, rodents are known for their high reproductive potential: Many species have multiple litters per year with as many as 8-10 young per litter (Corrigan 2001). Many species of rodents are omnivorous and can survive on a wide array of food types. Rodents can survive long periods of inclement weather or food shortages by storing foods for later use and by summer estivation and winter hibernation.

Numerous invasive rodents have become established in parts of the United States and its territories (Witmer and Pitt 2012). These include several species of rats (*Rattus* spp.), house mice (*Mus musculus*), Gambian giant pouched rats (*Cricetomys gambianus*), nutria (*Myocastor*

coypus), hoary marmots (*Marmota caligata*), and arctic ground squirrels (*Spermophilus parryii*). While most were introduced accidently, some were introduced for food or fur. Additionally, some native species of rodents [voles (*Microtus* spp.) and deer mice (*Peromyscus* spp.)] have been placed on islands, at least on a temporary basis, to study rodent species interactions (e.g., Crowell and Pimm 1976, Crowell 1983). Introduced rodents have caused serious impacts to native flora and fauna, agriculture, property, and other resources in the U.S. and around the world (e.g., Long 2003, Shiels et al. 2014).

Several types of damage have been caused by rodent introductions to the United States (Hygnstrom et al. 1994, Witmer and Singleton 2011). The substantial and world-wide loss of human food, both crops in field and stored foodstuffs, has been documented in several reviews (Meerburg et al. 2009a, Witmer and Singleton 2011). In addition to consuming human foodstuffs, rodents also contaminate much more stored food through high levels of defecation and urination. Rodents also transmit many diseases to humans, companion animals, and livestock (Meerburg et al. 2009b). For example, the plague bacteria, *Yersinia pestis* – causal agent of the Black Death that killed millions of humans worldwide in several pandemics – reached North America in the late 1800s via infected rats on ships arriving in California ports (Witmer 2004).

Rodents can be prolific on islands where they have few or no predators. Their omnivorous foraging has led to the endangerment or extinction of numerous island species, especially bird species (Moors and Atkinson 1984, Witmer et al. 1998, Veitch and Clout 2002, Engeman et al. 2006, Towns et al. 2011, Veitch et al. 2011). While their impacts to seabirds have long been known, invasive rodents also impact seeds and seedlings, invertebrates, sea turtle eggs and hatchings, and other resources (Witmer et al. 2007a, Caut et al. 2008, Angel et al. 2009, Towns et al. 2009, Drake et al. 2011, St Clair 2011, Shiels et al. 2014). Most seabirds that nest on islands have not evolved to deal with mammalian predators and are very vulnerable to introduced rodents and other species introductions.

In addition to direct effects, rodents can have many indirect effects on island resources through competition and trophic cascade effects (Russell 2011). Invasive rodents have reached over 80% of the world's island groups, where they have caused the demise of many endemic species (Atkinson 1985). As a result, there has been a concerted worldwide effort to eradicate introduced rodents from islands with numerous successes (Howald et al. 2007, Witmer et al. 2011). These efforts have relied heavily on the use of rodenticides (Howald et al. 2007, Witmer et al. 2007b). In this paper, we review aspects of invasive rodent management and the eradication attempts in the United States. We also discuss some of the challenges that remain.

INVASIVE RODENT MANAGEMENT

Many methods and tools have been developed and used to control rodent populations or to reduce the damage they cause (Witmer and Pitt 2012). Which methods are commonly used varies greatly from region to region around the world as well as between developed and developing countries (Witmer and Singleton 2011). Methods used also vary with regard to the type of management: With long-term management of rodent populations (such as in agricultural and urban/suburban settings) a greater variety of approaches are used, generally through an Integrated Pest Management (IPM) strategy (Witmer 2007, Witmer and Singleton 2011). While traps and rodenticides are the mainstays of rodent population management, IPM also employs habitat management, exclusion, and sanitation (Hygnstrom et al. 1994). On the other hand, if eradication of the invasive rodent species is the management goal, rodenticides are heavily relied upon, although traps may be used to some extent with the rodenticides. Some of the methods are highly regulated, and regulations vary across political jurisdictions. The many methods used to manage rodent populations and damage have been described at length by Prakash (1988), Buckle and Smith (1994), Hygnstrom et al. (1994), Caughley et al. (1998), and Witmer and Singleton (2011). In this paper, we will only address traps and rodenticides in more detail, because they are the main methods to monitor, manage, and eradicate invasive rodents on islands.

