

THE DEVELOPMENT OF AN INTEGRATED PEST MANAGEMENT PLAN FOR ROOF RATS IN HAWAIIAN MACADAMIA ORCHARDS

EARL W. CAMPBELL III, ANN E. KOEHLER, and ROBERT T. SUGIHARA, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Hawaii Field Station, P.O. Box 10880, Hilo, Hawaii 96721.

MARK E. TOBIN, United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Mississippi Field Station, P.O. Drawer 6099, Mississippi State, Mississippi 39762-6099.

ABSTRACT: Roof rats (*Rattus rattus*) damage an estimated 5 to 10% of the developing nut crop in Hawaiian macadamia (*Macadamia integrifolia*) orchards. Relevant aspects of roof rat biology in macadamia orchards have and continue to be studied with the ultimate goal of developing an ecologically sound and cost-effective integrated pest management plan. The field component of a two-year study of roof rat populations in macadamia orchards has recently been completed. The goal of this study is to clarify the relationship between roof rat seasonal abundance, macadamia flowering, and nut production on five orchards in three regions on the island of Hawaii. The authors herein present preliminary results from selected aspects of this research. This and other completed studies on rat feeding locations and the effect of simulated rat damage during different stages of nut development will aid in the determination of critical points in the crop cycle when rats cause significant economic damage and control of damage is warranted. This paper is intended to be an overview of research leading to the development of a realistic integrated pest management plan for roof rats in Hawaiian macadamia orchards.

KEY WORDS: integrated pest management, *Macadamia integrifolia*, *Rattus rattus*

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

INTRODUCTION

Hawaiian macadamia orchards (*Macadamia integrifolia*) provide roof rats (*Rattus rattus*) with abundant food and cover (Tobin 1992a, b). Mature macadamia kernels are composed of 71 to 75% oils and are a rich energy source (Tobin 1992a; O'Mara 1977). The cavities and crevices in the lava rock substrate of most Hawaiian macadamia orchards provide resident rats ample harborage (e.g., nests and burrows). Interlocking branches facilitate safe movement of rats among mature macadamia trees. If food supplies within a macadamia orchard are inadequate, windbreaks and adjacent noncrop wastelands provide alternative food.

Roof rats damage an estimated 5 to 10% of the Hawaiian macadamia crop (Fellows 1982; Tobin 1990). During the 1995 crop year, Hawaiian growers produced 52.5 million pounds net wet-in-shell macadamia nuts valued at \$36 million (Hawaii Agricultural Statistics Service 1996, cited in Tobin et al. 1997a). This would mean that projected farm value losses due to rats in Hawaii in 1995 ranged between \$1.8 to \$3.6 million.

A long-term intensive research effort has been conducted by staff of the National Wildlife Research Center Hawaii Field Station to reduce the impact of rodent depredation in Hawaiian macadamia orchards (Fellows 1982; Fellows et al. 1978, 1988; Pank et al. 1978; Tobin 1990, 1992a,b,c,d, 1995a,b; Tobin et al. 1993, 1994, 1996a,b, 1997a,b). One goal of this research has been to supply macadamia farmers with an integrated pest management plan for roof rats that would reduce the impact of this pest species in a cost-effective, ecologically sound manner. Such plans have been designed in North America for red-winged blackbird (*Agelaius phoeniceus*)

depredation on corn (Dolbeer 1990) and vole (*Microtus* spp.) depredation on fruit orchards (Tobin and Richmond 1993). In each of these publications, the authors clarified the relationship between vertebrate pest abundance levels and phases of a crop's life cycle with the intent of identifying the point that a pest causes significant economic damage. Present and past efforts by researchers studying roof rat depredations in macadamia orchards similarly are attempting to answer this question.

