ABUNDANCE AND HABITAT RELATIONSHIPS OF RATS IN HAWAIIAN SUGARCANE FIELDS

MARK E. TOBIN, Denver Wildlife Research Center, U.S. Department of Agriculture, P.O. Box 10880, Hilo, HI 96721
ROBERT T. SUGIHARA, Denver Wildlife Research Center, U.S. Department of Agriculture, P.O. Box 10880, Hilo, HI 96721

Abstract: A better understanding of factors that influence the distribution and abundance of 3 species of rats that occur in Hawaii and cause extensive damage to sugarcane fields should lead to more effective control strategies, such as species-specific use of rodenticides or habitat management that reduces pest populations. Thus, we estimated the relative abundances of the 3 species of rats at 4 Hawaiian sugarcane plantations that historically have received high levels of rodent damage, and quantified various environmental factors that might influence the distribution of these rodents. Overall, we captured 526 Norway rats (*Rattus norvegicus*), 335 Polynesian rats (*R. exulans*), and 139 black rats (*R. rattus*) during 11,200 trap-nights. Total capture success for the 3 species was similar among 3 Hawaii Island plantations and was about 5 times greater at each of these than at a plantation on the island of Kauai. Either Norway rats or Polynesian rats were most numerous within any given field; black rats were captured mostly near field edges. The abundance of Norway rats was positively associated with precipitation at 2 plantations, negatively related to this variable at another plantation, and negatively related to elevation at 2 plantations. Cane age, stalk density, mat depth, grass cover, and forb cover were associated with Norway captures at 1 plantation each. The analysis for black rats produced a significant ($P < 0.05$) regression for only 1 plantation, where capture success of this species was positively associated with cane age and grass cover, and negatively associated with precipitation and forb cover. The abundance of Polynesian rats was directly related to elevation in the sole significant ($P < 0.05$) regression for this species. Our data indicate that managers should direct controls first toward Norway rats, especially in low elevation fields that receive abundant rain, and then toward Polynesian rats.

J. WILDL. MANAGE. 56(4):816–822

Three species of rats occur in Hawaii. Polynesian rats accompanied early Polynesian settlers from the central Pacific, possibly as early as 1,500 years ago (Tomich 1986:41). Norway rats reached the islands shortly after Captain James Cook in the 1770's (Tomich 1986:41), but black rats probably did not arrive until after 1870 (van Riper and van Riper 1982, Tomich 1986:40).

All 3 species of rats commonly inhabit sugarcane fields and gnaw on sugarcane stalks, thereby increasing the incidence of secondary infection, diminishing cane quality, and reducing yields (Pemberton 1925, Doty 1945, Hood et al. 1971). Monetary losses fluctuate from year to year, depending largely on the prevailing price of sugar. In 1980, when the average price of raw sugar was at a 50-year high (Hawaiian Sugar Planters' Assoc. 1989), the Hawaiian sugarcane industry may have lost $20 million to rat depredations. Today statewide losses are estimated conservatively at $6 million annually (A. Ota, Hawaiian Sugar Planters Assoc., pers. commun.).

Individual sugarcane plantations in Hawaii extend from sea level to almost 1,000 m elevation and encompass a broad range of climatic and biotic conditions. A better understanding of factors that influence the distribution and abundance of each of the 3 species of rats in sugarcane fields should lead to more effective control. Predicting which species are most likely to inhabit specific fields may allow more effective and selective use of rodenticides. Identifying variables associated with high rat populations also may facilitate managing the habitat to reduce pest populations. Consequently, we estimated the relative abundances of the 3 species of rats on 4 sugarcane plantations that historically have experienced high levels of rat damage, and evaluated various environmental and cultural factors that might influence the distribution and abundance of these rodents.

We thank Hamakua Sugar Company, Inc.; Kau Agribusiness Company, Inc.; The Lihue Plantation Company, Ltd.; and Mauna Kea Agribusiness Company, Inc. for allowing us to conduct the study on their plantations and for furnishing us with ecological and agronomic data. The Lihue Plantation Company, Ltd. also helped with trapping. The late D. N. Hirata helped collect the data. R. M. Engeman assisted with the statistical analyses. M. L. Avery, D. P. Fellows, N. R. Holler, A. E. Koehler, L. W. Lefebvre, and C. P. Stone commented on earlier drafts of this manuscript.

