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Rodent Damage Research in Hawaii: Changing Times and Priorities

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Abstract: Rodent damage research in Hawaii has evolved in response to shifts from large-scale monoculture agriculture, such as sugarcane, to cultivation of diversified high-value specialty crops, such as export ornamental nurseries and forestry products. Recent findings and renewed conservation awareness of the impact of predators, especially rodents, as important limiting factors of many of Hawaii's endangered avifauna have stimulated increased efforts to reduce rodent depredation in conservation areas and other natural resources. Some of the early tools developed in agriculture have been incorporated and successfully used for protecting non-agricultural resources and new methods have been developed for current problems. This paper summarizes the rodent research that the National Wildlife Research Center's Hawaii Field Station has conducted over these years of changing economic times and priorities.

Key Words: agriculture, conservation, Hawaii, macadamia, native species, *Rattus* spp., rodent damage, sugarcane, wildlife damage

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INTRODUCTION

Rodent control has a long and varied history in Hawaii. Early sugarcane planters were faced with extensive losses and tried numerous techniques to reduce damage by rats (*Rattus rattus*, *R. exulans*, and *R. norvegicus*). Public officials also recognized the role of rodents as carriers of a number of diseases such as murine typhus, leptospirosis, and salmonellosis. Areas of the islands of Hawaii and Maui were bubonic plague-epidemic hotspots, and the last reported human case occurred in 1949. Plague was still cultured from fleas and rodent tissue until 1957 and is still kept under surveillance by local health vector control personnel (Tomich 1986). In response to requests by the Hawaiian Sugar Planters' Association (HSPA) and other agricultural groups, Congress established a field station in Hawaii in 1967. Operating through a memorandum of understanding with HSPA, the field station conducted laboratory and field research on the biology, impact, and control of rodents in sugarcane and other agricultural crops in Hawaii. Sugar losses were conservatively estimated at $10 million annually (HSPA estimates) and damage to macadamia nuts amounted to 5-10% of the annual crop (Mauna Loa Macadamia Nut Co., H. Ooka, pers. comm.).

HAWAIIAN AGRICULTURE

Sugarcane

Cultivated for over 150 years in Hawaii, sugarcane fields provide an ideal environment for rats. The mild climate, a long 2-plus year crop cycle, and numerous adjacent noncrop areas all contribute to ample food supply, protective cover, few predators, and high fecundity, factors leading to high populations of rats in and around sugarcane fields. A myriad of techniques, particularly acute rodenticides (i.e. barium carbonate, strychnine alkaloid, thallium sulfate, 1080, red squill), historically were employed by sugarcane growers to control rats and reduce damage. In each case, the practice of exclusive and prolonged use of a single toxicant resulted in declining efficacy over time (Doty 1945). The use of anticoagulant baits containing warfarin, fumarin, or pival, placed in ground bait stations, was limited to field perimeters with access trails or roads. Maintenance of bait stations was extremely labor-intensive, and because bait was not readily available to rats living in the interior of the fields, this baiting method was not effective in reducing damage to sugarcane stalks in-field (Lindsey et al. 1971). Mongooses (*Herpestes auropunctatus*), introduced to Hawaii in the late 1890s to control rats, proved ineffective as a predator (Tomich 1986). Losses to rodents were significant and more effective control methods were needed.

Early rodent control research by the Hawaii Field Station focused on a better understanding of the biology and ecology of the three depredating rat species – roof rats (*Rattus rattus*), Polynesian rats (*R. exulans*), and Norway rats (*R. norvegicus*), improving the efficacy of existing control techniques, and identifying new approaches to solving rat damage problems in sugarcane. Extensive screening of candidate toxicants and assessments of non-target and secondary hazards were also conducted. Assessments of direct crop damage and sugar yield losses were also examined at different plantations and climatic zones where sugarcane was grown in Hawaii (Hood 1968, Teshima 1972). Working cooperatively with HSPA, the necessary efficacy and hazards data was collected to register the aerial broadcast application of zinc phosphide-treated oats in sugarcane fields. Approved by the United States Environmental Protection Agency (EPA) in 1970, this was the first in-field (versus field perimeter) use pattern of a rodenticide for a food crop in the United States (Hilton et al. 1972). Improvements in bait formulations and optimization of application rates and schedules for individual plantations resulted in 40-60% reduction in rat damage in treated fields (Pank 1976). However, as in past plantation practices with toxicants, zinc phosphide was used exclusively 4-8 times during the 2-3 year crop cycle over consecutive years. This repeated and prolonged use resulted in significantly declining effectiveness (Sugihara et al. 1995). An interesting trend was noted at the Mauna Kea Sugar plantation on the island of Hawaii where zinc phosphide baiting was fully adopted operationally. There was a gradual shift in relative abundance from Polynesian rats, prior to zinc phosphide use, to predominantly Norway rats after sustained zinc phosphide baiting over a 20-year period (Hirata 1977, Tobin and Sugihara 1992). This suggests that zinc phosphide may have been selectively controlling Polynesian rats. Laboratory bioassays also showed that the zinc phosphide bait was less effective for Norway rats than for Polynesian rats (Sugihara et al. 1995).

