ECOLOGY AND IMPACTS OF INTRODUCED RODENTS (RATTUS SPP. AND MUS MUSCULUS) IN THE HAWAIIAN ISLANDS

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI‘I IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

BOTANY
(ECOLOGY, EVOLUTION, AND CONSERVATION BIOLOGY)

DECEMBER 2010

By

Aaron B. Shiels

Dissertation Committee:

Donald Drake, Chairperson
Curtis Daehler
Terry Hunt
Tamara Ticktin
Will Pitt
We certify that we have read this dissertation and that, in our opinion, it is satisfactory in scope and quality as a dissertation for the degree of Doctor of Philosophy in Botany (Ecology, Evolution, and Conservation Biology).

Dissertation Committee

_________________________
Chairperson
For Opa

(Martin C. Pohle, 1907-2002)

and

My Parents

(Stephen and Linda Shiels)
ACKNOWLEDGEMENTS

I am most grateful for my wife, Laura Shiels, and all of the support that she has furnished during the past 10 years. She has provided me with the necessary balance in my life. I am also grateful to my parents (Steve and Linda) and brother (Josh) for continually giving me opportunities and a wealth of support that has helped me to get to where I am today.
ABSTRACT

Introduced rats (*Rattus rattus*, *R. norvegicus*, and *R. exulans*) and/or mice (*Mus musculus*) occur on more than 80% of the world’s island groups, where they pose great threats to native species. Understanding the interactions between these introduced rodents and the environments which they have invaded can assist in land management and conservation efforts on islands. In three mesic forests in the Waianae Mountains, Oahu, Hawaii, rat and mouse abundances were estimated using mark-and-recapture, microhabitat use and den sites were determined using spool-and-line tracking, and rat home-ranges were estimated using radio-tracking. The diets of three of the rodents (*R. norvegicus* was absent from the three sites) were assessed using stomach content and stable isotope analyses. Additionally, field and captive-feeding trials were used to assess fruit and seed removal and consumption, and seed predation and dispersal, by *R. rattus*. *Rattus rattus* dominates these forests in abundance (7.1 indiv./ha) relative to the two smaller rodents, *R. exulans* (0.3 indiv./ha) and *M. musculus* (3.7 indiv./ha). Home-range estimates for *R. rattus* (N = 19) averaged 3.8 ha, and the single radio-tracked *R. exulans* had a home-range of 1.8 ha. Except for one individual *M. musculus*, all den sites of *R. exulans* and *M. musculus* were belowground, whereas dens of *R. rattus* were both above- and belowground. Most (> 88%) rodent activity occurred in areas where vegetation closely (10-30 cm above individuals) covered the rodent; 70% of the monitored movements of both *M. musculus* and *R. exulans* were on the ground surface, whereas *R. rattus* was mainly arboreal (32% ground, 64% arboreal) and was typically observed at ca. 3 m height when aboveground. Consistent with the evidence for (micro-) habitat partitioning among these three rodents, the diets of the three rodents may also provide evidence of niche partitioning. *Rattus exulans* had an intermediate diet (stomachs
containing 60% plant and 38% arthropod; N = 12) between the more carnivorous *M. musculus* (36% plant, 57% arthropod; N = 47) and the more vegetarian *R. rattus* (81% plant, 14% arthropod; N = 95); yet the lifetime average diet determined by stable isotope analysis (δ15N and δ13C) of bone marrow of *R. exulans* was indistinguishable from the lifetime diet of *M. musculus*.

