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The Impacts of Introduced Mammals in the Hawaiian Islands: A Literature Review

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ABSTRACT: Wildlife management and conservation biology are full of conflict, especially in regard to introduced vertebrates in Hawai'i. At present, there are 17 introduced mammals with established wild populations in Hawai'i, including 6 ruminants, 4 rodents, 3 feral pets, pigs, donkeys, rock wallabies, and mongooses. Disagreement about the reliability of information on the impacts of introduced mammals in Hawai'i is one reason for conflict between stakeholders, which may undermine conservation and management programs. The objective of this research was to assess what science has recorded in regards to the impact of introduced mammals on the native flora, fauna, and ecosystems of the Hawaiian Islands. A literature (peer-reviewed articles, theses, dissertations, and grey literature) search for data on the impact of these species resulted in 156 articles, which were assigned to 1 of 6 categories that describe science's 'Level of understanding' of the impacts of mammals in Hawai'i. The vast majority of the available data (134/156 articles) resulted from basic observations or general exclosure plots. In terms of their impact in Hawai'i, cats (21 articles), black rats (27 articles), and pigs (40 articles) are the most researched and hence best understood species. Very little is known about the impacts of dogs, rabbits, brush-tailed rock wallabies, and donkeys on the flora, fauna, and ecosystems of Hawai'i. Analysis of the dates of publication of articles suggests research may be influenced by the level of controversy surrounding a species.

KEY WORDS: controversy, disease, ecosystem structure and function, exclosure plots, exotic species, feral animals, Hawai'i, human-wildlife conflict, impact, introduced species, literature, introduced mammals

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INTRODUCTION

The fields of wildlife management and conservation biology are full of conflict, especially in Hawai'i. Different people value different aspects of the environment, and it can be exceptionally difficult for people to compromise on those values (Regan et al. 2006, Liukkonen et al. 2009). The State of Hawai'i is one area that suffers with a seemingly continuous case of conflict between stakeholders over the presence and impacts of introduced mammals. For example, in the 1990s, conflict over fencing designed to exclude wild pigs from a Natural Area Reserve on the Island of Hawai'i became violent, which resulted in a legislative resolution that required the State Department of Land and Natural Resources employ a professional mediator (Adler 2001, Josayama 1996). Across the 7 main islands, there are 17 introduced mammal species with established wild populations (Tomich 1986). Hawai'i's residents are in conflict over how to deal with the presence and impacts associated with some of these species.

The question is, why, after decades of research, conferences, public meetings, and dozens of task force groups, a situation that suggests an abundance of data related to introduced animals, are the people of Hawai'i still trying to resolve the same conflicts that were an issue several decades ago? Why is it that people do not seem to trust the scientists, wildlife biologists, and professional conservation personnel of Hawai'i to conserve the unique and fragile ecosystems of Hawai'i for the benefit of all? One reason may be that people do not trust the science being used to convince them to give up the activities or

objects they value. For example, an interviewee in a recent survey designed to assess hunter's attitudes was recorded as stating that "[A conservation organization] may be making false claims about pig densities increasing when there is no real data to support this" (Hubrecht 2006). If the people of Hawai'i cannot trust the data, then why would they trust conservation organizations to conserve Hawai'i's ecosystems? Further complicating this data issue is the fact that there have been relatively few attempts at synthetically compiling research on introduced animals in Hawai'i. Hence, the main objective of this research was to assess what science has recorded in regard to the impact of introduced mammals on the native flora, fauna, and ecosystems of the Hawaiian Islands. To do this, we conducted a comprehensive review of the literature on introduced terrestrial mammals in Hawai'i.

METHODS

We reviewed research conducted on introduced mammals in the Hawaiian Islands only. Thus, papers on commonly studied introduced mammal species were excluded if that research was conducted outside of the Hawaiian Islands. We took this more conservative approach, as an argument can be made that the impact of a given species will vary depending on a host of local environmental variables. We define *impact* as the positive or negative effect an introduced mammal may have on the productivity, survival, and abundance or ecosystem services provided by native Hawaiian flora, fauna, or ecosystems. A native species is defined as a

species that colonized the Hawaiian Islands without aid from people.