STUDY AREA

Hawaii is one of the few areas in the world where sugarcane is grown for ≥2 years before harvesting, and where this crop is harvested year-round. A total of 71,911 ha of sugarcane was cultivated commercially on the islands of Hawaii, Kauai, Maui, and Oahu during 1989 (Hawaiian Sugar Planters' Assoc. 1989). Each of the 13 commercial plantations operating in the state encompasses numerous fields containing sugarcane of various varieties and ages, and cultural practices often vary among fields. About 60% of the cane area in the state is irrigated. The most severe rat damage occurs in nonirrigated fields on the windward side of the islands of Hawaii and Kauai, where abundant rains and lush noncrop lands adjacent to sugarcane fields favor the proliferation and survival of rodents.

Three of the 4 plantations studied were on the island of Hawaii. Hamakua Sugar Company, Inc. and Mauna Kea Agribusiness Company, Inc. comprise 13,915 ha and 6,174 ha, respectively, on the northeastern slopes of Mauna Kea, toward the northern end of Hawaii Island, from near sea level to as high as 760 m elevation. This area receives abundant rain from prevailing northeasterly trade winds and is partitioned by numerous heavily vegetated valleys and gulches that have permanent and intermittent streams. Average annual precipitation exceeds 380 cm in some locations. Noncrop areas adjacent to sugarcane fields typically are vegetated with introduced species such as quack grass (*Panicum repens*), California grass (*Brachiaria mutica*), melastoma (*Melastoma candidum*), guava (*Psidium* spp.), wild ginger (*Zingiber zerumbet*), and numerous species of palms (Arecaceae) and ground ferns. Upper elevation boundaries of plantations generally abut forested lands that have unmanaged volunteer growths of noncommercial species.

Kau Agribusiness Company, Inc., encompasses 6,153 ha and extends from 365 m to 975 m elevation on the eastern flank of Mauna Loa, toward the southern end of Hawaii Island. Lava flows are more recent than on Mauna Kea, and the terrain lacks the steep gulches and valleys typical of the geologically older northern and eastern parts of the island. Precipitation generally is less than on the northeastern coast but still averages >250 cm/year at some higher locations. Noncrop areas adjacent to Kau sugarcane fields typically contain many of the same species as Hamakua and Mauna Kea plantations, but with a higher prevalence of overstory and subcanopy species such as guava, gum tree (*Eucalyptus* spp.), silk oak (*Grevillea robusta*), and Christmas berry (*Schinus terebinthifolius*).

The Lihue Plantation Company, Ltd., on the island of Kauai, encompasses 5,967 ha and extends from sea level to about 300 m elevation on the windward side of Kauai. Rainfall varies depending on the topography and averages 102–257 cm/year. Vegetation in waste areas adjacent to Lihue sugarcane fields is similar to that in high rainfall areas on the island of Hawaii, but with more concentrated stands of hau (*Hibiscus tiliaceus*), common ironwood (*Casuarina equisetifolia*), Java plum (*Syzygium cumini*), and koa haole (*Leucaena leucocephala*).

METHODS

We conducted the field work between 13 February and 26 May 1989. We numbered all sugarcane fields ≥12 months of age and randomly selected 14 for study at each plantation. We used a machete and compass to cut a transect from a noncrop edge of each field, extending perpendicularly 150 m into the interior. Based on a past study (Hood et al. 1967) that indicated standard rat snap traps baited with coconut are efficient for capturing all 3 species of rats, we secured 50 rat snap traps to the ground with flagged wire stakes at 3-m intervals along each transect. In a few fields that had no noncrop borders (i.e., that were surrounded by other sugarcane fields), the distance between some traps and the nearest noncrop area exceeded 150 m. We prebaited traplines by scattering grated coconut along each transect 3–4 days before baiting the traps with chunks of coconut and setting them for 4 consecutive nights. We ran the traps for 4 nights to minimize possible differential access to the traps due to interspecific competition. We checked the traps before 1200 hours each morning, rebaited them as necessary, and recorded the field, trap location, date, and species of all captures.

