Modelling the distribution of stoats on New Zealand offshore islands

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Abstract: Establishing the factors that correlate with the distribution of invasive species on islands provides a means of evaluating invasion potential and pathways, and enables the invasion risk for specific areas to be predicted. These island risk profiles then provide a basis for conservation managers to prioritise conservation areas, and to create appropriate monitoring regimes. In New Zealand, stoats (*Mustela erminea*) are invasive predators responsible for numerous local extinctions of birds, and they present a significant invasion risk for offshore islands. Here we examine the distribution of stoats on New Zealand's offshore islands in order to establish what factors are correlated with their distribution, and predict which islands display a high invasion risk. Data on the distribution of stoats were compiled, along with the characteristics of New Zealand's islands and their settlement history. The distribution of stoats on these islands was regressed on island characteristics using a logistic generalised linear model. Species interactions were examined by including the distribution of a range of other introduced mammalian species. The distribution of stoats was found to be strongly affected by the distance offshore and by the area of the island. No significant correlations with the extent of human settlement or the presence of other animals were detected. The model indicates that the invasibility of islands by stoats has been underestimated. Islands within 1 km of the mainland have a very high stoat invasion risk, which is consistent with known invasions, and for large islands (≥ 500 ha) there remains a significant risk to at least 3 km offshore. This model provides a framework for assessing risks of stoat incursion and makes specific predictions of islands with a significant invasion risk that have not had stoats detected before.

Keywords: invasion; invasive species; logistic model; *Mustela erminea*; risk profile

Introduction

New Zealand's offshore islands are a major focus for ecological research and conservation, due both to the high endemism of the biota present (Cheeseman 1888; Fleming 1979), and because they have provided refugia for species made extinct on the main islands following human settlement (Worthy & Holdaway 2002; Innes et al. 2010). A growing number of these islands have had successful invasive mammal eradications, enabling their ecological restoration and allowing them to provide sanctuary for endangered fauna (Atkinson 2001; Wilson 2004; Clout & Russell 2008). With the growing list of mammal-free islands, the risk of reinvasion has similarly increased: particularly as islands that are larger, inhabited and closer to the mainland have eradication operations conducted on them (Clout & Russell 2008). Of the suite of invasive species introduced to New Zealand, stoats (*Mustela erminea*) have one of the greatest island invasion/reinvasion potentials (Parkes & Murphy 2003; Bellingham et al. 2010), and have the greatest negative effect on bird population productivity (Lavers et al. 2010).

Stoats were introduced to New Zealand in 1884 (Thomson 1922) for the purposes of rabbit control, and were first noted for their invasion of islands in 1900, when they catastrophically invaded Resolution Island, causing the local extinction of a number of bird species (Hill & Hill 1987). Subsequent to this, stoats have been detected on at least 90 islands, and this colonisation is believed to have been entirely through unaided natural dispersal (King 2005). The best-documented series of these invasions have been the incursions of stoats on Maud Island 900 m offshore in the Marlborough Sounds. On this island there have been three separate invasions by pregnant female stoats since 1982, resulting in a total of 18 stoats caught on the island. The first of these invasions (a pregnant female with seven kits) extirpated the South Island saddleback (*Philesturnus caruncalatus)* population on the island (Crouchley 1994, King & Powell 2007). The smallest island in New Zealand shown to have a resident stoat population is Motuoruhi (57 ha). On this island, eight stoats were captured in the initial trapping season (2003), then over the subsequent 8 years only five stoats were sporadically caught, all incursions (Rob Chappell, DOC Coromandel, pers. comm. 2010). This island must be near the lower limit of island size that can support a stoat population for any length of time. For islands smaller than this, the presence of stoats will be determined by the immigration rate, and the duration of occupation by each stoat (before either leaving to another island or dying).

