TROPICAL ISLAND INVADERS: SWAMP HARRIER (*CIRCUS APPROXIMANS*) BEHAVIOR AND SEABIRD PREDATION ON MO'OREA, FRENCH POLYNESIA

REBECCA C. WILCOX

Environmental Science Policy and Management, University of California, Berkeley, California 94720 USA

Abstract. Islands of the south pacific are fragile ecosystems, home to native land and sea birds that evolved in the absence of predators. On Mo'orea, French Polynesia the first humans arrived around 600 AD bringing with them invasive vertebrate predators. This study examines one of these predators on Mo'orea by observing swamp harrier (*Circus approximans*) habitat preference and behavior to determine if it has changed in comparison to its source population. Also it will examine their role in seabird predation on Mo'orea through a series of animal waste sample collections at high elevations. Since swamp harrier introduction in 1885 their habitat preference has not much changed from their Australian source population. The majority of its time and foraging is spent over low vegetation, though some expansion into other habitats has occurred since there are no other raptors on the island with which to compete. Feral cats (*Felis catus*) are also prevalent on the island and along with the swamp harriers are preying upon the native seabird populations on Mo'orea. Tahiti petrels (*Pesudobulweria rostrata*) and Audubon's shearwaters (*Puffinus lherminieri*) are being preferentially eaten by these predators over the invasive songbirds at high elevation. Feral cats appear to be the more significant predator of seabirds and without their control nesting seabird colonies may cease to exist on Mo'orea.

Key words: Circus approximans; *invasive species; Mo'orea, French Polynesia; seabirds*, *feral cats*

INTRODUCTION

The biology of invasive species on islands is important to understand because of the negative effects invaders have on native flora and fauna. Species invasion is a common occurrence all over the world, with species being introduced for aesthetic purposes, biological control, accidentally or all on their own. Quickly adapting generalist species can thrive and prove to be very threatening to local biodiversity. This is particularly a problem on islands where endemism is high and diversity is low. Introduced predatory invasive organisms can damage fragile systems that previously lacked a predator (Wilson 2004). A generalist predator can put great pressure on local species dynamics, by changing their own ecology to adapt and thrive in a new ecosystem (Cockburn 1991).

Historically many Pacific islands lacked predatory animals (Steadman 2006), but humans have introduced many, including rats, mice, pigs, dogs, cats and predatory birds. This is also true for Mo'orea, a high basaltic island off the Northeast coast of Tahiti, with no native predators there is only one terrestrial predatory bird, the swamp harrier (*Circus approximans)* (Elliot 1999). A biological control gone wrong, the harrier was introduced by Europeans in 1885 to control rat populations (Gouni and Zysman 2007). The swamp harrier has now become common on the island and its diet is not restricted to rats alone (Fergison-Lee and Christie 2001). In its native range of Australia, harriers live in

swampy areas and nest on the ground (Merchant and Higgins 1993), preying upon small mammals and birds by flying low over grass and heavy ground cover before pouncing (Einoder and Richardson 2007). In Mo'orea grasslands are scarce and cliffs, forests and open cultivated lands (pasture, pineapple, fruit trees and timber plantations) dominate the landscape.

The swamp harrier, a generalist species (Einoder and Richardson 2007), introduced into an ecosystem absent of other raptors is hypothesized to not just prey upon animals in open habitats, but exploit other foraging niches that other raptors would if they were present (Tapia et al 2008). This could be detrimental to the many forest and sea birds of Mo'orea. These native species have already been pushed upward in elevation as native vegetation ranges constrict due to habitat conversion and competition with introduced invasive songbirds. Even Seabird nests and burrows on cliffs are accessible to aerial predators. For example, on islands off of New Zealand seabirds are preyed upon by swamp harriers (Hawk et al. 2005), which could also be the case in Mo'orea.

This study investigated what habitats swamp harriers prefer on Mo'orea and whether or not their foraging behavior and habitat use has changed from their Australian source population. Examining what habitats they are utilizing could give insight into whether or not they are diversifying the types of habitats they forage in to better exploit the whole island or if they have a high preference for certain habitats. Investigating their behavior will show how their hunting strategies and general behavior has changed to adapt to Mo'orea.