At each trap location we estimated the height and density of the lodged sugarcane mat layer and the species and abundance of non-sugarcane vegetation present. A person stood next to the trap, extended an arm perpendicularly away from the trap line, looked in the opposite direction, and inserted a 1.2-m-long wooden dowel through the mat layer until it touched the ground. The dowel was demarcated in decimeters to facilitate estimating the average height of the top of the mat layer. The observer then slipped a 0.2-m radius metal sampling hoop that was divided into quadrants over the dowel until it rested on top of the lodged sugarcane mat layer, and recorded the number of sugarcane stalks that passed through the imaginary cylinder extending from the ground through the perimeter of the hoop. Any noncrop vegetation present in the area defined by the cylinder was identified, and the number of quadrants it intersected was recorded.

We used ANOVA to evaluate differences among species and plantations in the total number of rats captured in each field. Species and plantation were fixed effects, and field was a random effect. We used Duncan's multiple range test (Saville 1990) to make pairwise comparisons between species and plantations. We regressed capture success for each species ($\bar{x}$ no. of rats caught/trap at each distance) on distance of trap from the nearest noncrop edge of the field.

We performed separate multiple linear regression analyses for each species and plantation to evaluate the effects of elevation, precipitation (total rainfall between planting and trapping), cane age (no. of months from planting to trapping), average stalk density, average mat depth, grass cover ($\bar{x}$ no. of quadrants with 1 or more grasses), and forb cover ($\bar{x}$ no. of quadrants with 1 or more forbs) on the number of rats captured in each field. Akaike's information criterion (AIC) was used to select the optimal model for each species and plantation (Akaike 1969). We used SAS microcomputer software (SAS Inst. Inc. 1988) for all statistical procedures.

RESULTS

During 11,200 trap-nights, we captured 1,087 rodents: 526 Norway rats, 335 Polynesian rats, 139 black rats, and 87 house mice (*Mus domesticus*). Because our trapping methods were not efficient for house mice, we did not analyze the mouse capture data statistically.

Combined capture success for the 3 species of rats was similar among Hamakua, Kau, and Mauna Kea, and was about 5 times greater at each of these 3 Hawaii Island plantations than at Lihue plantation on the island of Kauai. Norway rats made up an average of 53% of all rat captures (range = 40–61% at the 4 plantations), Polynesian rats comprised 33% (range = 18–46%), and black rats made up 14% (range = 3–25%) of the total. Either Norway rats or Polynesian rats invariably were most numerous within any given field.

The relative abundances of the 3 species varied among the 4 plantations ($F_{\text{interaction}} = 5.52$; 6, 156 df; $P < 0.001$) (Table 1). At Kau, Mauna Kea, and Lihue plantations, Norway rats were most numerous; whereas at Hamakua plantation, Polynesian rats were most numerous. We captured 90% of the black rats at 2 Hawaii Island plantations, Hamakua and Kau. Black rats were the second most numerous rat species at Kau plantation and the least numerous at the other 3 plantations.

Table 1. Average number (SE) of rats captured per field at 4 sugarcane plantations in Hawaii, February to May 1989.[a]

Plantation	Norway rat	Black rat	Polynesian rat	Total
Hamakua	9.1BI[b] (1.2)	3.2DE (0.9)	10.6HI (1.7)	22.9
Kau	12.6BC (1.9)	5.7EJ (0.7)	4.1FJ (1.1)	22.4
Mauna Kea	13.2CL (2.2)	0.6DM (0.2)	7.9GHN (2.1)	21.7
Lihue	2.7AK (1.0)	0.4DK (0.2)	1.3FK (0.7)	4.4
Total	37.6	9.9	23.9	71.4

[a] Fifty snap traps were baited with coconut and set for 4 consecutive nights in each of 14 randomly selected fields on each plantation.
[b] Means sharing a common letter within each column or row do not differ ($P > 0.05$) based on Duncan's multiple range test.

Norway rats predominated in 12 fields at Kau Agribusiness Company, Inc., 9 fields at Mauna Kea Agribusiness Company, Inc., 4 fields at Hamakua Sugar Company, Inc., and 9 fields at Lihue Plantation Company, Ltd. Polynesian rats were most numerous in all remaining fields except 3 at each of the latter 2 plantations, where Norway rats and Polynesian rats were captured in equal numbers.