This publication has two distinct goals. The first is to review several research findings that will aid managers in understanding the relationship between roof rat biology and macadamia crop cycles and the implications of this information for better rat control in macadamia orchards. The second goal of this paper is the presentation of initial results of selected aspects of a two-year study of roof rat populations in macadamia orchards from three regions on the island of Hawaii.

A REVIEW OF PAST RESEARCH HIGHLIGHTS Relative Importance of Macadamia Nuts in Roof Rat Diets in Macadamia Orchards

During an 11-month period between June 1990 and April 1991, roof rats were collected from a macadamia orchard near Hilo, Hawaii to determine relative dietary composition (Tobin 1995a; Tobin et al. 1994). All 199 rats (mean monthly number of rats collected = 18, SE = 1.9) collected for this study had macadamia nuts in their stomachs. Macadamia nuts were the major item in all stomachs examined. Fragments of macadamia nuts were present in stomach samples with an average relative abundance of 85% (SE = 2%, N = 11 months). Insect fragments were present in 66% of all rat stomachs and

had an average relative abundance of 8% (SE = 2%, N = 11 months). Moss sporophytes, seta or capsules were present in 48% of all rat stomachs and had an average relative abundance of 4% (SE = 1%, N = 11 months). Non-moss vegetation, fruit seeds, and non-insect animal matter occurred in minor amounts (average relative abundance < 1%). The results of this study strongly support the observation that roof rats foraging within macadamia orchards use nuts as a primary food resource. Certainly, roof rat depredation could seriously impact macadamia nut yield and quality.

Effects of Roof Rat Trapping on Rat Populations, Nut Damage, and Yield of Macadamia Nuts

The effect of intensive snap trapping on roof rat populations in a macadamia orchard near Hilo, Hawaii was evaluated during the 1990-1991 and 1991-1992 crop cycles (Tobin 1992a; Tobin et al. 1993). Nut damage and macadamia yield were compared between sites where roof rat populations had and had not been controlled. As expected, roof rat abundance declined appreciably where snap trapping was undertaken. The control of roof rats in selected macadamia orchards reduced cumulative rat damage in trapped sites compared to reference sites during both crop seasons. Surprisingly, trapping had no effect on macadamia yields at harvest: the number of nuts, mass per unit and the total mass of undamaged nuts did not differ between the trapped and reference sites. These results suggest that researchers and managers should examine crop yield more closely when assessing the efficacy of roof rat control in macadamia orchards. Additionally, indices such as the proportion of nuts damaged by rats may exaggerate the ultimate effectiveness of rat control measures in Hawaiian macadamia orchards.

The Effect of Simulated Rat Damage on Yields of Macadamia Trees

The previous study prompted researchers into further investigation of the effect of rat damage on the yields of macadamia trees (Tobin et al. 1996a; Tobin et al. 1997a). During the 1995 crop season, a simulated rat damage study was conducted at two locations on the island of Hawaii. Ten to 30% of the developing nut clusters were removed from selected five-year-old trees at 90, 120, or 150 days post-anthesis (dpa). Mature nut yield for all macadamia trees used in this experiment was measured at harvest (210 to 215 dpa). Removal of 10% of developing nut clusters, regardless of timing, had no measurable effect on yield compared to a control group. Similar results were also observed for trees where 30% nut clusters were removed at 90 and 120 dpa. Significant differences were observed between treated trees and control trees when 30% of nut clusters were removed at 150 dpa. Overall, these results suggest that growers should focus efforts to manage rodent damage during later phases of nut development (>150 dpa). However, if rodent populations are extremely high and damage levels exceed 30% of nut clusters earlier in the crop cycle, macadamia trees may be less likely to compensate for this damage. In such situations, rodent control should be focused earlier in the crop cycle. The researchers are currently initiating a second experiment to investigate the impact of simulated rodent damage during the later phases

of nut development (> 150 dpa), when the impact of high levels of rodent damage may have greater impact on the yield of macadamia trees.