A wide array of traps have been developed and used to manage rodents and many types are commercially available (Winn 1986, Hygnstrom et al. 1994, Proulx 1999). Trap types are subdivided into live traps and kill traps. With live traps, the rodent becomes contained in a box or cage trap after tripping a treadle. Another type of live trap is the leg-hold trap, which when tripped by the rodent's paw, springs the jaws of the trap to close tightly around the leg and hold the animal until the trapper arrives. Leg-hold traps are generally only used for larger rodent species such as nutria, muskrats, and beaver. Live traps often can be purchased at hardware or garden stores as well as through catalogues or websites. Leg-hold traps are generally obtained through websites or catalogues. Multiple capture live traps have been developed and tested for some rodent species such as nutria (Witmer et al. 2008). Animals captured in live traps can be relocated to other locations (where regulations allow) or euthanized. An advantage of live traps is that non-target animals captured often can be released unharmed.

Kill traps cause the rapid death of the rodent by body constriction when the rodent trips the trap's trigger mechanism. The most common type of rodent kill trap is the snap trap. These are commonly sold at hardware and garden stores. Another type of kill trap is the Conibear trap, used for larger rodent species. They can be purchased through websites or catalogues. Hygnstrom et al. (1994) provided good illustrations of various types of traps and directions for their proper and effective use. Effective trapping requires skill and practice. Using the proper type of trap for the situation, proper placement, and appropriate bait is very important to achieve a high level of trap success (i.e., a high capture rate). A disadvantage of kill traps is they can injure or kill non-target animals, including birds.

Various types of traps are also used to monitor rodent populations. Rodent population monitoring is essential so that necessary management action can be taken before

populations get very large, at which point extensive damage to resources cannot be avoided.

Rodenticides are widely used in the United States as well other parts of the world. Because of their toxic nature and potential harm to people, pets, and livestock, rodenticides are carefully regulated by the United States Environmental Protection Agency (EPA) as well as by state agencies. There are many types of rodenticides, and these vary by active ingredient as well as formulation (Witmer and Eisemann 2007). These materials vary widely in their mode of action and in toxicity. The types and uses of rodenticides in the United States were reviewed by Witmer and Eisemann (2007). Their specific use for conservation purposes (i.e., the eradication of invasive rodents) was reviewed by Witmer et al. (2007b).

Proper training and careful use is required to safely use rodenticides so that they are effective in reducing rodent populations while minimizing the hazard to non-target animals. An EPA-approved product label provides considerable information on the product and its use, including: the registrant and EPA registration number(s); active ingredient and concentration; target species and settings in which it may be used; directions for use; storage and disposal requirements; precautionary statements; safety and environmental hazards; and threatened and endangered species considerations.

Both primary (direct consumption) and secondary hazards (consuming a poisoned rodent or poisoned non-target animal) can occur to non-target animals when rodenticides are used. Rodenticides such as brodifacoum (a second-generation anticoagulant) are highly toxic but also result in persistent residues in body tissues of animals that consume poisoned rodents (Witmer and Eisemann 2007). There is a growing concern about the secondary effects of these residues in predatory animals (e.g., Thomas et al. 2011). The main safeguard for the safe use of rodenticides in the United States is carefully following the EPA label instructions for the product. Other considerations include the product used; when, where, and how it is applied; cleaning up spills promptly; and not using rodenticides where highly valued or protected wildlife occur (determined by scouting the area before use).