Stoats are extremely adept swimmers and it is believed that this is their primary invasion pathway. There are eyewitness accounts of a stoat swimming 'a determinedly straight course' for some 400 m to an island in Baltimore Bay (south-west Ireland) that still had healthy rabbits after the mainland stock had been decimated by myxomatosis (King & Moors 1979). In New Zealand, stoats have been seen swimming across Acheron Passage towards Resolution Island (Wodzicki & Bull 1951) – a distance of at least 560 m; they have been recorded swimming in Lake Taupo over 1.6 km from land (Fitzgerald 1978); and a stoat was observed swimming across

Lake Waikaremoana, a distance of 3–4 km (J. Miles, DOC, pers. comm. 2011). Stoats have also been observed floating on woody debris in the Hauraki Gulf in the vicinity of the Noises Islands (B. Neureuter, Neureuter Family Trust, pers. comm. 2003). Stoat trapping data from the western Coromandel islands (R. Chappell unpubl.) indicates that stoats will swim over a kilometre not as a single life event, but as a routine dispersal for food. Not only do stoats swim out to islands, but they can also swim significant distances between small islands. This has been the observed pattern in their native range where stoats have been recorded swimming in Scottish lochs to very small islets to briefly explore for prey before moving on (Boyd 1958), and in Finland where stoats move frequently among thousands of islands (Heikkila et al. 1994).

The distribution of stoats on islands was reviewed by Taylor and Tilley (1984) and McKinlay (1997), who concluded that minimum swimming distance is the primary determining factor of stoat presence. These reviews state that 1.2–1.5 km is the maximum swimming range of stoats, and this belief is often quoted in relation to island restoration potential (e.g. Miller et al. 1994; Colbourne 2005). These previous studies, however, have only been qualitative, simply reviewing which islands have had stoats recorded on them, and equating the maximum distance recorded with the maximum swimming range. In these studies it was also assumed that established stoat populations on islands more than 1.5 km offshore (e.g. Rangitoto and Motutapu) must have been anthropogenically introduced, so these were excluded from estimates of invasion potential. More recently, Elliott and colleagues (2010) modelled stoat invasion rates on the small islands in Fiordland. They found that beyond 500 m the invasion rate dropped off significantly, so that islands beyond this distance were likely to have one stoat invade every 10 years or so. This study, while useful for island management in the region, does not assess the absolute potential for island invasion; rare long-distance-dispersal events are important for assessing invasion risk. Also, like the previous papers, Elliot and colleagues focused only on island distance offshore, neglecting other potential factors that may influence stoat invasion.

In recent years there have been a number of stoat incursions on islands thought to be outside their swimming range (see Appendix 1 for a full list of islands where stoats have occurred). This highlights the need for a better understanding of stoat invasion pathways and potential. Ideally, quantitative information and statistical modelling should enable the development of island 'risk profiles', which managers could then justifiably use to prioritise islands for conservation management, and to effect monitoring regimes on those considered at risk (Atkinson & Taylor 1991). Such risk profiling and modelling have been developed for New Zealand islands by Russell and Clout (2004) for the four rodent species present, which are the other mammalian predators likely to invade islands.

This paper sets out to quantify those characteristics that are correlated with the distribution of stoats on islands. This is done using the extensive data now available for New Zealand's islands over 5 ha in area, including both offshore and lacustrine islands.

Methods

Datasets

Data on the geographical morphology, habitats, exotic mammal distributions and settlement history of islands ≥ 5 ha (excluding the North and South Island) were obtained from Russell & Clout (2004). Species distribution data were then updated; primarily from the Department of Conservation (DOC) incursions database and from monitoring records obtained from local DOC offices. As stoats have never been taken to or recorded on Stewart Island, the islands surrounding it were excluded from the model.

Classification of species distribution was simplified to presence (at some stage of the island's history), absence (not found on the island despite some investigation), or unknown (not enough information). Species absence is difficult to confirm, particularly for less detectable species such as stoats (Choquenot et al. 2001). They may have once occurred and subsequently gone extinct without any record (a temporal error), or may be present in such low numbers that they remain undetected (a spatial error). These errors may vary with other factors measured (area, settlement history) or unmeasured (island visitation rate, sampling effort) in the study. Measurement of such errors would be difficult (McArdle et al. 1990). On most islands, monitoring effort specific to stoats has been sporadic or opportunistic over the last century, and conducted only for short periods. The model therefore included any island where even minimal monitoring has been undertaken and it is acknowledged that there will be an underestimate of stoat incursions due to these factors, but an overestimate of current presence.

The co-occurrence of stoats and other invasive mammals (at some stage of the island's history) may not coincide perfectly due to the inexact nature of the records of invasion timing. It is assumed, however, that when both stoats and other mammal species have been recorded on an island, it is likely that they will have co-occurred at some point. The timings of invasions (where known) were not incorporated into the models. Data on 16 variables were collected for each island in the study (Table 1).