Movement Patterns and Seasonal Activity of Roof Rats in Hawaiian Macadamia Orchards

Radio transmitters were placed on 54 rats between November 1991 and May 1992 to determine movement patterns and seasonal activity in a macadamia orchard near Hilo, Hawaii (Tobin 1995a, b; Tobin et al. 1996b). The mean minimum convex polygon home ranges for all roof rats radio collared was 0.2 ha (SE = 0.02) with no significant difference (F = 1.93; 1, 48; P = 0.017) in home range detected between males (0.22 ha, SE = 0.02, N = 21) and females (0.18 ha, SE = 0.025, N = 33). Similarly, no significant differences were observed in rat home ranges for both sexes among the three seasons (peak harvest, peak anthesis, and midseason) of the macadamia crop cycle (F = 0.62; 2, 48 df, P = 0.54). It is interesting to note that no rats were located on the ground during this foraging study. All radio-collared rats were located either in trees or in burrows. This result led researchers to question the efficacy of the common practice of broadcast baiting of zinc phosphide coated oat groats in Hawaiian macadamia orchards and stimulated the following study.

Bait Placement and Acceptance by Rats in Macadamia Orchards

Using a non-toxic oat bait treated with a 0.75% tetracycline hydrochloride (THC) marker, researchers determined effectiveness of differing bait placement for roof rats in macadamia orchards (Tobin et al. 1997b). THC-marked baits were broadcast on the ground, placed in burrows on the ground, and put in branch crotches in trees in macadamia orchards located in three regions on the island of Hawaii (Keaau, Hamakua, and Kona). Due to substrate differences between study sites, THC-treated baits were placed only in rat burrows at two study sites (Keaau and Kona). Thirteen to 18 days following bait placement, rats were snap trapped in treated orchards to determine the proportion of marked rats associated with differing baiting regimes. Orchards where THC-treated bait was placed in trees had the greatest percentage of marked animals (Keaau 91%, Hamakua 79%, and Kona 70%), while orchards where THC-treated bait was broadcast on the ground had the lowest efficacy (Keaau 36%, Hamakua 11%, and Kona 0%). Placement of bait in rat burrows had an intermediate level of effect (Keaau 70% and Kona 57%). These results suggested that the placement of toxic bait in trees is the most effective way to control roof rats in the macadamia orchards. Additionally, these results show that the broadcast baiting of rodenticides on the ground in macadamia orchards without interior ground vegetation is ineffective.

A TWO-YEAR COMPARISON OF RODENT ABUNDANCE IN MACADAMIA ORCHARDS ON THE ISLAND OF HAWAII: PRELIMINARY RESULTS FROM THREE SITES

The researchers recently completed the field component of a two-year study of rodent populations in macadamia orchards on the island of Hawaii. The

ultimate goal of this study is to clarify the relationships among rodent seasonal abundance, macadamia flowering, and nut production in five orchards from three climatically different regions on the island of Hawaii (Figure 1). Previous observations indicated that rat abundance in orchards varies widely on the island of Hawaii both geographically and temporally. Climatic factors such as average annual rainfall, which ranges between 250 mm to > 11,000 mm on the island of Hawaii (Giambelluca and Sanderson 1993), and differing cultural practices may strongly influence rodent abundance in orchards.