INVASIVE RODENT ERADICATION

Since the early 1990s, federal and state agencies, along with conservation organizations, have been eradicating rodents from various islands in the United States, primarily for conservation purposes. There have been about 400 attempted eradications worldwide with a success rate of about 85%. There have been far fewer attempts at island eradication in the United States (Witmer et al. 2011), with a somewhat lower success rate (~73%; approximately 22 successful eradications in 30 attempts). For several islands in the United States and around the world, however, it is too early to determine if the attempted eradication has been successful or not. In recent years, there have been more attempts to determine if an eradication attempt failed or there was a rapid re-invasion by rodents from nearby islands or from ships or cargo. Genetic analyses of DNA from rats before and/or after eradications is helping sort out the issue of re-invasion versus failed eradication (e.g., Savidge et al. 2012). Numerous additional eradications are underway or being planned. Most (~70%) rodent eradications around the world have used the second-generation anticoagulant brodifacoum (Howald et al. 2007). In the United States, however, about half of eradications have used the first-generation anticoagulant diphacinone (Witmer et al. 2011). Initial rodent eradications used hand-broadcast and bait station application of rodenticides, but in recent years, aerial broadcast via helicopter has become common. This allows rodent eradications on much larger and more rugged islands, such as Rat Island, Alaska (2,700 ha) (Witmer et al, 2011). Currently, the USDA Animal and Plant Health Inspection Service (APHIS) has two rodenticides registered with the EPA for island conservation purposes: one formulation of diphacinone pellets, and two formulations of brodifacoum pellets (Witmer et al. 2007b).

A variety of mitigation measures are employed to reduce non-target hazards and environmental impacts. Examples include the rodenticide type, formulation, method and timing of baiting; placement of some non-target wildlife species in captivity until after the baiting operation; removal of rodent carcasses; and avoidance of bait placement in aquatic systems (Witmer et al. 2007b). In general, impacts to non-target species during invasive rodent eradications should be considered in terms of population-level effects, rather than the effects to individuals, and in terms of the "greater good' that is achieved from a successful eradication. While there will probably always be some losses of non-target animals, proper precautions should minimise such risk and allow for the rapid recovery of affected populations (Howald et al. 2005). Those involved with successful invasive rodent eradications on islands are often surprised at how rapidly the island's flora and fauna recover after rodents are removed (e.g., Witmer et al. 2007a, Aguirre-Munoz et al. 2008, Ruscoe et al. 2012).

Planning and conducting a successful invasive rodent eradication from islands poses many challenges and should not be undertaken without a thorough commitment and adequate resources. The basic tenets of a successful eradication are: all individuals must be put at risk; animals must be removed faster than they can reproduce; and the risk of immigration must be zero (Parkes and Murphy 2003). An eradication attempt that is 99% successful can ultimately result in 100% failure. Because of the large commitment of resources and funds in eradication efforts, the potential for failure should be minimized. Planning and implementation components include: preliminary monitoring and research; feasibility of eradication; regulatory compliance; public information and communications media; public support; technical assistance and operations; planning, logistics, procurement of equipment and other services; monitoring and research; staff recruitment and training; implementation; contingency planning; follow up monitoring; and implementation of a bio-security plan. Adequate attention must be given to all these aspects of an eradication attempt.

CONSERVATION CHALLENGES AND RESEARCH NEEDS

A number of challenges remain with invasive rodent management and eradication in the United States. Some of the challenges faced include public and agency concerns about the use of toxicants and traps, land access (especially to private lands), public attitudes, resource availability, and detection and monitoring difficulties (Witmer and Hall 2011, Witmer et al. 2011, Witmer and Pitt 2012). Additional challenges are surfacing as we attempt more rodent eradications on tropical islands. For example, while most methods used in rodent eradications were developed for temperate islands, tropical islands pose additional problems, such as relatively rapid bait degradation and bait consumption by invertebrates (especially land crabs). Additional challenges are posed by inhabited islands and by certain geophysical features of the island setting such caves, cliffs, shorelines, and tree canopies. While it may be tempting to develop and apply a "cookbook" approach to invasive rodent eradications, it is important to acknowledge and address the varying climates, topographies, plant and animal communities, and varying species interactions that occur on islands.