Statistical analysis

Logistic multiple regression models (McCullagh & Nelder 1989) were constructed in the program R (Ihaka & Gentleman 1996), relating the presence of stoats to explanatory variables hypothesised a priori (Table 1). The variables *Elevation*, *Area* and *Distance* were $\log_{10}$ transformed to remove right-skewness in their distributions. This resulted in more linear model fits and increased normality in their distributions.

Models were constructed with the goals of identifying and interpreting the explanatory variables that govern stoat distribution on New Zealand offshore islands and to predict islands at risk from stoat incursion that have not previously had stoats detected on them. To produce this predictive model, backwards selection was performed using the χ^2 approximate likelihood ratio test (Wilks 1938). Collinearity was tested for using standard variance inflation factors for each explanatory variable (Fox & Monette 1992). Diagnostic ROC statistics were calculated for the model to assess predictive power. It is regarded that C statistics ≥ 0.8 indicate models with excellent discriminatory capability (Hosmer & Lemeshow 2000); therefore models with very high discriminatory power.

Table 1. Variables and their description within the context of this study.

Variable	Description	Range
Continuous		
Area^a	Land area of the island (ha)	2.5 – 174 600
Elevation^a	Maximum elevation of the island (m)	4 – 1196
Distance source^a	Distance from the nearest steppingstone island or mainland (whichever is closer) (m)	25 – 39 600
Discrete		
GDI^a	Geological Diversity Index (number of rock types present *sensu* Atkinson 1992)	1–6
BHDI^a	Biological Habitat Diversity Index (number of biological habitat types present *sensu* Atkinson (1992))	0–34
Binary (0/1)		
Mammals	Presence/absence of stoats, Norway rats, ship rats, kiore, mice, rabbits, possums and cats	0/1 each
Categorical		
Landing	Presence of a landing structure (wharf)	
Settlement	– : Never inhabited A: Abandoned R: Government (Ranger) station F : Unmanned farm I : Inhabited	
Latitude	0 : Northern – north of 38°S (Bay of Islands, Hauraki Gulf, Bay of Plenty) 1 : Central – between 38°S and 42°S (Marlborough Sounds, Greater Cook Strait) 2 : Southern – south of 42°S (Fiordland)	

^{a} $\log_{10}$ transformed

Results

A clear relationship between stoat presence and both *Area* and *Distance from Source* was detected (Fig. 1). The relationship between stoat presence/absence appeared to break down for small islands, where very few islands have stoat presence recorded, and these islands were scattered across a wide distance range. Islands under 50 ha are believed to be approaching the minimum size required to support a resident stoat population, and inclusion of these islands will cause a temporal error due to the difference in the detectability of stoats on these islands. As it was believed that the assumption of presence equalling detection on these islands was violated, islands < 50 ha were excluded from the model.

The optimal model for predicting stoat presence/absence on islands had three significant variables: *Area, Distance from Source* and *Latitude*, with interactions between *Latitude* and *Area* (Table 2). The northern and southern islands had similar prediction curves, but the central islands had a very high likelihood of stoat presence. This pattern was greatly influenced by a single point (Kapiti Island) due to the low number of islands in this group and the great distance to this island. Because the inclusion of *Latitude* as an explanatory variable appeared to be linked with this, a reduced model was created that excluded *Latitude* as a variable (Table 2).

Table 2. *P*-values of significant explanatory variables in the stoat distribution model.

Variable	Full model	Latitude excluded
$\log_{10}$(*Distance*)	<0.001 ***	<0.001 ***
$\log_{10}$(*Area*)	0.001 **	0.001 **
Latitude	0.102	
$\log_{10}$(*Area*):*Latitude*	0.027 *	

*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$

Stoat presence was positively related to $\log_{10}$ *Area* and negatively related to $\log_{10}$ *Distance from Source*, as classical island biogeographical theory would suggest. No significant relationships were observed between stoat presence and any anthropogenic factors (settlement history or landing structures). The presence/absence of any of the other introduced mammals investigated did not significantly add to the model, given the other variables retained. Collinearity was not observed between the variables retained in the model, and while some collinearity was observed between *Area* and some of the rodents present, these rodents were not significantly correlated with stoat presence when *Area* was not included in the model.

The model produced for stoat presence/absence prediction had high predictive power and discrimination. This is particularly evident in the ROC C statistic = 0.97, which approaches 1 for perfectly discriminating models. Across all latitudes, very small islands have extremely low probability of stoat presence across all distances. Islands of 50 ha area have a probability of close to 100% stoat presence when near to a source population, and greater than 50% probability of stoat presence out to distances of 1750 m. Larger islands of 500 ha have a greater than 50% probability of stoat presence out to over 2600 m, and for large islands over 1000 ha there is a greater than 50% probability to 3000 m.