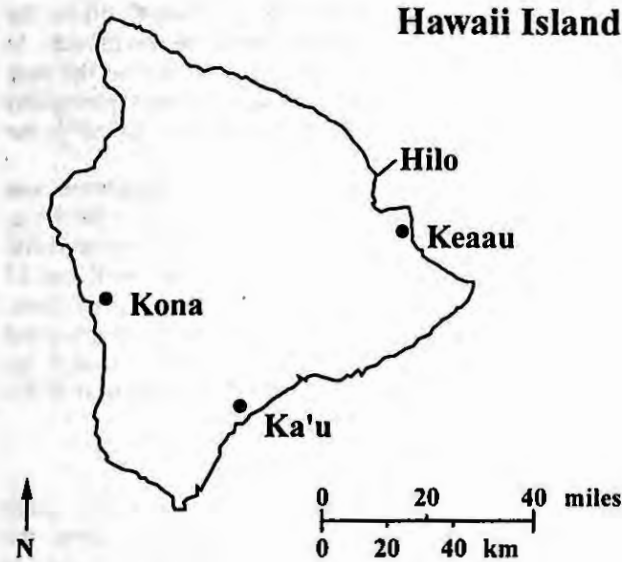


Figure 1. Map of the island of Hawaii showing sites where a two-year study of rodent populations in macadamia orchards was conducted.

In this publication the researchers present preliminary results comparing rodent abundance and rodent species composition for infield and noncrop areas for three orchards (Keaau-57, Kona-P, and Ka'u-61-01) that are representative of macadamia orchards from different regions of the island of Hawaii. During 1996 and 1997, rodent abundance was sampled in each orchard along standardized transects at intervals of approximately two months (i.e., $N = 12$ for two years, one sample per 60 day period). In each orchard, 100 standard rat traps with enlarged (5 X 5 cm) triggers were placed in orchard and noncrop habitat (50 rat traps per habitat, respectively). In orchards, rat traps were placed on the lower lateral branches of trees (approximately 0.75 to 2.75 m above ground). In noncrop habitat rat traps were placed on the ground. All rat traps were pre-baited and baited with coconut chunks. Each trapping session in a particular orchard lasted four nights with two nights of pre-baiting and two nights of trapping. All captures were labeled in the field and taken to the National Wildlife Research Center Hawaii Field Station for identification and necropsy.

To assess changes in rodent abundance among sites, a relative index of trap success that adjusted for tripped traps ("corrected capture success") was calculated for each night of trapping (Nelson and Clark 1973; Innes 1990). No significant seasonal trends in rodent abundance were observed for either infield or noncrop sites in the three orchards sampled during the two years of this study (Figure 2). One-tailed paired t-tests were used to detect significant differences in rodent abundance within each orchard between noncrop and infield sites during the study. No significant differences were detected in rodent abundance over the two year study between the infield and noncrop sites in the Ka'u-61-01 orchard ($t = 0.24$, 11 df, $P = 0.23$). Significant differences in rodent abundance were detected between infield and noncrop sites in the Keaau-57 and Kona-P (respectively, $t = -6.77$, 11 df, $P = 0.000002$; $t = 3.24$, 11 df, $P = 0.004$). Kona-P had significantly greater rodent captures in infield sites compared to noncrop, a trend opposite of that observed in Keaau-57.