Nonetheless, we will hopefully continue to relieve the burdens on insular and mainland ecosystems caused by rodent introductions. The flora and fauna of islands generally respond favorably and rapidly after invasive rodents are removed. Endemic, threatened, or endangered species can be, and have been, re-introduced after successful rodent eradications. For example, the endangered St. Croix ground lizard (*Ameiva polops*) was recently reintroduced to Buck Island in the United States Virgin Islands after the successful eradication of roof rats (*R. rattus*) (Witmer et al. 2007a). The recent eradication of Polynesian rats (*R. exulans*) and house mice from Cocos Island (a small island off of Guam) set the stage for the re-introduction of the endangered Guam rail (*Gallirallus owstonii*) (Lujan et al. 2010).

Additional research is needed to improve existing methods and to develop new methods for invasive rodent detection and control. More research is needed in both lethal and nonlethal means of resolving rodent damage situations (Witmer et al. 1995, Witmer and Singleton 2011, Witmer and Pitt 2012). The research should include, but not be limited to, detection methods, new rodenticides, effective repellents, barrier development and improvement, biological control, fertility control, and habitat manipulation. Researchers also need to identify effective commercially-available rodenticide formulations for the various invasive rodents in each region of the country as Pitt et al. (2011b) have done for rats and mice in Hawaii and Witmer and Moulton (2014) have done for house mice on the United States mainland. Another important research need is greater evaluation of the effectiveness of combinations of techniques, given that combinations could potentially be much more effective in the reduction of damage and may be more acceptable to the public.

CONCLUSIONS

Invasive rodents will continue to pose challenges to land and resource managers, commodity producers, and homeowners. Many tools are available to reduce rodent populations and associated damage. They should be used in a well-thought-out IPM approach. Rodenticides will continue to be an important tool against rodents and their damage, but care must be exercised in their use. It is probably safe to assume that much of the public will continue to be leery of toxicant use. Hence, public education will be important to ensure continued availability of rodenticides. Continued technology development and transfer are essential to improve the effectiveness and safety of rodenticides and other methods used to control or eradicate invasive rodents.

Seabird populations, sea turtle populations, and other island resources warrant protection from invasive rodents. The recovery of fauna and flora on uninhabited islands after a successful rodent eradication is particularly notable and thus should continue to inspire future research and eradication efforts. The significant impacts of introduced rodents on native flora and fauna have been repeatedly demonstrated. Invasive rodents are very adaptable, can exploit a wide array of resources as food and cover, and can increase reproduction very quickly when and where abundant resources exist (Macdonald et al. 1999). While invasive rodents will continue to pose challenges to land and resource managers, they can be controlled or even eradicated with a well-planned and adequately-supported effort using rodenticides and other tools. With proper planning, non-target losses will be minimal and those populations, along with other island resources, will often recover quickly after the invasive rodents have been removed.

ACKNOWLEDGMENTS

We acknowledge the informative discussions, presentations, and publications of our colleagues around the world all of which helped us put this paper together. We also thank the many agencies, universities, and private institutions that have assisted in the efforts to understand, control, and eradicate invasive rodents and other invasive species that pose such a serious threat to biodiversity and ecological integrity worldwide.

LITERATURE CITED

Aguirre-Munoz A., D. A. Croll, C. J. Donlan, R. W. Henry III, M. A. Hermosillo, G. R. Howald, B. S. Keitt, L. Luna-Mendoza, M. Rodreguez-Malago, L. M. Salas-Flores, A. Samaniego-Herrera, J. A. Sanchez-Pacheco, J. Sheppard, B. R. Tershy, J. Toro-Benito, S. Wolf, and B. Wood. 2008. High-impact conservation: invasive mammal eradications from the islands of western Mexico. Ambio 37:101-107.

Angel, A., R. Wanless, and J. Cooper. 2009. Review of impacts of the introduced house mouse on islands in the Southern Ocean: are mice equivalent to rats? Biol. Invasions 11:1743-1754.

Atkinson, I. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pp. 35-81 *in*: P. Moors (Ed.), Conservation of Island Birds. Technical Bulletin No. 3, International Council of Bird Preservation, Cambridge, UK.

Buckle, A. P., and R. H. Smith. 1994. Rodent Pests and Their Control. CAB International, Oxon, UK. 405 pp.

Caughley, J., M. Bomford, B. Parker, R. Sinclair, J. Griffiths, and D. Kelley. 1998. Managing Vertebrate Pests: Rodents.