The likelihood of seed predation and dispersal by *R. rattus* was tested with field and laboratory experiments. In the field, fruits of eight native and four non-native common woody plant species were arranged individually on the forest floor in four treatments that excluded vertebrates of various sizes. Eleven species had a portion (3-100%) of their fruits removed from vertebrate-accessible treatments, and automated cameras photographed only *R. rattus* removing fruit. In the laboratory, *R. rattus* were offered fruits of all 12 species used in the field trials, as well as 21 of the most problematic non-native species in Hawaii, to assess consumption and seed fate. Rats ate pericarps (fruit tissue) and seeds of most species, and the impacts on these plants ranged from potential dispersal of small-seeded (≤ 1.5 mm length) species that survived gut passage (e.g., the native *Kadua affinis*, and the non-natives *Clidemia hirta*, *Buddleia asiatica*, *Ficus microcarpa*, *Miconia calvescens*, and *Rubus rosifolius*) to predation where < 35% of the seeds survived. Many species had some partly damaged or undamaged seeds that survived rat exposure. Combining field and laboratory findings indicates that many interactions between *R. rattus* and seeds of native and non-native plants may result in seed dispersal. Therefore, rats are likely to be affecting plant communities through both seed predation and dispersal, and these findings should be applied to aid land management efforts where introduced rodents have invaded.
TABLE OF CONTENTS

Dedication..................................................................................................................iii

Acknowledgements.................................................................................................iv

Abstract....................................................................................................................v

List of Tables.............................................................................................................ix

List of Figures............................................................................................................xi

Chapter 1. Introduction.............................................................................................1
  Questions..................................................................................................................5
  Study site..................................................................................................................5
  Rat history in Hawaii...............................................................................................7
  Research questions, hypotheses, workplans.........................................................12

Chapter 2. Population ecology of introduced rodents (*Rattus rattus*, *Rattus exulans*, and *Mus musculus*) and their habitat uses in Hawaiian mesic forest........................................31
  Abstract..................................................................................................................32
  Introduction.............................................................................................................33
  Methods..................................................................................................................37
  Results....................................................................................................................47
  Discussion..............................................................................................................78
  Acknowledgements...............................................................................................92

Chapter 3. Niche partitioning based on diet analysis of three introduced rodents in Hawaiian montane forest..........................................................93
  Abstract..................................................................................................................94
  Introduction.............................................................................................................95
  Methods..................................................................................................................98
  Results....................................................................................................................102
  Discussion..............................................................................................................112
  Acknowledgements...............................................................................................121

Chapter 4. Are introduced rats (*Rattus rattus*) both seed predators and dispersers in Hawaii?.................................................................122
  Abstract..................................................................................................................123
  Introduction.............................................................................................................124
  Methods..................................................................................................................126
  Results....................................................................................................................132
  Discussion..............................................................................................................139
  Acknowledgements...............................................................................................147
Chapter 5. Frugivory by introduced black rats (Rattus rattus) promotes dispersal of invasive plant seeds……………………………………………………………………..148
  Abstract…………………………………………………………………………………………149
  Introduction……………………………………………………………………………………150
  Methods…………………………………………………………………………………………153
  Results…………………………………………………………………………………………160
  Discussion……………………………………………………………………………………166
  Acknowledgements…………………………………………………………………………172

Chapter 6. Conclusions……………………………………………………………………………173

Appendix A. Woody plant (≥ 1 cm d.b.h.) densities at Kahanahaiki Forest, Oahu……..184
Appendix B. Woody seedling (indiv. ≤ 50 cm tall) densities at Kahanahaiki………………186
Appendix C. Flower, fruit, and seed production at Kahanahaiki…………………………187
Appendix D. Prey items in scat of feral cats and mongoose at Kahanahaiki………………189
Appendix E. Captive-feeding trials involving rodents and Deroceras laeva slugs……….190
Appendix F. Captive-feeding trials involving rodents and Limax maximus slugs……….191
Appendix G. Estimated ages of some black rats at Kahanahaiki…………………………..192

Literature Cited…………………………………………………………………………………………193
LIST OF TABLES

Table 1. Density estimates for rats (*Rattus* spp.), with emphasis on the Hawaiian Islands..................................................................................................................................................13

Table 2. Rodent size characteristics from captured individuals at three mesic forest sites in the Waianae Mountains..................................................................................................................................................48

Table 3. Size characteristics of each sex and age of black rats captured at three sites.....49

Table 4. Size characteristics of adult and juvenile black rats captured at the three sites..49

Table 5. Size characteristics of each sex and age of Pacific rats captured at the three sites..........................................................................................................................................................50