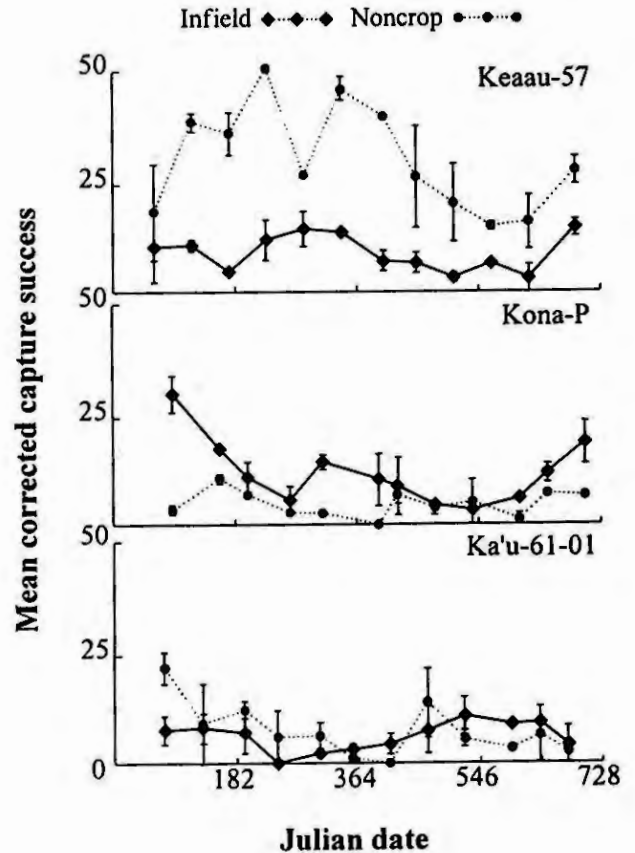


Figure 2. Mean corrected rodent capture success and standard error ($N = 2$) for four species of rodents combined (roof rat, Polynesian rat, Norway rat, and field mouse) from infield and noncrop habitats in three macadamia nut orchards on the island of Hawaii during a two year period. Traps were set and monitored for two nights at approximately 60-day intervals at each site.

The most frequently captured identifiable rodent species in infield sites in the three macadamia orchards were roof rats (100% Kona-P, 98% Ka'u-61-01, and 93% Keaau-57) (Figure 3). Roof rats comprised a greater proportion of the rodent community in all infield sites compared to adjacent noncrop sites. Seven percent of the rodents captured in infield habitat at Keaau were Polynesian rats (*Rattus exulans*); Norway rats (*Rattus norvegicus*) comprised 2% of the rodent captures in K'au-61-01. House mice (*Mus musculus*) were never captured in infield habitat in the three macadamia orchards sampled. In non-crop sites, the most common species of rodent captured was roof rat (mean = 44%, SE = 6%, N = 3 sites) followed by house mouse (mean = 35%, SE = 12%, N = 3), Polynesian rat (mean = 21%, SE = 14%, N = 3), and Norway rat (mean = 1%, SE = 0.3%, N = 3).

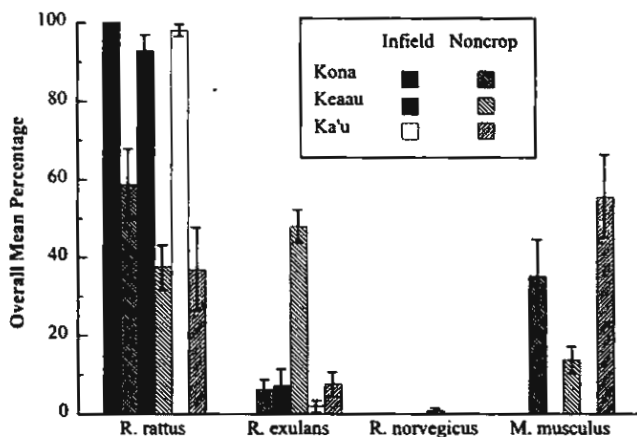


Figure 3. Mean percentage rodent species composition and standard error for four species of rodents (roof rat, Polynesian rat, Norway rat, and field mouse) captured in infield and noncrop sites in three macadamia nut orchards (Keaau-57, K'au-61-01, and Kona-P) on the island of Hawaii during a two-year period between 1996 and 1997 (N = 12). Traps were set and monitored for two nights at approximately 60-day intervals at each site.

Overall, these results confirm that roof rats are the primary rodent species foraging in macadamia trees in Hawaiian orchards. In adjacent noncrop habitats a suite of rodent species are found; primarily roof rats, house mice, and Polynesian rats. It should be noted that differing sampling techniques (e.g., tree vs. ground trapping) probably influenced the relative capture success of all rodent species in orchard (e.g., infield) vs. noncrop habitats. Roof rats are more arboreal than the other rodent species captured in this study, and thus more likely to encounter traps set in trees. Since previous studies have shown that roof rats forage primarily in macadamia trees in Hawaiian orchards this sampling technique was most efficient for this species. Placement of rat traps on the ground allowed standardized comparisons among different noncrop habitats due to habitat variability (e.g., grassland, secondary forest, scrub) between noncrop sites.