Bureau of Resource Sciences and Grains Research and Development Corp., Canberra, Australia. 130 pp.

Caut, S., E. Angulo, and F. Courchamp. 2008. Dietary shift of an invasive predator: Rats, seabirds and sea turtles. J. Appl. Ecol. 45:428-437.

Corrigan, R. M. 2001. Rodent Control: A Practical Guide for Pest management Professionals. GIE, Inc., Richfield, OH. 355 pp.

Crowell, K. L. 1983. Islands–insight or artifact?: Population dynamics and habitat utilization in insular rodents. Oikos 27:442-454.

Crowell, K. L., and S. L. Pimm. 1976. Competition and niche shifts of mice introduced onto small islands. Oikos 27:251-258.

Drake, D. R., T. W. Bodey, J. C. Russell, D. R. Towns, M. Nogales, and L. Ruffino. 2011. Direct impacts of seabird predators in island biota other than seabirds. Pp. 91-132 *in*: C. P. H. Mulder, W. B. Anderson, D. R. Towns, and P. J. Bellingham (Eds.), Seabird Islands: Ecology, Invasion, and Restoration. Oxford University Press, New York, NY.

Drake, D. R., and T. L. Hunt. 2009. Invasive rodents on islands: Integrating historical and contemporary ecology. Biol. Invas. 11:1483-1487.

Engeman, R., J. Woolard, N. Perry, G. Witmer, S. Hardin, L. Brashears, H. Smith, B. Muiznieks, and B. Constantin. 2006. Rapid assessment for a new invasive species threat: the case of the Gambian giant pouched rat in Florida. Wildl. Res. 33:439-448.

Howald, G., K. Faulkner, B. Tershy, B. Keitt, H. Gellerman, E. Creel, M. Grinnell, S. Ortega, and D. Croll. 2005. Eradication of black rats from Anacapa Island: Biological and social considerations. Proc. California Island Symposium 6:299-312. National Park Service Technical Publication CHIS-05-01, Institute for Wildlife Studies, Arcata, CA.

Howald, G., C. J. Donlan, J. P. Galvan, J. C. Russell, J. Parkes, A. Samaniego, Y. Wang, D. Veitch, P. Genovesi, M. Pascal, A. Saunders, and B. Tershy. 2007. Invasive rodent eradication on islands. Conserv. Biol. 21:1258-1268.

Hygnstrom, S. E., R. M. Timm, and G. E. Larson (Editors). 1994. Prevention and Control of Wildlife Damage. Cooperative Extension Service, University of Nebraska, Lincoln, NE.

Kraus, F. 2009. Alien Reptiles and Amphibians. Springer, Berlin, Germany. 563 pp.

Lever, C. 2005. Naturalised Birds of the World. T & AD Poyser, London, UK. 352 pp.

Long, J. 2003. Introduced Mammals of the World. CSIRO Publishing. Collingwood, Australia. 590 pp.

Lujan, D. T., D. S. Vice, J. P. Guerrero, and C. C. Candaso. 2010. Rodent eradication on Cocos Island, Guam: Integrating wildlife damage management, resort operations, and non-target concerns. Proc. Vertebr. Pest Conf. 24:9-13.

Macdonald, D., F. Mathews, M. Berdoy, and M. Deporter. 1999. The behavior and ecology of *Rattus norvegicus*: From opportunism to kamikaze tendencies. Pp. 49-80 *in*: G. Singleton, L. Hinds, H. Leirs, and Z. Zhang (Eds.), Ecologically-based Management of Rodent Pests. Australian Centre for International Agricultural Research, Canberra, Australia.

Meerburg, B. G., G. R. Singleton, and H. Heirs. 2009a. The Year of the Rat ends – time to fight hunger. Pest Manage. Sci. 65:351-352.

Meerburg, B. G., G. R. Singleton, and A. Kijlstra. 2009b. Rodent-borne diseases and their risks for public health. Crit. Rev. Microbiol. 35(3):221-270.

Moors, P. J., and I. A. E. Atkinson. 1984. Predation on seabirds by introduced animals, and factors affecting its severity. Pp. 667-690 *in*: P. J. Moors (Ed.), Conservation of Island Birds: Case Studies for the Management of Threatened Island Birds. International Council for Bird Preservation, Technical Publ. No. 2. Cambridge, UK.