The study also aims to look at the potential predation effect on local seabird and songbird populations on Mo'orea, specifically the Tahiti petrel (*Pseudobulweria rostrata*) and Audubon's shearwater (*Puffinus lherminieri)* (Thibault 1974). Seabirds are vulnerable targets because they have a strong scent and are large, noisy and clumsy (Bonnaud et al 2007). Many biologists have suggested that the swamp harrier is adversely affecting seabirds, but feral cats (*Felis catus*) are also known to be active predators of seabirds as well (Steadman 2006, Bonnaud et al 2007, Fitzgerald 1988). This investigation will evaluate the amount of predation on seabirds by examining seabird kill sites and collecting and dissecting both swamp harrier pellets and cat scats from high elevations. The abundance of burrows along different peaks and their proximity to kill sites and animal waste samples could give insight into the effect introduced predators have on seabird and songbird populations.

METHODS

Study Organisms

The swamp harrier is an introduced terrestrial vertebrate and is the only predatory bird on the Mo'orea (Elliot 1999). In Australia, where the swamp harrier originates, they are also known as marsh hawks. They are commonly found in swamplands, grass and agricultural fields and uncommonly found in mountains where there are no permanent wetlands (Merchant and Higgins 1993). They are one of the few raptors that roost on the ground, generally in small groups, where they will bed down in tall vegetation (Merchant and Higgins 1993). In Australia their diet is dominated by small mammals, land and freshwater birds (Ferguson-Lees and Christie 2001, Barker-Grabb 1984). Swamp harriers, like other raptors, regurgitate pellets after meals that can be used to determine their diet (Bird et al 2008).

Feral cats are also an introduction that came with the Europeans after the 1760s. They are common domesticated pets on Mo'orea but have also become feral and spread all over the island. Cats have been introduced on islands all over the world and are known predators of seabirds of all sizes (Faulquier et al 2009). Feral cats are partially nocturnal, agile predators who commonly return to successful hunting sites (Fitzgerald 1988).

Feral cat diet is determined by behavioral observations and collection of scat (Bonnaud et al 2007) and in mainland areas prey primarily on small mammals (Fitzgerald 1989).

Study Site

The study took place on the island of Mo'orea (17°30'S, 149°50'W) in the Society Island chain of French Polynesia. Mo'orea is a 5.5 million-year-old high basaltic island 17 kilometers northwest of the large island of Tahiti. It is 132 square kilometers and is covered by forest, cliff, agricultural and rural habitats. The island was first colonized by Polynesians around 600AD, and the first Europeans set foot on Mo'orea in 1769. Before human habitation the island was predator-free and there were many more species of birds present, including a higher number of nesting seabirds (Steadman 2006). Mo'orea is a good place to look at how the introduction of predators has affected the ecosystem because it is a model island system (Vitousek 2002) and the trends observed here could be used to project effects in similar situations.

Observations and animal waste samples were collected on Mo'orea from 14, September to 15, November 2009. Three Pines (17°32.067'S, 149°49.323'W) and Three Coconuts (17°32.839'S, 149°50.516'W) lookouts were used as observation points to watch swamp harrier behavior and habitat preference in the Opunohu and Paopao valleys. These vantage points were chosen because they allowed views of every habitat type in each valley. Two transects were run along the trails on Mt Rotui and Mt Moaputa to collect animal waste samples. Roost sites were searched for in Opunohu and Paopao Valleys in order to find more raptor pellets.

Habitat Preference and Behavior

Swamp harriers were observed 3-4 times a week for a total of 35.6 hours. Behavior was measured by selecting an individual and then following it with binoculars 8x42 for as long as it would stay in view (Vukovich and Ritchison 2008). Then behavior was recorded per minute as: in transit, strike, social interaction, or foraging. An approximate elevation was also recorded for each minute the bird was observed: (1) low (below treetops); (2) low-mid (treetops and less than 15 meters above them); (3) mid (between 15 and 60 meters above the treetops); and (4) high (60 meters and higher above treetops).