We used multiple methods of searching for literature including keyword searches in ISI's Web of Knowledge, Google Scholar/Web, and the University of Hawai'i Library Catalogue. We searched for articles in the U.S. Fish and Wildlife Service National Digital Library, and in the Hawai'i Department of Land and Natural Resources Library. We also manually searched article bibliographies, local conservation magazines, and conference proceedings, such as the *'Elepaio* and the *Atoll Research Bulletin*. If a single dataset was published more than once, then we only included the most rigorous publication in this review (e.g., a peer-reviewed paper over a grey literature item).

The literature was separated into three categories: journal articles (peer-reviewed), theses/dissertations (reviewed by university academics), and grey literature (not necessarily reviewed by qualified scientists/academics prior to publication), and then assigned to one or more of the 6 categories we used to describe sciences 'level of understanding' of the impacts of introduced mammals, based on its methodology (Table 1). We terminated the search for grey literature when further documentation simply reiterated information already present in Table 1.

The 6 categories used to describe sciences 'level of understanding' (Table 1) are defined as:

1. Evidence of an interaction: Studies that contain data or observations of an interaction between an introduced mammal and a native species/habitat, including direct and indirect observations, dietary/fecal studies, unpaired exclosures, and disease assays that record an introduced species as a carrier of a disease known to impact a native species.

2. Multi-species exclosure or control: Studies that account for some uncontrollable variables but cannot assign impact to a single introduced species. This includes studies utilizing paired exclosure plots or control programs that exclude/control multiple introduced species without monitoring the density of each introduced species.

3. Theoretical modeling: Studies that model the possible outcomes of the impact of an introduced species on a native species using hypothetical data.

4. Native success plus monitoring introduced species: Studies that compare the success of a native species to the density and/or impact of one or more introduced species without manipulating the density of the introduced species.

5. Field experiment: Studies that manipulate and monitor the density of an introduced species and compare it to the success of a native species.

6. Predicted outcome: Studies that model the fate of a native species using real data on the impact of an introduced species.

The overall 'level of understanding' for each species' impacts is indicated by the shading in Table 1. Shading indicates the presence of either a peer-reviewed article and/or theses in the current and/or previous cells.

The date of publication for each article was analyzed

to illustrate any patterns in scientific study of the impact of mammals on Hawaiian flora, fauna, and ecosystems.

RESULTS

We found a total of 156 documents containing data on the impacts of introduced mammals in Hawai'i. These documents consisted of 82 peer-reviewed articles, 10 theses, and 64 grey literature items. The vast majority of the articles (134/156) were classified as either 'Evidence of an interaction', or 'Multi-species exclosure or control'.

Wild pigs (*Sus scrofa*), black rats (*Rattus rattus*), and feral cats (*Felis catus*) were the three most rigorously studied species, whereas there was little to no data on the impacts of brush-tailed rock wallabies (*Petrogale penicillata*) and donkeys (*Equus asinus*). Even if the subjective ranking of the 6 categories of scientific study was reordered, pigs, cats, and rats would probably still fall out as the most-studied species, as they are the subject of the vast majority of the scientific articles we found, with 40, 27, and 21 articles respectively.

The impacts of some species, such as black rats, pigs, and mongooses (*Herpestes javanicus*) have been a regular topic of study since at least the 1960s. The impacts of other species, such as rabbits (*Oryctolagus cuniculus*), wallabies, and axis deer (*Axis axis*) are a topic of interest for short periods of time (Figure 1). Either way, controversy or a lack thereof seems to influence the number of articles on the impact of introduced mammals in Hawai'i.