National Invasive Species Council. 2008. 2008-2012 National Invasive Species Management Plan. National Invasive Species Council, Washington, D.C. 35 pp.

Parkes, J., and E. Murphy. 2003. Management of introduced mammals in New Zealand. NZ J. Zool. 30:335-359.

Pimentel, D. 2011. Biological Invasions: Economic and Environmental Cost of Alien Plant, Animal, and Microbe Species. CRC Press, Boca Raton, FL. 449 pp.

Pitt, W. C., R. T. Sugihara, L. C. Driscoll, and D. S. Vice. 2011a. Physical and behavioural abilities of commensal rodents related to the design of selective rodenticide bait stations. Intl. J. Pest Manage. 57:189-193.

Pitt, W. C., L. C. Driscoll, and R. T. Sugihara. 2011b. Efficacy of rodenticide baits for the control of three invasive rodent species in Hawaii. Arch. Envir. Contam. Toxicol. 60:533-542.

Prakash, I. (Editor). 1988. Rodent Pest Management. CRC Press, Boca Raton, FL. 496 pp.

Proulx, G. 1999. Mammal Trapping. Alpha Wildlife Research & Management, Ltd., Sherwood Park, Alberta, Canada. 231 pp.

Ruscoe, W., P. Sweetapple, M. Perry, and R. Duncan. 2012. Effects of spatially extensive control of invasive rats on abundance of native invertebrates in mainland New Zealand forests. Conserv. Biol. 27:74-82.

Russell, J. C. 2011. Indirect effects of introduced predators on seabird islands. Pp. 261-279 *in*: C. P. H. Mulder, W. B. Anderson, D. R. Towns, and P. J. Bellingham (Eds.), Seabird Islands: Ecology, Invasion, and Restoration. Oxford University Press, New York, NY.

Savidge, J., G. Witmer, S. Jojola, J. Pierce, and P. Burke. 2012. Genetic evaluation of an attempted *Rattus rattus* eradication on Congo Cay, U.S. Virgin Islands, identifies importance of eradication units. Biol. Invasions 14:2343-2354.

Shiels, A., W. Pitt, R. Sugihara, and G. Witmer. 2014. Biology and impacts of Pacific Island invasive species: The black rat *Rattus rattus*. Pacific Sci. 68:145-184.

St Clair, J. J. H. 2011. The impacts of invasive rodents on island invertebrates. Biol. Conserv. 144:68-81.

Thomas, P. J., P. Mineau, R. F. Shore, L. Champoux, P. A. Martin, L. K. Wilson, G. Fitzgerald, and J. E. Elliott. 2011. Second generation anticoagulant rodenticides in predatory birds: Probabilistic characterization of toxic liver concentrations and implications for predatory bird populations in Canada. Envir. Internat. 37:914-920.

Timm, R. M. 1994. Norway rats. Pp. B105 - B120 *in*: S. E. Hygnstrom, R. M. Timm, and G. E. Larson, (Eds.), Prevention and Control of Wildlife Damage. Cooperative Extension Service, University of Nebraska, Lincoln, NE.

Towns, D. R., D. A. Wardle, C. P. Mulder, G. W. Yeates, B. M. Fitzgerald, G. R. Parrish, P. J. Bellingham, and K. I. Bonner. 2009. Predation of seabirds by invasive rats: Multiple indirect consequences for invertebrate communities. Oikos 118:420-430.

Towns, D. R., G. V. Byrd, H. P. Jones, M. J. Rauzon, J. C. Russell, and C. Wilcox. 2011. Impacts of introduced predators on seabirds. Pp. 56-90 *in*: C. P. H. Mulder, W. B. Anderson, D. R. Towns, and P. J. Bellingham (Eds.), Seabird Islands: Ecology, Invasion, and Restoration. Oxford University Press, New York, NY.

Veitch, C. R., and M. N. Clout (Editors). 2002. Turning the tide: The eradication of invasive species. Proceedings of the International Conference on Eradication of Island Invasives. Occ. Paper of the IUCN Species Survival Commission, No. 27. IUCN, Gland, Switzerland and Cambridge, UK. 414 pp.