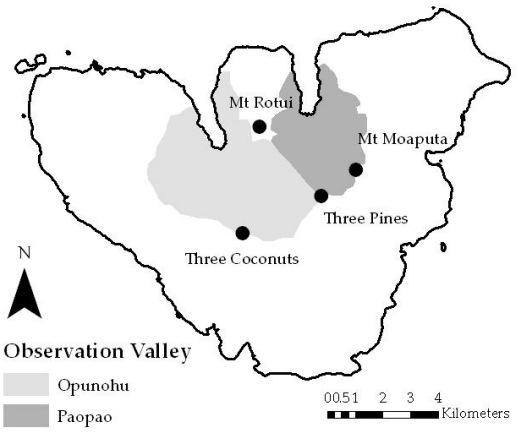

FIG. 1. Mo'orea, French Polynesia. Observations took place at three coconuts and three pines lookouts over the two valleys. Animal waste samples were collected at Mt Rotui and Mt Moaputa. This map was created at the Giff Lab at UC Berkeley.

Habitat preference was determined by observing what habitat type the bird was flying over during each minute of flight (Tapia et al. 2008). The different habitats were described as: (1) forest (medium to dense forest cover and plantations including Caribbean pine (*Pinus caribaea*), Albezia (*Falcataria moluccana*), fruit trees etc.); (2) low vegetation (pineapple fields, shrub and grassland); (3) cliff (sparse trees and rock faces along mountains); and (4) rural (areas near housing and human development, including the coast). Observational periods were mostly during mid day and early evening (Bibby et al 1998).

Habitat preference and behavior were

analyzed using non parametric statistics because the data was not in a normal distribution. χ^2 tests were used to see if swamp harriers were actively choosing their habitat or if they had no preference and used each habitat relative to the proportion present. Behavior was also analyzed using χ^2 tests.

Seabird Predation

Waste samples were collected in open areas along the trials of Mt Rotui (2 sample collections) and Mt Moaputa (1 sample collection). GPS points were taken at each collection site to record the elevation and location. The samples collected are either swamp harrier pellets or cat scat from an individual that has eaten a bird. They range from loose to densely packed groups of feathers, debris and bones. The samples consist of 3-5 segments that are 2-4cm long by 1-3cm wide. Piles of feathers were also examined along the trail. These piles were assumed to be kill sites, where the carcass had already been taken away by rats or cats. Feather samples were taken along with a GPS point at each kill site. Each kill site was marked with flagging to prevent recounting on future site visits. Waste samples and kill sites were assumed to be representative of only one bird during analysis (Faulquier et al 2009). Seabird burrow locations were also mapped using a GPS whenever encountered along the trails.

Kill site feathers and waste samples were taken back to the lab for analysis. Waste samples were dried and dissected (Redpath et al 2001). Each sample was weighed, measured and then taken apart to analyze feathers and bones. Bird remains were divided into two groups: Procellariidae (petrels) and Passeriformes (songbirds) (Table 1) based on feather size and color and the size of bones.

To analyze the animal waste samples a Pearson's χ^2 test was used to determine if seabird kills were related to seabird burrow locations. A Spearmans test was used to see if there was a significant difference in elevation between where seabird and songbird remains were found.

RESULTS

Habitat Preference

Swamp harrier habitat preference between Opunohu and Paopao valleys proved to be significantly different (χ^2=67.38, df=4, p<0.001) so habitat preference for each valley was analyzed separately. Assuming that swamp harriers don't actively prefer any of the habitat types they should spend a proportional amount of time in each habitat type based on the amount of that habitat present. Using a χ^2 test it was determined that swamp harriers in both the Opunahu and Paopao valley are choosing the habitats that they spend time in (Fig. 4 and 5). The Opunohu valley is less developed with housing and agriculture than the Paopao valley (Fig. 3) and is dominated by forest (Fig. 2). Swamp harriers in the Opunohu valley showed a preference for the forested lands, with some, but much less time spent in the cliff, low vegetation and rural habitats (Fig. 4). In the adjacent Paopao valley habitat preference was centered around low vegetation (Fig. 5).

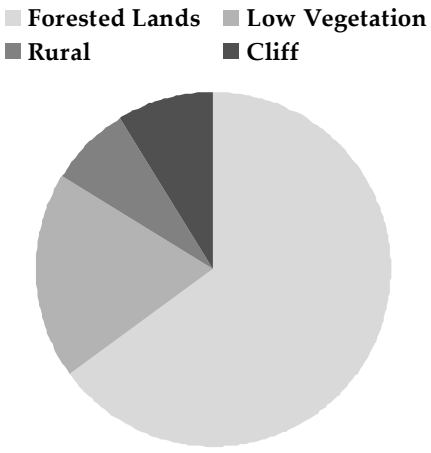

FIG. 2. This chart shows the proportional habitat composition of Opunohu valley. The valley is dominated by forested lands, but all 4 habitat types are represented.