No significant seasonal trends were observed in rodent abundance for either noncrop or infield habitats sampled. Trends in rodent abundance and species composition could be attributed to differing cultural practices and local climate. In the case of Keaau-57, significantly higher rodent abundance levels in noncrop areas compared to infield areas could be due to removal of all debris from the orchard floor, a common practice in many large commercial orchards that reduces harborage and alternative foods for rodents. Noncrop areas near Keaau-57 were mixed secondary forest with undergrowth, which provide food and harborage for all species of rodents sampled in this study.

Kona-P is a small orchard surrounded by dry scrub and grass. Rodent abundance was significantly higher for infield habitat in Kona-P compared to noncrop habitat. In this orchard rocks which were piled up around the base of each macadamia tree to provide support potentially provided additional harborage for rodents living in the orchard.

No significant difference in rodent abundance was observed between infield and noncrop sites for the Ka'u-61-01 orchard which was located on a large commercial orchard in a dry area of the island. Like the Keaau-57 orchard, K'au-61-01 had little debris on the forest floor. Unlike Keaau-58, K'au-61-01 was bordered by grassland and dry scrub. These two factors probably reduced the suitability of both infield or noncrop habitats near K'au-61-01 for rodents.

SUMMARY

To design an effective integrated pest management plan for roof rats in Hawaiian macadamia orchards, the relationship of roof rat abundance and the crop's life cycle needs to be understood. Past and present research by staff of the National Wildlife Research Center Hawaii Field Station have been directed toward this goal. Past research efforts have identified several key points leading to a successful integrated pest management plan for roof rats in macadamia orchards. First, roof rats are the primary rodent pest species of concern for macadamia producers. Second, broadcast baiting of rodenticides on the ground in macadamia orchards without interior vegetation is ineffective for roof rat control. Third, macadamia trees can compensate for rodent damage early in the crop cycle. Presently, Hawaii Field Station staff are examining the potential for registration (United States Environmental Protection Agency 24c registration) of anticoagulant rodenticide use in bait boxes in macadamia trees. If such registrations are developed, they could provide macadamia producers with a precise technique to control roof rat damage at the sites where it occurs.

Continuation of damage simulation studies will help farmers determine economically significant thresholds for employing measures to control rat depredation in Hawaiian macadamia orchards. This two-year study of the relationship between roof rat seasonal abundance, macadamia flowering, and nut production in three regions on the island of Hawaii will allow farmers to tailor their rodent control plans to their specific situations. Each of these steps, supported by data from past research, will facilitate the development of an integrated pest management plan for roof rats in Hawaiian macadamia orchards.