Capture success declined with increasing distance from the nearest noncrop edge of the field for black rats ($R^2 = 0.47$; $F = 43.77$; 1, 49 df; $P < 0.001$), but not for Norway rats ($R^2 < 0.001$; $F = 0.04$; 1, 49 df; $P = 0.85$) or Polynesian rats ($R^2 = 0.01$; $F = 0.44$; 1, 49 df; $P = 0.51$) (Table 2).

Elevation, precipitation, and forb cover were the factors that best explained capture success for Norway rats at Mauna Kea ($R^2 = 0.53$; $F = 3.71$; 3, 10 df; $P = 0.49$). At Hamakua, elevation, precipitation, stalk density, mat depth, and grass cover best explained capture success for this species ($R^2 = 0.86$; $F = 8.82$; 5, 8 df; $P = 0.004$). Precipitation and cane age were the most important variables at Kau ($R^2 = 0.60$; $F = 8.27$; 2, 11 df; $P = 0.006$). Grass cover alone provided the best explanation of capture success for Norway rats at Lihue ($R^2 = 0.22$; $F = 3.33$; 1, 12 df; $P = 0.09$).

For black rats, Kau was the only plantation where any of the variables were strongly associated with capture success. The model selected for this plantation included precipitation, cane age, grass cover, and forb cover ($R^2 = 0.88$; $F = 16.7$; 4, 9 df; $P < 0.001$).

Capture success of Polynesian rats at Lihue was related only to elevation ($R^2 = 0.65$; $F = 22.62$; 1, 12 df; $P < 0.001$). No variable proved to have a strong relationship with capture success for this species at any of the 3 Hawaii Island plantations.

DISCUSSION

Relative Abundances of Rat Species

Our study is the first in Hawaii to sample sugarcane fields randomly for the purpose of estimating the relative abundances of the 3 species of rats over entire plantations. Prior to 1950, most trapping in Hawaiian sugarcane fields was done to reduce pest populations and not to compare species abundances (e.g., Pemberton 1925, Barnum 1930, Doty 1945). Later studies were conducted in fields selected for convenience or

Table 2. Percent capture success[a] of rats (*Rattus* spp.) at various distances from the nearest noncrop edge of sugarcane fields in Hawaii, 1989.

	Distance (m)						
Species	≤25	>25 ≤50	>50 ≤75	>75 ≤100	>100 ≤125	>125 ≤150	>150
Norway rat	21	19	17	17	18	21	16
Polynesian rat	14	10	11	11	9	13	40
Black rat	13	7	4	3	2	2	0

[a] Average no. of rats captured/trap at each distance × 100.

to meet other objectives. Most of these studies estimated a preponderance of Polynesian and black rats and a relative scarcity of Norway rats (e.g., Tomich 1970, Kami 1966, Lindsey et al. 1973, Nass 1977). Two recent studies (Hirata 1977, Karim 1983) indicated that since the late 1960's, populations of Norway rats have increased relative to the other 2 species in sugarcane fields. Our study confirms this trend and verifies that Norway and Polynesian rats were the most abundant species.

Our low trap success on Kauai was unexpected. Lihue plantation has a history of heavy rat damage (Barnum 1930, Doty 1944, Anonymous 1957), and current management personnel at this plantation believe that rats continue to be a serious problem (R. Robinson, The Lihue Plantation Co., Ltd., pers. commun.). The low populations we encountered could be due to natural population fluctuations or to rat control practices at Lihue. This plantation currently is the only sugarcane plantation in Hawaii that uses anticoagulants around the perimeters of fields to reduce invasion by rats. U.S. Fish and Wildlife Service personnel assessed rat depredations in 6 fields at Lihue in 1979 and also attributed low rat populations and a scarcity of fresh damage in part to wide-scale baiting with anticoagulant rodenticides (U.S. Fish and Wildl. Serv. 1979).