The Hawaii Field Station also evaluated the effects of various non-lethal cultural practices on rodent populations and damage to sugarcane. Elimination or manipulation of adjacent wasteland habitats to reduce reservoir rat populations (Sugihara et al. 1977), in-field weed control, incorporation of "rat-resistant" characteristics (i.e., harder rind, larger stalks, upright growth habit) into HSPA's breeding and variety selection program (Sugihara 1990), and earlier harvesting were examined but not fully implemented by the plantations for various reasons, mainly economical.

By the middle to late 1990s, rising labor and land costs, aging milling infrastructure, stricter EPA environmental regulations, the soft drink industry's reliance on alternative sugar sources (i.e., sugar beet, corn), and less expensive foreign imports forced many Hawaiian growers and processors to phase out of sugarcane production. Of the 20-plus plantations on 4 islands growing sugarcane when the field station was established in 1967, today only a single plantation survives on the island of Maui, with a smaller operation on the island of Kauai. Once the premier agricultural industry in Hawaii, sugarcane acreage and production have drastically decreased over the years (Hawaii Agri. Stats. Serv. 2000)

Macadamia Nuts

Commercial cultivation of macadamia nuts (*Macadamia integrifolia*) started in the 1950s with large-scale orchard plantings occurring in the mid-1970s, when approximately 5,000 acres were harvested. Acreage and production gradually increased and peaked in 1998, when approximately 60 million pounds of wet-in-shell nuts were harvested on 20,000 acres (Hawaii Agri. Stat. Serv. 2002). During the 2000-2001 harvest season, 52 million pounds of nuts with a net farm value of $31 million were produced in Hawaii by 4 major grower/processors and 650 individual farms. Similar to sugarcane fields, macadamia nut orchards offer an ideal food source and habitat for rats. There is ample supply of highly nutritious nuts, rich in proteins and carbohydrates (Cavaletto 1983), available to rats over the long 8- to 9-month nut harvesting season. Rats are able to reproduce year-round (Tobin et al. 1994). Their arboreal habits within the orchard results in easy tree-to-tree access and protection from predators such as mongooses, barn owls (*Tyto alba*), and the Hawaiian hawk (*Buteo solitarius*). In addition, the loose lava substrate provides ideal and abundant refugia sites, and the numerous interior windrows, waste areas, and adjacent noncrop areas support invading reservoir rat populations.

Rodent control practices used over the years by individual growers to reduce nut damage by rats consisted mainly of trapping, use of zinc phosphide baits, and anticoagulant rodenticide bait stations placed along interior windbreaks (Fellows 1982). However, these techniques were not adequately reducing nut damage to acceptable levels. Basic research conducted by the Hawaii Field Station identified roof rats as the major species of concern in macadamia nut orchards due to their relative abundance, arboreal habits, and common use of in-tree and in-field refugia sites (Tobin et al. 1994, Tobin et al., 1996). Polynesian rats are common in noncrop areas and windrows and are occasionally trapped in the interior of macadamia nut orchards. However, laboratory feeding trials showed that this species was unable to easily penetrate the hard outer shell of the macadamia nut. Norway rats are restricted to waste areas and structures near orchards and are generally not found in-field, but they can be responsible for significant "hidden" nut losses due to their extensive transport and caching of harvested nuts in warehouses and drying sheds (R. Sugihara, pers. observations).

Radio-telemetry studies on nightly movement patterns showed that roof rats have restricted home ranges in macadamia nut orchards and mostly occupy underground refugia sites. They emerge soon after sunset, forage in neighboring trees, and return to their burrows prior to sunrise (Tobin et al. 1996). There is minimal rodent ground activity in mature orchards where weeds and other vegetation are absent due to extensive shading of intertwining tree branches. Field trials using tracer-labeled placebo baits indicated the highest acceptance and least non-target hazards when baits were placed in-tree versus on the ground or in terrestrial burrows (Tobin et al. 1997b). The common practice of broadcasting or placement of rodenticide baits on the ground in mature macadamia nut orchards was proven ineffective. Based on these findings, a Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Section 24(c) special local need (SLN) registration of diphacinone bait was obtained from EPA for use in Hawaii. The label permits use of diphacinone bait in tamper-proof bait stations secured to lateral branches in macadamia nut trees as an operational control method to reduce nut damage by rats.