LITERATURE CITED

- DOLBEER, R. A. 1990. Ornithology and integrated pest management: Red-winged blackbirds (*Agelaius phoeniceus*) and corn. *Ibis*. 132:309-322.
- FELLOWS, D. P. 1982. Rat damage and control in macadamia. Proc. 22nd Annual Hawaii Macadamia Nut Assoc. Annual Meeting. p. 94-103.
- FELLOWS, D. P., R. T. SUGIHARA, and L. F. PANK. 1978. Evaluation of treatment techniques to control rats in macadamia orchards. Proc. 18th Annual Hawaii Macadamia Nut Assoc. Annual Meeting. p. 43-55.
- FELLOWS, D. P., F. PANK, and R. M. ENGEMAN. 1988. Hazards to birds from zinc phosphide rat bait in a macadamia orchard. *Wildl. Soc. Bull.* 16:411-416.
- GIAMBELLUCA, T., and M. SANDERSON. 1993. The water balance and climatic classification. In *Prevailing trade winds: weather and climate in Hawaii*. M. Sanderson, ed. University of Hawaii Press, Honolulu, Hawaii. p. 56-72.
- HAWAII AGRICULTURAL STATISTICS SERVICE. 1996. Hawaii macadamia nuts, preliminary season estimates. Hawaii Department of Agriculture and U.S. Department of Agriculture, Honolulu, Hawaii. 5 pp.
- INNES, J. 1990. Ship rat. The handbook of New Zealand Mammals. C. M. King, ed. Oxford University Press, Auckland, New Zealand. p. 206-225.
- NELSON, L. JR., and F. W. CLARK. 1973. Correction for sprung traps in catch/effort calculation of trapping results. *Journal of Mammalogy*. 54(1):295-298.
- O'MARA, P. 1977. Macadamia varieties in southern Queensland. *California Macadamia Society Yearbook* 23.
- PANK, L. F., D. P. FELLOWS, D. N. HIRATA, and R. T. SUGIHARA. 1978. The efficacy and hazards of zinc phosphide rat control adjacent to macadamia orchards. Proc. 18th Annual Hawaii Macadamia Nut Assoc. Annual Meeting. p. 27-41.
- TOBIN, M. E. 1990. Rodent control in macadamia orchards. Proc. 30th Annual Hawaii Macadamia Nut Assoc. Annual Meeting Proc. p. 18-23.
- TOBIN, M. E. 1992a. Rodent damage to Hawaiian macadamia orchards. Proc. 15th Vertbr. Pest Conf. 15:272-276.
- TOBIN, M. E. 1992b. Rodent control research in Hawaiian macadamia orchards. Proc. First Intl. Macadamia Res. Conf. H. C. Bittenbender, ed. p. 54-57.
- TOBIN, M. E. 1992c. Rodent control research in macadamia orchards. 32nd Hawaii Macadamia Nut Assoc. Annual Meeting Proc. 7 pp.
- TOBIN, M. E. 1992d. Hawaii mac facts: control of rat damage in macadamia nut orchards. *Hawaii Macadamia Nut Assoc. Newsletter*. 5(2):8.
- TOBIN, M. E. 1995a. Rat biology and control in macadamia orchards. Proc. 35th Annual Hawaii Macadamia Nut Assoc. Annual Meeting. p. 54-56.
- TOBIN, M. E. 1995b. Controlling rats in macadamia orchards. *Pacific Nut Producer*. 1(7):20-21.
- TOBIN, M. E., A. E. KOEHLER, R. T. SUGIHARA, G. R. UEUNTEN, and A. M. YAMAGUCHI. 1993. Effects of trapping on rat populations and subsequent damage and yields of macadamia nuts. *Crop Protection* 12(4):243-248.
- TOBIN, M. E., A. E. KOEHLER, and R. T. SUGIHARA. 1994. Seasonal patterns of fecundity and diet of roof rats in a Hawaiian macadamia orchard. *Wildl. Res.* 21:519-526.
- TOBIN, M. E., A. E. KOEHLER, and R. T. SUGIHARA. 1997a. Effects of simulated rat damage on yields of macadamia trees. *Crop Protection*. 16(3):203-208.
- TOBIN, M. E., A. E. KOEHLER, R. T. SUGIHARA, and R. M. ENGEMAN. 1996a. Effects of stage of nut development and simulated rat damage on macadamia yields. Proc. 17th Vertbr. Pest Conf. 17:119-122.
- TOBIN, M. E., and M. E. RICHMOND. 1993. Vole management in fruit orchards. *Biological Report* 5. United States Fish and Wildlife Service Technical Report Series. 18 pp.
- TOBIN, M. E., R. T. SUGIHARA, and A. E. KOEHLER. 1997b. Bait placement and acceptance by rats in macadamia orchards. *Crop Protection* 16(6):507-510.
- TOBIN, M. E., R. T. SUGIHARA, A. E. KOEHLER, and G. R. UEUNTEN. 1996b. Seasonal activity and movements of *Rattus rattus* (Rodentia, Muridae) in a Hawaiian macadamia orchard. *Mammalia*. 60(1):3-13.