Influence of Environmental Factors

All 3 Norway rat regression models for the Hawaii Island plantations explained a significant ($P < 0.05$) amount of the variation in capture success for this species. Precipitation was an important factor for all 3 of these plantations, and elevation was important for 2 of them. The Norway rat model for Lihue was marginally ($P = 0.09$) successful, accounting for only 22% of the variation in the data. The analyses produced only 1 significant ($P < 0.05$) regression each for Polynesian rats (at Lihue) and black rats (at Kau).

Because most rat damage to Hawaiian sugarcane occurs in high rainfall areas, one might expect fields that receive more rain to have more rats. In this study, rat abundance was positively associated with precipitation only for Norway rats at Mauna Kea and Hamakua. At Kau the abundances of Norway rats and black rats were negatively associated with precipitation. At the 2 former plantations, high rainfall areas generally have lusher noncrop vegetation, which may harbor larger rat populations that can invade adjacent sugarcane fields. At Kau, the decline of Norway captures in high rainfall areas may be due to a relative scarcity of this species in the native ohia-koa forests (Tomich 1986:41) that are common in the high elevation, high rainfall areas. Black rats are common in native forests (Tomich 1986:38), and the reasons for the scarcity of this species in high rainfall sugarcane fields at Kau are unclear.

Capture success of Norway rats was inversely related to elevation at Hamakua and Mauna Kea. A similar relationship was observed at Kau with a model that was a close competitor to that selected by the AIC criterion, but which included elevation ($R^2 = 0.56$) in place of precipitation ($R^2 = 0.60$) as an explanatory variable. Others (van Riper and van Riper 1982, Tomich 1986) also have reported that in Hawaii, Norway rats are most common at low elevations. Polynesian rat numbers at Lihue increased with elevation. Ten out of 18 Polynesian rats captured at Lihue were taken from 1 isolated field that was surrounded by noncrop forests and pasture and was 100 m higher than any of the other fields sampled at this plantation.

Sugarcane plantations in Hawaii contain fields interspersed with crops of various ages. Most rats living in cane fields either die or migrate to surrounding areas during harvest (Tomich 1970, Nass et al. 1971), and populations within the field do not rebound until the second half of the next crop cycle (Lindsey et al. 1973). During most of the first year, the sugarcane stalks stand erect, the crop canopy is open, and most fields have little ground cover. Some rats forage along the periphery of young sugarcane fields, but few establish infield dens until the cane is between 8 and 12 months old (Lindsey et al. 1973, Nass 1977). At about this time, sugarcane stalks become lodged and dead leaves begin to accumulate. Rat damage accumulates slowly at first, but escalates rapidly after the crop is 14 or 15 months old (Hood et al. 1971).

One might expect infield rat populations also to increase over the course of the second year of the crop cycle. However, cane age was associated with rat abundance only for Norway rats and black rats at Kau. Although we sampled all fields with sugarcane >12 months of age, the average age of the sugarcane in the fields actually selected for trapping was 20.6 months, and the youngest cane was 15.8 months. The lack of fields with younger cane may have obscured any changes in rat abundances that might occur during the second year of the crop cycle.

Norway rats in Hawaii are a commensal species that thrives best where foods from domestic or agricultural sources are plentiful (Tomich 1986:41). Bianchi (1961) suggested that in Hawaiian sugarcane fields this species feeds on grasses and grasshoppers to maintain their populations. However, Fellows and Sugihara (1977) analyzed the stomach contents of Norway rats captured in 13- to 24-month-old cane fields and found a preference for broadleaf noncrop vegetation and fruits, but not for grass vegetation and seeds. In this study, grass cover was positively related to Norway rat captures only at Lihue, and at Hamakua it was negatively related to the abundance of this species. Forb cover was positively associated with Norway rat captures at Hamakua.