New Zealand islands for which stoats have not been recorded, but which had a non-negligible likelihood of stoat presence (Pr(stoats) ≥ 0.1) were predicted using the model. These predictions identify islands that are either affected by factors not modelled, have had undetected stoat incursions, or are at risk of stoat incursion. Six islands over 50 ha that have never had stoats recorded on them had a predicted probability of over 10% for stoat presence (Table 3).

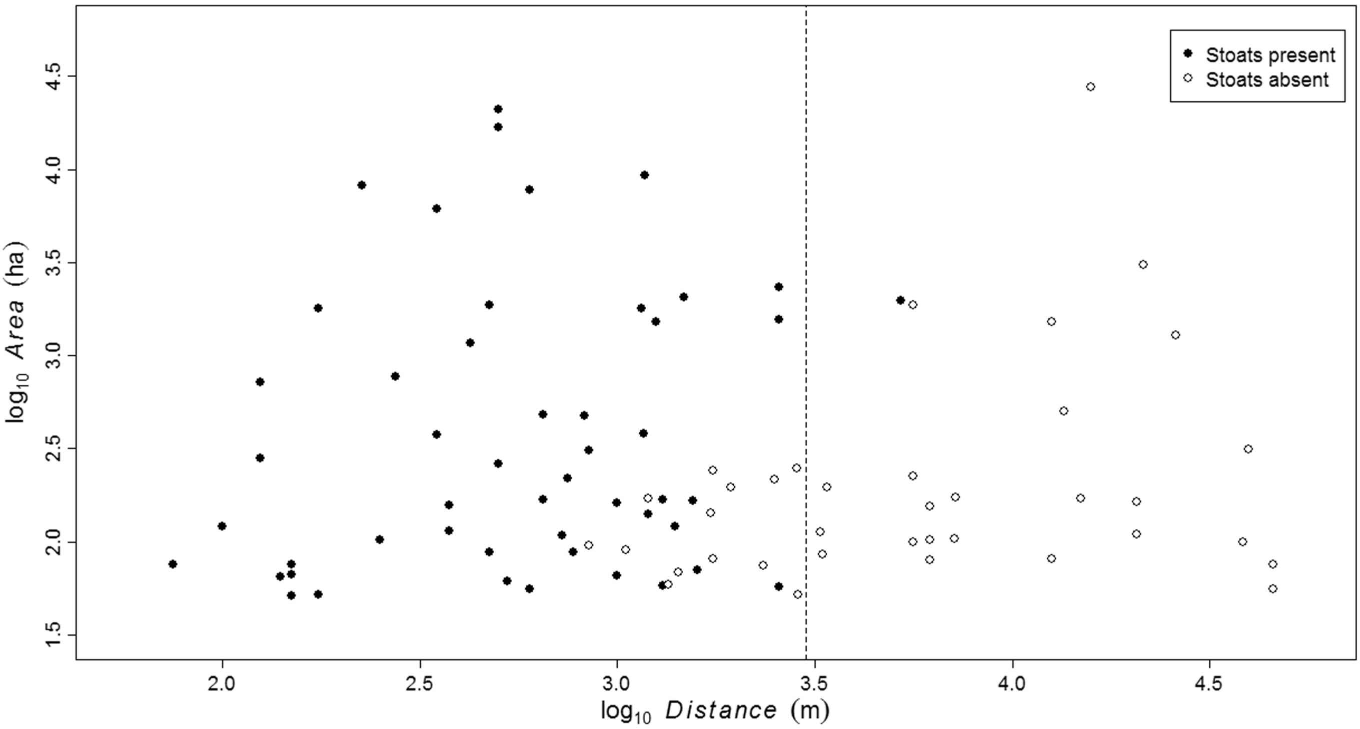

Figure 1. Incidence of stoats on New Zealand islands of varying area and distance from a source population. The dashed line indicates a swimming distance of 3 km.

Table 3. Islands where stoat presence has a probability of ≥ 0.1 given the model but which have not had recorded stoat sightings. CL = 95% confidence limits.