DISCUSSION

Feral cats and black rats have been the subjects of the most rigorous scientific study in Hawai'i (Table 1). The frequency of studies on feral cats has increased in recent years, from 0.1 articles/decade prior to 1980, to 0.6 articles/decade following 1980. Studies have now produced enough data to allow population viability analysis of the possible impacts of unchecked cat predation on 'Ua'u (Hawaiian dark-rumped petrels, *Pterodroma phaeopygia sandwichensis*) (Hu et al. 2001). The results indicated that unchecked feral cat predation could eliminate a 'Ua'u colony within 65 years. Unfortunately, while feral cats reportedly prey upon other native Hawaiian bird species, such as the Palila (*Loxioides bailleui*) (Pletschet and Kelley 1990, Amarasekare 1993;1994), 'Alala (*Corvus hawaiiensis*) (Anonymous n.d.), and Nēnē (*Branta sandvicensis*) (Hoshida et al. 1990, Rave et al. 2005, Zaun and Weathers 2009), these bird species have not been subjected to PVA analysis, which could generate the data needed to convince stakeholders of the threat posed by feral cats.

Black rats have been a fairly consistent topic of scientific study in Hawai'i since 1973 (Figure 1). The level of interest in black rats could be related to their ability to consume and affect the population stability of almost any native Hawaiian taxa. Black rats are known to consume the fruits, seeds, and bark of native plants such as *Acacia koa* (Scowcroft and Sakai 1984), native snails (Hadfield et al. 1993, Hadfield and Saufler 2009), and arthropods (Sugihara 1997, Cole et al. 2000), as well

Table 1. ‘Level of understanding’ of the various impacts of each of the 17 introduced mammal species in the Hawaiian Islands.

Species	Interaction	Increasing Level of Understanding →(Journal Article; Thesis; Grey Literature)					
		Evidence	Multi-Species Exclosure or Control	Theoretical	Native Success + Monitoring Introduced	Field Experiment	Predicted Outcome
Cat (<i>Felis catus</i>)	Competition	0; 1; 1					
	Predation	11; 2; 2			2; 0; 0		1; 0; 0
	Disease	2; 0; 1	1; 0; 0				
	Grazing	0; 1; 0					
	Erosion						
	Ecosystem Structure and Function						
Black rat (<i>Rattus rattus</i>)	Competition	1; 0; 1					
	Predation	8; 0; 1	0; 0; 1		1; 0; 0	5; 0; 0	
	Disease	4; 0; 0	2; 0; 0				
	Grazing	6; 0; 2	1; 0; 0		1; 0; 0		
	Erosion						
	Ecosystem Structure and Function	3; 0; 1	0; 0; 1				
Pig (<i>Sus scrofa</i>)	Competition	0; 1; 0					
	Predation	0; 1; 1					
	Disease	1; 1; 1	0; 0; 1		1; 0; 0		
	Grazing	0; 2; 5	0; 0; 2		1; 0; 0	0; 0; 1	
	Erosion	0; 1; 2				0; 0; 1	
	Ecosystem Structure and Function	1; 2; 16	2; 2; 5	0; 0; 1	7; 1; 1	0; 0; 1	
Cattle (<i>Bos taurus</i>)	Competition						
	Predation						
	Disease						
	Grazing	1; 0; 2	3; 0; 3		1; 0; 1		
	Erosion						
	Ecosystem Structure and Function	0; 0; 1	0; 0; 1		1; 0; 1		
Sheep (<i>Ovis aries</i>)	Competition						
	Predation						
	Disease						
	Grazing	0; 0; 3	1; 0; 5		4; 0; 0		
	Erosion	0; 0; 2					
	Ecosystem Structure and Function		2; 0; 1				
Polynesian rat (<i>Rattus exulans</i>)	Competition	2; 0; 0					
	Predation	7; 0; 0	2; 0; 0		1; 0; 0		
	Disease	3; 0; 0	2; 0; 0				
	Grazing	4; 0; 0	1; 0; 0				
	Erosion						
	Ecosystem Structure and Function	2; 0; 0	0; 0; 1				
Goats (<i>Caprus hircus</i>)	Competition						
	Predation						
	Disease	1; 0; 0					
	Grazing	1; 0; 5	6; 0; 2		1; 0; 0		
	Erosion	2; 0; 4					
	Ecosystem Structure and Function	0; 1; 2	3; 0; 2				
Small Indian mongoose (<i>Herpestes javanicus</i>)	Competition	1; 1; 0					
	Predation	6; 3; 2			1; 0; 0		
	Disease	3; 0; 0	2; 0; 0				
	Grazing	2; 1; 0					
	Erosion	0; 0; 1					
	Ecosystem Structure and Function	2; 0; 1					
Mouflon sheep (<i>Ovis musimon</i>)	Competition						
	Predation						
	Disease						
	Grazing	0; 0; 4	2; 0; 2		2; 0; 0		
	Erosion	0; 0; 1					
	Ecosystem Structure and Function		1; 0; 1				

Table 1 (cont.)