Cultural practices, such as the alteration or removal of vegetation or debris from waste areas, elimination of in-field rock piles created as a result of removing loose rocks under trees to facility hand-harvesting of nuts, and clearing of thick vegetation and branch prunings from interior windrows have been recommended to reduce rat habitat; however, some of these techniques are not always logistically or economically practical. The extensive intercropping of macadamia nuts with coffee, avocados, and other fruit trees in many small farms presents some unique control challenges. For these and other small orchards with localized nut damage, in-tree rat snap trapping can be an inexpensive and effective control method to reduce rat populations (Tobin et al. 1993).

Selection of macadamia nut clones with shorter harvest season to reduce year-round availability of food for rats, and mechanical row-hedging to limit easy tree-to-tree access, have shown limited success. A multi-season simulation study indicated that at low rat damage levels, young macadamia nut trees were able to compensate for nut losses occurring early in the crop cycle; however, moderate nut damage occurring later in the season usually resulted in losses at harvest (Tobin et al. 1997a). Thus, timing of control efforts becomes an important management decision to maximize returns on treatment costs. An integrated approach to managing rodent damage in macadamia nuts, utilizing a combination of cultural, mechanical, and chemical methods, rather than the reliance on a single technique, offers the best solution (Campbell et al. 1998).

Macadamia nut growers in Hawaii have been faced with real and difficult economic challenges in recent years. Steadily decreasing farm nut prices and increasing labor, production and marketing costs have resulted in a decrease of 2000 harvested acres and 150 individual growers in the last 3 years alone (Hawaii Agri. Stats. Serv. 2000).

Diversified Agriculture

Diversified agricultural commodities in Hawaii now surpass sugarcane and macadamia nuts combined in farm level revenues (Hawaii Agri. Stats. Serv. 2000). Large tracts of former sugarcane fields and abandoned orchards have been converted to cultivation of high-value crops, plant nurseries, and forest tree products. Coffee, papaya, banana, ginger root, and avocado farms have expanded on the newly available lands. Specialty tropical fruits such as rambutan, litchi, and kava, a medicinal herb, once restricted to small backyard orchards, are now grown commercially for the local and export market. On the islands of Oahu and Maui, acres of corn and various grains for the seed industry are now found on former sugarcane fields. The number of export ornamental floriculture nurseries has increased on the island of Hawaii, and large-scale plantings of forestry products for the processed (i.e., eucalyptus) and high value woods (i.e. mahogany, Koa) market have recently been established on that island (Hawaii Agri. Stats. Serv. 2000).

Rodent depredation problems in diversified agricultural crops have thus far been seasonal and localized. Reports include damage to inflorescence and ripe coffee berries, cosmetic damage to bananas due to rats nesting in fruit bunches, feeding on ripe avocado fruit, clipping of nursery seedlings, loss of palm seeds, and bark girdling of forestry out-plantings. The Hawaii Field Station recommendations of clean cultural practices, trapping, and limited use of rodenticides have been successful in reducing or eliminating rodent losses in these crops. However, as land-use patterns have changed from plantation-scale monoculture agriculture to diversified crops and forestry, other problems with rodents or other pest depredations may escalate in the near future.

CONSERVATION OF NATIVE SPECIES

There has been increased evidence and awareness of rats as a limiting factor of native species in Hawaii (Stone 1985, Scott et. al 1986, Miller and Hatfield 1993, Sugihara 1997). The severe plight of Hawaii's threatened and endangered plant and animal species has renewed interest in rodent control research in conservation and natural resource areas in Hawaii and the Pacific region by state and federal agencies, private landowners, and local and national conservation groups. The Hawaii Field Station has assumed a leadership role in addressing the problem by providing rodent biology and control expertise to cooperators as well as conducting management-oriented research to mitigate impacts of rats in native ecosystems. In consultation with Wildlife Services Operations staff on the use of traps and pulsed applications of acute and chronic rodenticides, rat predation has been significantly reduced or eliminated on fragile seabird colonies on refuges in Hawaii, American Samoa (Rose Atoll), Wake, and Midway Islands (Ohashi 1992).