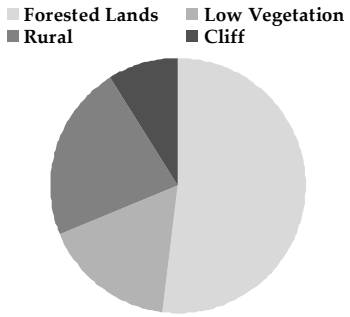

FIG. 3. This chart shows the proportional habitat composition of Paopao valley. The valley is dominated by forested lands, but all 4 habitat types are represented.

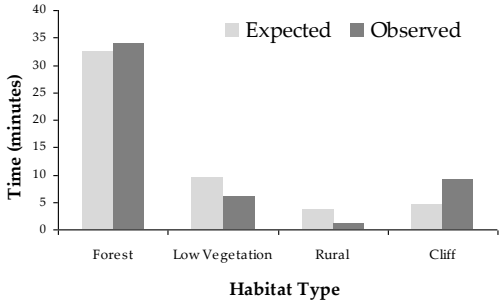

FIG. 4 This chart shows the habitat preference for the Opunohu valley. χ^2 test showed that time spent in certain habitats was not random (χ^2=7.644, df=3, p=0.05).

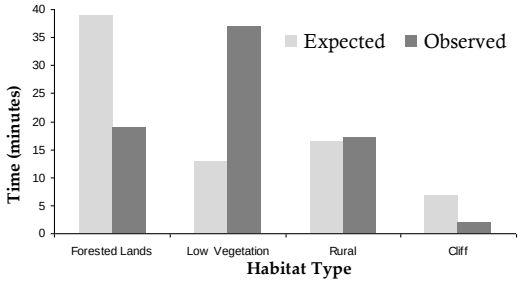

FIG. 5 This chart shows the habitat preference for the Paopao valley. χ^2 test showed that time spent in certain habitats was not random (χ^2=59.7, df=3, p<0.001).

Foraging Behavior

Swamp harrier foraging was observed in both valleys with the majority of foraging took place in the areas with low vegetation (Fig. 5 and 6). Time was also spent in the forested and cliff areas. χ^2 tests showed that foraging height at each location was chosen (Table 2). Foraging over the low vegetation took place at low elevation (Fig. 8) underneath the tree canopy. Foraging in the forested lands took place at low-mid elevation (Fig. 8), flying within 15 meters of the canopy.

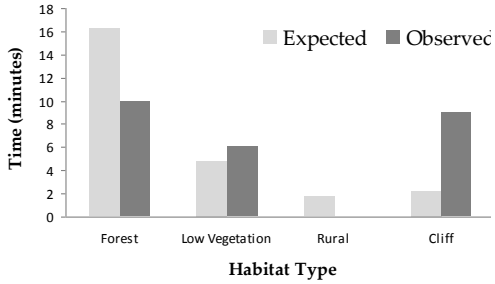

FIG. 6 Swamp harrier foraging was split relatively equally between forest, low vegetation and cliff in the Opunohu valley. A χ^2 test showed that time spent foraging in certain habitats was significant (χ^2=24.73, df=3, p<0.001).

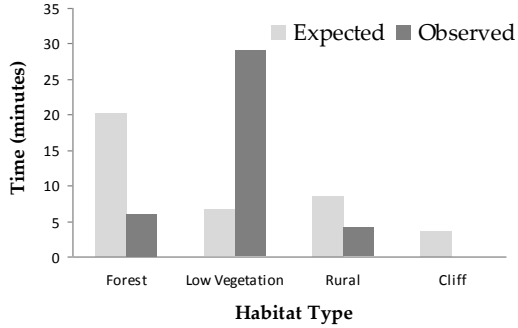

FIG. 7 Paopao valley foraging preference. A χ^2 test was used to show that swamp harrier foraging location was selected in Paopao valley (χ^2 =91.49, df=3, p<0.001). The majority of foraging time was spent in low vegetation.

TABLE 1. Possible kill site and animal waste sample prey items are listed in the table below. Also listed are prey mass (g) and native or introduced status.