Species	Interaction	Increasing Level of Understanding → (Journal Article; Thesis; Grey Literature)					
		Evidence	Multi-Species Exclosure or Control	Theoretical	Native Success + Monitoring Introduced	Field Experiment	Predicted Outcome
Axis deer (<i>Axis axis</i>)	Competition						
	Predation						
	Disease						
	Grazing	0; 1; 2			1; 0; 0		
	Erosion	1; 0; 1					
	Ecosystem Structure and Function	1; 1; 2					
House mouse (<i>Mus musculus</i>)	Competition						
	Predation	4; 0; 0					
	Disease	3; 0; 0	2; 0; 0				
	Grazing	3; 0; 0	1; 0; 0				
	Erosion						
	Ecosystem Structure and Function	2; 0; 0					
Norway rat (<i>Rattus norvegicus</i>)	Competition						
	Predation	2; 0; 0					
	Disease	4; 0; 0	2; 0; 0				
	Grazing	1; 0; 0					
	Erosion						
	Ecosystem Structure and Function	1; 0; 0					
Black tailed deer (<i>Odocoileus hemionus columbianus</i>)	Competition						
	Predation						
	Disease						
	Grazing	1; 0; 4	0; 0; 1				
	Erosion	0; 0; 1					
	Ecosystem Structure and Function	1; 0; 5	0; 0; 1				
Dog (<i>Canis familiaris</i>)	Competition						
	Predation	3; 1; 3					
	Disease	1; 0; 0					
	Grazing						
	Erosion						
	Ecosystem Structure and Function						
Rabbit (<i>Oryctolagus cuniculus</i>)	Competition	0; 1; 1					
	Predation	1; 0; 0					
	Disease						
	Grazing	2; 1; 1					
	Erosion						
	Ecosystem Structure and Function						
Brush-tailed rock wallaby (<i>Petrogale pencillata</i>)	Competition						
	Predation						
	Disease						
	Grazing	1; 0; 1					
	Erosion						
	Ecosystem Structure and Function	0; 0; 1					
Donkey (<i>Equus asinus</i>)	Competition						
	Predation						
	Disease						
	Grazing						
	Erosion						
	Ecosystem Structure and Function						
Not species specific	Predation	Rats-grazing 1; 0; 1	General predation 1; 0; 0 Rats-predation 2; 0; 0	Rats-predation 1; 0; 0	General predation 1; 0; 0		

Note: For specific citations, please contact the senior author

Figure 11-vii. Number of articles per species per year since 1917.

Note: a) From 1993-1994 a legislative resolution ordered staff from Division of Forestry and Wildlife to use mediation to resolve a conflict between pig hunters and Natural Area Reserves staff (Josayama 1996); b) Goats were eradicated from Ni'ihau in 1910, Lana'i in 1981, and Kaho'olawe in 1980 (Campbell and Donlan 2005); c) Hawai'i Division of Fish and Game attempted to hybridize feral sheep and mouflon sheep between 1957 and 1966 (Walker 1958, Walker 1960, Walker 1962); d) The formation of the Maui Axis Deer Group occurred in 1996 which supported doctoral research into the impacts of Maui axis deer (Subcommittee on Public Information and Deer Management Planning of Maui Axis Deer Group 2002).

Figure 11-vii (cont.)

as the eggs and nestlings of native birds. Some of the most rigorous studies revealed that predation by black rats significantly reduced the population growth rate of 'Elepaio (*Chasiempis sandwichensis*) in the Ko'olau mountain range on O'ahu (VanderWerf and Smith 2002, VanderWerf 2009).