Native forest habitats in Hawaii are home to many rare and threatened plants, birds, snails, and invertebrates, as well as some of the highest densities of rodents in Hawaii (Sugihara 1997). Besides direct predation, Polynesian rats, roof rats, and house mice (*Mus musculus*) are serious potential competitors for food and habitat. Past and present control efforts to remove feral pigs, goats, and sheep that seriously degraded the forest habitat have resulted in marked recovery of vegetation. However, in many of these protected areas there has been limited breeding success of native birds and lack of regeneration of certain plants (i.e., hoawa, *Pittosporum* spp.; and sandalwood, *Sandalum ellipticum*) due to seed depredation by rodents (Hakalau Forest Natl. Wildl. Refuge, pers. comm.).

The Hawaii Field Station worked cooperatively with state, local, and private conservation groups to obtain a special local need (SLN) registration of diphacinone bait for use in ground-placed bait stations to protect endangered flora and fauna in easily accessible native Hawaiian conservation areas (Conry 1994). Diphacinone was selected as the rodenticide to pursue for registration based on its effectiveness against rats (Tobin 1992), relatively low non-target risks (Kaukeinen 1982), and limited persistence in the environment (Lund 1988). Diphacinone bait stations have since been used operationally in a number of native species restoration programs. However, this method is labor intensive, requires the establishment of access trails, and is impractical for large areas in rugged and remote locations. Modifying this use pattern to include aerial or hand-broadcast application of pelleted diphacinone baits will give resource managers in Hawaii a more effective control tool to treat larger and remote areas. Broadcast application of rodenticides has been used successfully elsewhere in similar habitats to reduce rodent depredations (Miller and Anderson 1992, Innes et al. 1995) and has been identified as the most effective and practical method to control rats in native ecosystems (Moors et al. 1992, Tobin 1994).

Initial research to collect the necessary efficacy and hazards data to support a broadcast application of rodenticide bait in native Hawaiian conservation habitats has been conducted by the Hawaii Field Station in collaboration with other federal and local researchers over the last 4-5 years. Studies include laboratory toxicity trials to determine the minimum exposure times and dosages needed to achieve acceptable control with a pellet diphacinone bait formulation (Swift 1998) and field bait acceptance trials using placebo pellet baits treated with a biomarker (Dunlevy 2000). These results support the potential efficacy of broadcast application of diphacinone bait pellets to reduce rodent populations in conservation areas in Hawaii.

A recent study utilizing remotely operated cameras assessed the potential avian and mammalian non-target risks of broadcast baiting in wet and mesic native forests (Dunlevy and Campbell 2002). Preliminary results show that other than rodents, extremely low bait visitation rates (<1%) were recorded for birds (no native species) or other non-target animals (mongooses, feral cats). Plans are underway to evaluate diphacinone residues in snails and slugs that commonly feed on rodenticide baits. Mollusks are potential food sources for selected native birds, and there are a few endemic tree snails (Gagne and Christensen 1985, Hadfield et al. 1993) that could potentially be impacted by broadcast application of diphacinone baits in conservation areas in Hawaii.

DISCUSSION AND SUMMARY

This paper describes some of the past and present rodent research conducted at the Hawaii Field Station. Some of the control tools developed 20-30 years ago to reduce rodent depredations to agricultural crops have found renewed use today in a new era of Hawaiian agriculture, conservation of native floral and faunal resources, and continuing battle to prevent introduced invasive vertebrates from establishing a foothold in our fragile Hawaiian ecosystem. While the use of toxicants has proven to be the most effective and economical method for wide-scale control of rodents, many of the operational failures have been attributed to management shortcomings in the selection and use of these chemicals; an easily neglected responsibility during periods of depressed crop prices and economic hardship. Alternative control techniques such as biological control (predators), cultural practices (clean crop, resistant varieties, habitat alteration), and mechanical control (trapping) have had limited success or proven impractical or economically unfeasible. However, with few new chemicals being introduced and many older labels not being renewed as well as the popular shift towards non-lethal control techniques; growers and resource managers may need to revisit some of these alternative approaches. An integrated pest management approach incorporating accurate problem identification, pest species biology, control implementation, and vigilant monitoring and evaluation of efficacy offers the best solution.

The demise of sugarcane and current economic instability of the macadamia nut industry in Hawaii have contributed to a refocusing of rodent research priorities at the Hawaii Field Station. The change from monoculture to the intensive land practices of diversified agriculture has resulted in a shift from large losses to rodents by a few (plantations) to fewer losses by many individual growers. The role of rodents limiting the conservation of native species has seen renewed interest by conservationists and governmental agencies. Although lacking local administrative (funding) support, the Hawaii Field Station has taken a leading role in cooperation with other agencies and private conservation groups towards the development of safe and effective rodent control technique for native habitats. The Hawaii Field Station will have a continuing role in rodent research and in addressing emerging rodent and other invasive vertebrate depredation problems in Hawaii

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