Name	Mass (g)	Introduced/ Native	Reference
Passeriformes (songbird)			
Red-vented bulbul (*Molpastes cafer)*	34*	Introduced	Lal and Thabliyal 1981
Silvereye (*Zosterups lateralis*)	13	Introduced	Bird et al. 2008
Common myna (*Pycnonotus cafer)*	125	Introduced	Bird et al. 2008
Procellariidae (petrels)			
Tahiti petrel (*Pseudobulweria rostrata*)	405*	Native	Villard et al. 2006
Audobon's shearwater (*Puffinus lherminieri*)	200*	Native	Bretagnolle et al. 2000

** These values were obtained by averaging values found in the referenced literature.*

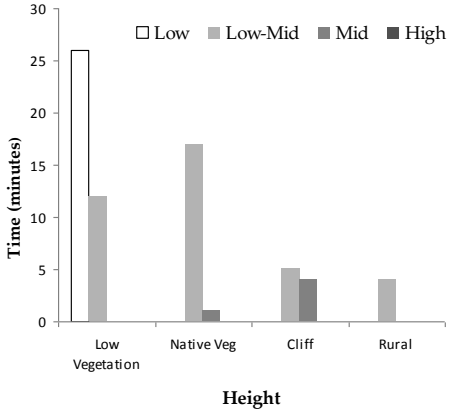

FIG. 8. A χ^2 test was used to shows the height, relative to tree canopy, at which swamp harriers few while hunting in the 4 different habitat types (Table 2). Foraging in low vegetation was done at low elevation and at low-mid elevation in forest, cliff and rural.

Seabird Predation

A total of 20 kill sites and 45 animal waste samples were collected and analyzed. All samples contained bird remains. Seven samples were the remains of *Passeriformes* (songbirds) while 58 of the samples were the remains of *Procellaridae* (seabirds). Through literature review, surrounding evidence and consultation with local experts it was determined that smaller densely packed samples are swamp harrier pellets while loose feather and organic matter samples are cat scat. Of the animal waste samples 7 (16%) samples were swamp harrier pellets while 38 (84%) were feral cats.

Significantly more seabirds were eaten at higher elevations (Fig. 9) than songbirds. Seabird remains were also significantly more abundant when seabird burrow sites were present (Fig 9).

TABLE 2. Pearson's χ^2 test was used to evaluate whether the hunting preference used over each habitat was by chance or preferentially chosen by swamp harriers. Significant values are italicized. These results are also shown in Fig. 8.

Vegetation Type	**χ^2**	**df**	**p-value**
Low Vegetation	40.54	3	*<0.001*
Forest	49.811	3	*<0.001*
Cliff	53.37	3	*<0.001*
Rural	61.93	3	*<0.001*

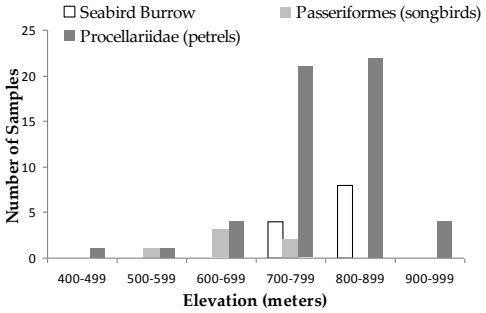

FIG. 9. Above is the distribution of sea and song bird remains and seabird burrow locations along Mt. Moaputa and Mt. Rotui. A Pearson's χ^2 test showed that seabirds are eaten at higher elevations and songbirds at lower elevations (χ^2=11.729, df=3, p=0.006). A Sherman's test showed that more bird remains are found near burrow sites (ρ=0.9177, p=0.0280).

DISCUSSION

Habitat Preference

Compared to swamp harrier habitat preference in Australia, habitat preference has not significantly changed in Mo'orea. Examination of the Paopao valley habitat preference shows that the majority of time was spent in areas of low vegetation, either pineapple fields, shrub, or grassland. This is the habitat height that in Australia harriers spend the majority of their time in (Merchant and Higgins 1993). This suggests that further expansion of pineapple fields would expand the preferred foraging habitat of the swamp harrier. Evaluation of the habitat preference for Opunohu valley shows that when low-lying vegetation is less abundant harriers will spend more time in densely forested land. Combining habitat utilization results for both valleys show swamp harriers focus their time in the low vegetation they are spending time in all four habitat types. This is most likely because they are not being crowded into just the low-lying vegetation by competing raptor species. Another reason for this utilization of alternative habitats could be that in Australia, harriers are known depend on freshwater aquatic birds as a major food source (Barker-Gabb 1984), which are not available on Mo'orea, causing them to expand their habitat utilization in search of different prey.