Feral cats, black rats, and wild pigs are the most common topics of scientific studies on the impacts of mammals in Hawai'i. The large number of studies on cats and pigs could be a reflection of the controversial nature of these species. Feral cats are very similar to our beloved pet cats and hence are protected by a number of groups across the U.S. Similarly, wild pigs are protected by hunters and people who believe wild pigs are a pivotal element of native Hawaiian culture (Hubrecht 2006). Unfortunately, studies have shown the presence of both species to be detrimental to the native elements of Hawai'i's environment. Contradictory values create controversy, which seems to drive scientific interest and studies.

In contrast dogs, rabbits, brush-tailed rock wallabies, and donkeys have received little scientific interest. Sporadic mass faunal killings by feral/stray dogs generate brief spurts of outrage and news reports, but this does not seem to be conducive to encouraging structured scientific inquiry. The lack of rigorous scientific study makes it difficult to convince stakeholders feral dogs are a problem that should be addressed. While a single dog has been known to devastate a population of wedge-tailed shearwaters (*Puffinus pacificus*) (The Nature Conservancy 2009), anecdotes do not tell us if sporadic predation by dogs will negatively impact faunal populations in the long-term.

Wild rabbits in Hawai'i were a topic of interest when rabbits were present on Hawaiian islets such as Laysan, Lisianski, and Manana Island (Dill and Bryan 1912). Rabbits completely suppressed the vegetation on these islands, and they may have contributed to the increase in erosion (Atkinson and Atkinson 2000) and the extinction of the Laysan millerbird (*Acrocephalus familiaris*), the Laysan honeyeater (*Himatione sanguine fraithii*), and the Laysan rail (*Porzana palmeri*) (Watson 1961). Such a devastating impact drew research interest. Unfortunately, resources and research opportunities restricted the quality of research to observational and anecdotal evidence, information that cannot be easily transferred to other environments. Today, wild rabbits are only found on the main Hawaiian Islands. As yet, there is no documented evidence that rabbits are altering any of Hawai'i's ecosystems. However, no one is monitoring or documenting changes that may be occurring, as they are neither a game species nor a protected species. A lack of controversy seems to have stopped the flow of interest (most recent article published in 1975) and research funds into the impacts of feral rabbits on Hawai'i's fragile ecosystems. This lack of interest may be a grievous error should feral rabbits, usually abandoned pets, become established in the inaccessible mountain areas of Hawai'i.

Brush-tailed rock wallabies are also a sorely understudied species in Hawai'i. Interest peaked for a short period of time, when one study suggested that Hawai'i's wallabies may be a new species or the only

remaining remnant of a species thought to be extinct in Australia (Lazell 1980). Then, genetic research found that the species still exists in Australia (Eldridge and Browning 2002). Combine that with a Hawaiian population that does not seem to be expanding or dispersing (Lauret 1982), and interest and funding to monitor rock-wallabies ran out (Bedish 1993). Nobody has studied the brush-tailed rock wallabies of Hawai'i since 1993 (R. Walker, retired wildlife biologist, Hawai'i Division of Fish and Wildlife, pers. commun.).

There are no documents that discuss feral donkeys in Hawai'i. The current size of the feral donkey population, which according to traffic warning signs is on old lava flow near Kailua-Kona, Hawai'i, is unknown. However, donkeys have been described as having a voracious and non-discriminating appetite (McKnight 1958, Giffin 1979), making them completely adaptable to most range conditions and capable of potentially damaging any plant species in Hawai'i. The lack of scientific study into the impacts on donkeys on plant succession in Hawai'i is disturbing. Conservation professionals may also want to reflect on current management policies for donkeys, as they are neither a game species nor a particularly common pet, and hence may be less controversial to manage or eradicate than other introduced species.

The majority of the articles, and hence our understanding of the impacts of introduced mammals in Hawai'i, is based upon the two weakest categories of scientific investigation: 'Evidence of an interaction', and 'Multi-species enclosure or control'. Studies in the 'Evidence of an interaction' category were typically dietary studies or simple observations of an interaction. Dietary studies cannot easily distinguish between predation and scavenging. Whilst predation may negatively impact a native faunal species, scavenging will not. Observations are also insufficient for determining if an introduced species is having a positive or negative influence on the intrinsic rate of increase of a native species.