Table 6. Size characteristics of each sex and age of house mice captured at the three sites..........................................................................................................................................................50

Table 7. Home-ranges (95% kernel) for radio-collared rats from two mesic forest sites (KHI and MAK)..................................................................................................................................................61

Table 8. The 14 black rats and four Pacific rats at KHI assessed for den sites and movements using radio-tracking.................................................................64

Table 9. The 10 black rats at MAK and one Pacific rat at HON assessed for den sites and movements using radio-tracking..............................................................................................................66

Table 10. Average distances (m) black rats were observed using spool-and-line tracking at the three study sites........................................................................................................................................73

Table 11. Frequency that black rats were observed on surface, above-, and belowground at the three study sites...............................................................................................................................................76

Table 12. Relative abundances of major food types identified in stomachs of three rodent species in KHI mesic forest..........................................................................................................................104

Table 13. Frequency of rodent stomachs with identifiable seed, fruit, and arthropod taxa at KHI.......................................................................................................................................................106

Table 14. Characteristics of the 12 fleshy-fruited woody plants used in field and captive feeding trials.................................................................................................................................128

Table 15. Percentage of fruit remaining at the end of each trial for exclosure treatments at KHI.......................................................................................................................................................133

Table 16. Characteristics of the 25 invasive plant species used in this study............154
Table 17. The origin, approximate number of years in Hawaii, and the likely dispersal vector for 25 invasive plant species used in this study…………………………………156

Table 18. Eigenvalues and factor loadings for the first three principal components of variables relating to the characteristics of fruits and seeds of 25 plant species introduced in Hawaii………………………………………………………………………164
LIST OF FIGURES

Figure 1. Map of the three study sites in the Waianae Mountains, Oahu, Hawaii........6

Figure 2. The processes that affect plant recruitment.................................................24

Figure 3. Picture of a black rat fitted with a bobbin for spool-and-line tracking............45

Figure 4. Abundances (No. indiv./100 trap night) of three rodent species captured at the three study sites..........................................................52

Figure 5. Densities (No. indiv./ha) of three rodent species captured at the three study sites..........................................................53

Figure 6. Percentages of captured black rats that were juveniles at the three study sites..........................................................55

Figure 7. Picture of a black rat live-trapped at HON with ear mites and lesions........56

Figure 8. Relationship between rat activity in tracking tunnels and rat abundance......59

Figure 9. Home-range polygons (95% kernel) for four black rats at MAK.............62

Figure 10. Average and maximum height (m) that rodents were observed aboveground at KHI and HON.......................................................71

Figure 11. Average and maximum distance (m) that rodents were observed from trap (point of capture) at KHI and HON.................................................72

Figure 12. Frequency of each rodent species on surface, above-, and belowground microhabitats at KHI and HON.......................................................74

Figure 13. Frequency of each rodent species on substrate types at KHI and HON......75

Figure 14. Frequency of den sites occupied by each rodent species at the three study sites.................................................................................77

Figure 15. Relative abundances of three major items found in stomachs of the three rodent species at KHI.......................................................105

Figure 16. Relative abundances of major food items found in stomachs of black rats when few, and the majority, of Pacific rats and mice were trapped at KHI........109

Figure 17. Average δ¹⁵N and δ¹³C values for all three rodent species and some of their potential prey items from KHI.........................................................111
Figure 18. Percentage of fruit remaining at each sampling period for each species in open ground treatment at the field site KHI

Figure 19. Percentage of pericarp mass and seed mass remaining when fruits were offered to black rats in captivity

Figure 20. Percentage of seeds surviving 24 hour exposure to captive black rats

Figure 21. The four scenarios by which black rats may interact with fruits and disperse seeds

Figure 22. Average pericarp mass and seed mass remaining for 25 invasive plant species in Hawaii

Figure 23. Average seed survival of 25 invasive plant species in Hawaii that were offered to captive black rats

Figure 24. Relationship between seed mass remaining following black rat interaction and PC1, where PC1 reflects sizes of fruits and seeds