Foraging Behavior

Hunting behavior of swamp harriers on Mo'orea appears to be quite similar to their source population. The majority of their hunting time is spent in the low-lying vegetation (Fig. 6 and 7). There they hunt by soaring low over the ground before pouncing on prey (Fig. 8) which is the same strategy that populations in Australia use (Einoder and Richardson 2007). Their hunting range has expanded through into the rural, cliff and forest areas (Fig. 6 and 7). In the forested areas, swamp harriers use a similar hunting strategy to what they exercise over the low vegetation. They fly at low-mid elevation (Fig. 8), within 15 meters of the canopy, and search for prey before pouncing. More hunting in the forest canopy could be placing pressure on the native forest birds.

Through personal observations swamp harriers do not appear to be nesting or roosting in grasslands as they are known to do in Australia (Merchant and Higgins 1993). Nesting sites on Mo'orea appear to be located at higher elevations, away from open grasslands, where dense forest transitions into cliffside. The location of roosting sites was attempted, but their remote and cryptic locations made this impossible to do during the course of the study. This apparent change in roosting location could be due to disruption from humans and invasive animals, which could be pushing them into more isolated, higher elevation areas.

Seabird Predation

There are a large number of seabirds being lost to invasive predators as indicated by Fig. 9. Songbirds or petrels are consistently being consumed at elevations of 400 meters

and higher. Even though songbirds were found in waste samples at all elevations along the trails (personal observation), the predators shifted their energy to catching petrels. Seabird remains were associated with seabird burrows, which suggests that predators are catching individuals as they leave and enter the burrow. In the 4-week period between sample collections on Mt Rotui, 25 new samples were documented. This shows that there could be nearly 1 bird being killed each day. If this is the case then the predation pressure on both songbirds and seabirds is very high on Mt Rotui. This study took place during the breeding season of the Tahitian petrel (Thibault 1974) which means that there is more available prey than at other times of the year. The breeding season is a crucial time for building the next generation and this potentially significant level of predation during this time does not bode well for the success of the Mo'orean seabird population.

Samples collected show the relative predation of swamp harriers and cats on Mo'orea seabird populations. The cat scat samples were much more prominent (84% of samples) than swamp harrier pellets (16% of samples), and are therefore the major predator of seabirds on Mt Rotui and Mt Moaputa. This does not account for possible swamp harrier kills that are regurgitated at other locations such as roosting sites (Redpath et al 2001), which could not be examined. Seabird populations in the presence of swamp harriers are known to be able to succeed (Powlesland et al 2002) while some believe that seabird populations cannot succeed in the presence of feral cats (Bonnaud et al 2007). Cats are a versatile generalist predator and their introduction onto Mo'orea adds it to the long list of islands whose native fauna are being extirpated due to their presence (Fitzgerald 1988). Cats have been successfully removed on other islands (Faulquier et al 2009) but with Mo'orea's size and human population it would be a daunting task to remove all of the cats and prevent reintroduction from the urban sector.

Conclusion

The swamp harrier's habitat utilization has expanded to include most of the habitat types on the island though they do not use them all equally. Their time is focused in the low-lying vegetation which is very similar to their Australian source population. Without competition from other raptor species they are not restricted to one habitat type and are seen frequenting all habitat types on the island. Similar to their source population they spend the majority of their foraging time in low-lying vegetation, though some time is spent foraging over the forests.

Both swamp harriers and feral cats are preying upon seabird populations and prefer to capture seabirds rather than songbirds at high elevations where seabirds are readily available. Both introduced species have adapted some of their strategies in order to be successful on Mo'orea. The swamp harriers changed where they nest, and are expanding their traditional hunting range to include the forest and cliff areas. The feral cats on the island have moved away from rural lands into the higher elevations to capture seabirds. As a result it appears the native bird populations are being adversely affected. Examination of these introduced species on Mo'orea shows that both purposeful and indirect introductions are flourishing. Feral cat populations need to be controlled to conserve seabird populations on Mo'orea. If present feral cat populations continue to increase Audobon's shearwaters and Tahiti petrels may cease to exist on Mo'orea.

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