General enclosure plots and control programs are also a weak method of investigating the impacts of introduced mammals in Hawai'i. The weakness of these general programs is that they exclude multiple introduced mammal species from an area. While the fence or traps allow us to see a natural ecosystem as it recovers and to measure the damage caused by introduced mammals (grazers in particular), they do not tell us which species was causing the damage. Was it all of them, or one particular species? General enclosures do not help land managers prioritize the objectives associated with introduced mammals and conservation, except to place fencing at the top of the list, especially when given limited funds to achieve those objectives. Data relating to the magnitude of the threat posed by each species is required in order to prioritize management activities efficiently, especially when related to controversial game species.

There is no easy way to manage a controversial species. However, it may be wise to start with accurate information that all stakeholders can trust. Informing pig hunters, for example, that pigs are predators of Nēnē eggs and goslings (Bryan 1937, Smith 1952, U.S. Fish and Wildlife Service 2004) without data as evidence, is

unlikely to be an effective technique for convincing pig hunters to relinquish an activity they value. Presenting locally obtained data may be more effective. Of course, there will always be some people who cannot be convinced to change their ways.

If conflict between stakeholder groups is impeding the progress of conservation activities, then resource managers should also consider allocating some resources to understanding the values and motivations of stakeholders. Research into the impacts of introduced mammals will not alter a stakeholder's opinion if they do not value native organisms or ecosystems. Just because stakeholders value the presence of one introduced mammal does not mean that they value the presence of all introduced mammal species. Studies into the human dimensions of wildlife frequently address questions pertaining to the values and motivations of stakeholders (Decker et al. 2001). Human dimensions studies can be combined with ecological studies to create management plans that are both scientifically sound and socially acceptable.

Information from scientific studies outside of Hawai'i may support some of the unverified claims regarding the impacts of introduced mammals in Hawai'i. For example, pigs have been recorded as predators of dark-rumped petrels (*Pterodroma phaeopygia*), a ground-nesting bird, on the Galapagos Islands (Tomkins 1985). Logically, if pigs may prey upon ground-nesting birds in the Galapagos, then they may prey on ground-nesting birds such as the Nēnē in Hawai'i. However, conservation professionals need to be careful when using outside information to support their management programs, as not all scientific information is transferable between ecosystems, and any number of factors may make petrels in the Galapagos more prone to predation by pigs than Nēnē. Conservation professionals should also be open to revealing the source and accuracy of their information, especially when managing a controversial species. If the currently available information is not sufficient to deal with conflict over controversial species, then funds should be allocated to obtaining more locally relevant data.

This research has highlighted the gaps in knowledge in regard to the impacts of introduced mammals in Hawai'i, which are substantial. There is no literature on feral donkeys; peer-reviewed articles only contain observations on the impacts of black-tailed deer (*Odocoileus hemionus columbianus*), dogs, rabbits, and brush-tailed rock wallabies; and Norway rats (*Rattus norvegicus*) have only been a topic of more advanced research in terms of diseases they may be able to transfer. The management of some of these species is controversial, as there are stakeholders that value their presence: black-tailed deer are a game species (DLNR 2001) valued by hunters; dogs and rabbits are common pets, which attracts the attention of animal rights activists; and brush-tailed rock wallabies are a threatened species in their native range (Eldridge and Browning 2002, Taggart et al. 2008), which raises ethical issues. Furthermore, it is difficult for conservation professionals to rally support and funds for management programs without data to back up the necessity of their management program.

We recommend that Hawai'i's universities and con-

servation organizations start working together to fill in the knowledge gaps on the impacts of introduced mammals in Hawai'i. Some of the most pertinent questions to be answered may be: 1) Are colony cats a source of disease for native Hawaiian fauna? 2) Are rodents competing with native fauna for resources? 3) Do wild pigs increase the rate of erosion in Hawaiian watersheds? 4) Is predation by the mongoose impacting coastal biodiversity? 5) Do axis deer prefer to graze native Hawaiian plants? 6) Do feral ungulates graze areas infrequently visited by hunters more intensely? 7) How many feral donkeys are there on the Island of Hawai'i, and where are they? and, 8) Is stochastic predation by feral dogs a threat to sea birds?

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