Interspecific Competition

Polynesian rats declined precipitously throughout New Zealand after the introduction of Norway rats, black rats, and house mice (Taylor 1975). In Malaysia, Norway rats are confined to city harbor areas and adjacent streets, where they are much more numerous than either Polynesian rats or black rats (Harrison 1957; Searle and Dhaliwal 1957). The latter 2 species cooccur throughout much of Malaysia, but Polynesian rats tend to avoid direct contact with the ground, where black rats are most active (Harrison 1957). On Ponape Island, however, about 800 nautical miles southeast of Guam, black rats and Polynesian rats occupy similar niches with no apparent interspecific strife (Barbehenn and Strecker 1962). Polynesian rats reportedly disappeared rapidly after the introduction of Norway and black rats into Hawaii (Stone 1917, van Riper and van Riper 1982), but supporting data are lacking (Tomich 1986:44). If Polynesian rats did decline in Hawaii after contact with the other 2 species of rats, they apparently have recovered and today are the most abundant lowland rodent throughout much of Hawaii (Tomich 1986:44).

RESEARCH AND MANAGEMENT IMPLICATIONS

Norway rats began to increase relative to the other 2 rat species about the time zinc phosphide was registered for use in sugarcane (Hirata 1977, Karim 1983). This toxicant is more effective against Polynesian rats than Norway rats (Fellows 1977, Tobin et al. 1990), which may explain why Mauna Kea, the only plantation on Hawaii Island that currently broadcasts zinc phosphide baits, also had the most Norway rats.

The abandonment of anticoagulant baiting on Hawaii Island sugarcane plantations probably is another factor contributing to a resurgence in infield Norway rat populations. Growers there formerly used anticoagulants to keep rat populations under control (Doty 1951, Kartman and Lonergan 1955), but they discontinued this practice during the early 1980's because of concerns about nontarget hazards to feral pigs and subsequent secondary exposure of human hunters (Hilton and Pank 1981, Engeman and Pank 1984). Current regulations in Hawaii require use of tamper-proof bait stations that exclude pigs and other nontarget animals, although questions remain about possible secondary hazards to raptors (Mendenhall and Pank 1980).

Managers at Kau historically have assumed that their rat problems are less severe than those at Mauna Kea and Hamakua. However, the similar capture success at these plantations indicates the need for effective control measures at all 3 Hawaii Island plantations. Controls should be directed first toward Norway rats, especially in low elevation fields that receive abundant rain, and then toward Polynesian rats.

Factors other than those investigated in this study undoubtedly influence the distribution and abundance of sugarcane rats. Variety of sugarcane, type of soil, abundance of insects and other invertebrates within cane fields, and abundance of wild fruits or other vegetation in noncrop areas adjacent to fields are possible limiting factors. More study is needed to determine the effects of these variables on rat populations.

LITERATURE CITED

AKAIKE, H. 1969. Fitting autoregressive models for prediction. Annu. Inst. Stat. Math. 21:243–247.

ANONYMOUS. 1957. A concentrated attack on rat control. Hawaiian Sugar Planters' Assoc., Exp. St. Rep.:38–40.

BARBEHENN, K. R., AND R. L. STRECKER. 1962. Intra- and interspecific behavior: field data. Pages 166–173 *in* T. I. Storer, ed. Pacific Island rat ecology. Bishop Mus. Bull. 225, Honolulu.

BARNUM, C. C. 1930. Rat control in Hawaii. Hawaiian Planters' Rec. 34:421–443.

BIANCHI, F. A. 1961. The rat population of the Hawaiian sugar cane fields. Abstr. Symp. Pac. Sci. Congr. 10:209.

DOTY, R. E. 1951. Warfarin (Compound 42)—a promising new rodenticide for cane fields. Hawaiian Planters' Rec. 54:1–21.

———. 1945. Rat control on Hawaiian sugar cane plantations. Hawaiian Planters' Rec. 49:71–241.

———. 1944. Rat-trapping records show effectiveness of control methods. Hawaiian Planters' Rec. 48:73–82.

ENGEMAN, R. E., AND L. F. PANK. 1984. Potential secondary toxicity from anticoagulant pesticides contaminating human food sources. New England J. Med. 311:257–258.

FELLOWS, D. P. 1977. Evaluation of new rodenticides and formulations. Progress Rep.-Work Unit DF-103.7. U.S. Fish and Wildl. Serv. 22pp.

———, AND R. T. SUGIHARA. 1977. Food habits of Norway and Polynesian rats in Hawaiian sugarcane fields. Hawaiian Planters' Rec. 59:67–86.

HARRISON, J. L. 1957. Habitat of some Malayan rats. Proc. Zool. Soc. London. 128:1–21.