Veitch, C.R., M.N. Clout, and D.R. Towns (Editors). 2011. Island Invasives: Eradication and Mangement. Intl. Union for the Conservation of Nature, Gland, Switzerland. 542 pp.

Wilson, D.E., and D. M. Reeder. 2005. Mammal Species of the World, 3rd Ed. The Johns Hopkins University Press, Baltimore, MD. 2142 pp.

Winn, J. (Editor). 1986. Identifying and Managing Aquatic Rodents in Texas: Beaver, Nutria and Muskrats. Texas Agricultural Extension Service, College Station, Texas. 46 pp.

Witmer, G. W. 2004. Rodent ecology and plague in North America. Proc. International Congress of Zoology 19:154-156, China Zoological Society, Beijing, China.

Witmer, G. 2007. The ecology of vertebrate pests and integrated pest management (IPM). Pp. 393-410 *in:* M. Kogan, and P. Jepson (Eds.), Perspectives in Ecological Theory and Integrated Pest Management. Cambridge University Press, Cambridge, UK.

Witmer, G., and J. D. Eisemann. 2007. Rodenticide use in rodent management in the United States: An overview. Proc. Wildl. Damage Manage. Conf. 12:114-118.

Witmer, G. W., and P. L. Fuller. 2011. Vertebrate species introductions in the United States and its territories. Curr. Zool. 57:559-567.

Witmer, G. W., and P. Hall. 2011. Attempting to eradicate invasive Gambian giant pouched rats (*Cricetomys gambianus*) in the United States: Lessons learned. Pp. 131-134 *in*: C. R. Veitch, M. N. Clout, and D. R. Towns (Eds.), Island Invasives: Eradication and Management. Intl. Union for the Conservation of Nature, Gland, Switzerland.

Witmer, G., and G. Singleton. 2011. Sustained Agriculture: The Need to Manage Rodent Damage. Pp. 1-38 *in*: F. C. Wager (Ed.), Agricultural Production. Nova Science Publishers, Inc., New York, NY.

Witmer, G., and W. Pitt. 2012. Invasive rodents in the United States: Ecology, impacts, and management. Pp. 47-75 *in*: J. Blanco, and A. Fernandes (Eds.), Invasive Species: Threats, Ecological Impact and Control Methods. Nova Science Publishers, Inc., New York, NY.

Witmer, G. W., and R. S. Moulton. 2014. Improving invasive house mice control and eradication strategies via more effective rodenticides. Proc. Vertebr. Pest Conf. 26:67-72.

Witmer, G. W., M. Fall, and L. Fiedler. 1995. Rodent control, research, and technology transfer. Pp. 693-697 *in*: J. Bissonette and P. Krausman (Editors), Integrating People and Wildlife for a Sustainable Future: Proceedings of the First International Wildlife Management Congress. The Wildlife Society, Bethesda, MD.

Witmer, G., F. Boyd, and E. Campbell. 1998. Rat management for endangered species protection in the U.S. Virgin Islands. Proc. Vertebr. Pest Conf. 18:281-286.

Witmer, G. W., F. Boyd, and Z. Hillis-Starr. 2007a. The successful eradication of introduced roof rats (*Rattus rattus*) from Buck Island using diphacinone, followed by an irruption of house mice (*Mus musculus*). Wildl. Res. 34: 108-115.

Witmer, G., J. Eisemann, and G. Howald. 2007b. The use of rodenticides for conservation efforts. Proc. Wildl. Damage Manage. Conf. 12:160-166.

Witmer, G. W., J. Pierce, and W. C. Pitt. 2011. Eradication of invasive rodents on islands of the United States. Pp. 135-138 *in*: C. R. Veitch, M. N. Clout, and D. R. Towns (Eds.), Island Invasives: Eradication and Management. Intl. Union for the Conservation of Nature, Gland, Switzerland.

Witmer, G. W., P. W. Burke, S. Jojola, and D. L. Nolte. 2008. A live trap model and field trial of a nutria multiple capture trap. Mammalia 72:352-354.