HAWAIIAN SUGAR PLANTERS' ASSOCIATION. 1989. Hawaiian Sugar Manual 1989. Hawaiian Sugar Planters' Assoc., Aiea, Hawaii. 29pp.

HILTON, H. W., AND L. F. PANK. 1981. Recommendations on anticoagulants and zinc phosphide as rodenticides. Insect and Rat Control Report 32, Hawaiian Sugar Planters' Assoc. Exp. Stn. 2pp.

HIRATA, D. N. 1977. Species composition of rats on Mauna Kea Sugar Company from 1967 through 1976. Hawaiian Sugar Tech. Rep.:91–94.

HOOD, G. A., R. D. NASS, G. D. LINDSEY, AND D. N. HIRATA. 1971. Distribution and accumulation of rat damage in Hawaiian sugarcane. J. Wildl. Manage. 35:613–618.

———, ———, ———, AND ———. 1967. Rat populations in relation to sugarcane. Annu. Prog. Rep., Denver Wildl. Res. Cent. 19pp.

KAMI, H. T. 1966. Foods of rodents in the Hamakua District, Hawaii. Pac. Sci. 20:367–373.

KARIM, M. A. 1983. Effects of zinc phosphide treatments on Hawaiian sugarcane rat populations. Ph.D. Thesis, Bowling Green State Univ. Bowling Green, Ky. 186pp.

KARTMAN, L., AND R. P. LONERGAN. 1955. Observations on rats in an enzootic plague region of Hawaii. U.S. Dep. Health, Education, and Welfare Public Health Rep. 70:585–593.

LINDSEY, G. D., R. D. NASS, G. A. HOOD, AND D. N. HIRATA. 1973. Movement patterns of Polynesian rats (*Rattus exulans*) in sugarcane. Pac. Sci. 27:239–246.

MENDENHALL, V. M., AND L. F. PANK. 1980. Secondary poisoning of owls by anticoagulant rodenticides. Wildl. Soc. Bull. 8:311–315.

NASS, R. D. 1977. Movements and home ranges of Polynesian rats in Hawaiian sugarcane. Pac. Sci. 31:135–142.

———, G. A. HOOD, AND G. D. LINDSEY. 1971. Fate of Polynesian rats in Hawaiian sugarcane fields during harvest. J. Wildl. Manage. 35:353–356.

PEMBERTON, C. E. 1925. The field rat in Hawaii and its control. Hawaiian Sugar Planters' Assoc. Exp. Stn. Bull. 17. 46pp.

SAS INSTITUTE INC. 1988. SAS/STAT User's Guide, Release 6.03 edition. SAS Inst. Inc., Cary, N.C. 1,028pp.

SAVILLE, D. J. 1990. Multiple comparison procedures: the practical solution. Am. Stat. 44:174–180.

SEARLE, A. G., AND S. S. DHALIWAL. 1957. The rats of Singapore Island. Proc. Ninth Pac. Sci. Congr. 19:12–14.

STONE, W. 1917. The Hawaiian rat. Occas. Pap. Bishop Mus. 3:253–260.

TAYLOR, R. H. 1975. What limits kiore (*Rattus exulans*) distribution in New Zealand? N.Z. J. Zool. 2:473–477.

TOBIN, M. E., R. T. SUGIHARA, AND A. K. OTA. 1990. Rodent damage to Hawaiian sugarcane. Proc. Vertebr. Pest Conf. 14:120–123.

TOMICH, P. Q. 1986. Mammals in Hawaii, Second edition. Bishop Mus. Press, Honolulu. 375pp.

———. 1970. Movement patterns of field rodents in Hawaii. Pac. Sci. 24:195–234.

U.S. FISH AND WILDLIFE SERVICE. 1979. Survey: rat damage on Lihue Plantation. Wildl. Damage Res. Stn. Audit Rep. 8pp.

VAN RIPER, S. G., AND C. VAN RIPER III. 1982. A field guide to the mammals in Hawaii. The Oriental Publishing Co., Honolulu. 68pp.

Received 9 August 1991.
Accepted 3 May 1992.
Associate Editor: Fagerstone.