Island	Distance (m)	Area (ha)	Probability	Lower CL	Upper CL
*Rotoroa, Hauraki Gulf	1050	90	0.917	0.832	1.002
Breaksea, Breaksea Sound	1200	170	0.890	0.782	0.999
Motuihe, Hauraki Gulf	1940	195	0.596	0.424	0.767
Tinui, Rangitoto Island	850	95	0.459	0.207	0.711
Slipper GP (Whakahau)	2850	247	0.250	0.104	0.395
Tiritiri Matangi	3400	196	0.110	0.019	0.202

*Rotoroa has recently had possible stoat sign (footprints) detected on it (Jo Ritchie, Natural Logic Environmental Management, pers. comm. 2011)

Discussion

The model of stoat presence on islands has very high discriminatory power. This is due to the probable single invasion pathway of stoats, which rely almost exclusively on swimming to reach islands. Factors that affect the potential to swim to an island were the only ones significantly correlated with stoat presence, and these variables are more predictable and less idiosyncratic than the anthropogenic variables. The factors identified as relevant to stoat presence (distance and area) were similar to those identified as important to ship rat (*Rattus rattus*) distributions, but ship rat distributions were also affected by the settlement history and the presence of wharves (Russell & Clout 2004). This highlights that stoats probably rely solely on swimming as their invasion pathway, in contrast to the multiple invasion pathways (swimming and human-mediated transport) of ship rats. It remains plausible that some of the stoat populations/incursions on islands were the result of deliberate unrecorded releases, though a hypothesis of dispersal by swimming appears to account for all islands in the model.

Island distance

The model of stoat distribution on islands is consistent with the predictions of Taylor and Tilley (1984) and McKinlay (1997) that swimming distance to each island is a significant predictive factor. Recent stoat incursions on islands have shown that the distance a stoat can swim is greatly in excess of these authors' previous estimates of 1.5 km, and this is reflected in the model.

Unlike previous studies, the model produced a probability curve of stoat incursion over various swimming distances rather than a swimming limit, and this is likely to be more biologically accurate. There is no clear limiting distance when it comes to island invasion; it is probable that even for the more distant islands on which stoat incursions have occurred, there remains some physiological and behavioural potential to go further. As distance to an island increases, the probability of a stoat choosing to swim the distance, and being able to successfully accomplish this swim, decreases. This probability decreases rapidly as the limits of stoat physiology are approached. The sigmoid decay curve of swimming distance versus stoat presence probability is very similar to that found by Elliot et al. (2010), who found that the frequency of incursion decreased as swimming distance increased. This is likely to be true over the longer distances assessed in this study, with the very long distances dispersed being increasingly rare.

The model used the minimum single swimming distance; however, this may not in fact be the true invasion route. It is likely that the recent (2010) stoat incursion on Rangitoto Island in the Hauraki Gulf (Veale et al. in press) was a direct swim from the mainland (3 km), rather than via Browns Island (two swims of 1.6 km and 2.6 km), given the location of the capture on the island. The multiple individual incursions recorded on Motukawanui Island, which is a large island with sandy beaches facing the mainland, are more likely to be a direct swim of 2.3 km to the island, rather than multiple swims between rocky islets. Shore morphology has been shown to strongly affect ship rat colonisation and gene flow (Fewster et al. 2011), with limited dispersal between islands separated by rocky cliffs, but regular dispersion between islands with sandy beaches. Such characteristics may similarly affect stoat incursion probability. It is also important to note that while we discuss the minimum swimming distance as calculated on a map, this is unlikely to be the true distance swum by an animal. Stoats are unlikely to search a coastline to locate the shortest distance to an island, but instead just set off from a point favourable to swimming. This minimum swimming distance also ignores water currents, which may increase or decrease the true distance swum.

Beyond focusing on the distance a stoat can swim, the interactions between *Distance to Source*, *Area* and *Latitude* reveal a number of important aspects of stoat invasion ecology.

Island size

There are a number of possible explanations for the significant positive relationship between island size and stoat presence, all of which may contribute to varying degrees. The variable *Area* was significant while biological habitat diversity was not, suggesting that it is the number of individuals, and associated probability of extinction, that limits stoat presence on small islands (Gotelli & Graves 1996). Stoats are apex predators that require large home ranges unless there is a very high concentration of food (Cuthbert & Sommer 2002). Given this, the dramatic decline in the probability of stoat presence for islands under 50 ha is likely to be primarily due to the low carrying capacity of these islands; they are too small for a resident stoat population to establish. This breakdown of relationship between area and distance for islands below 50 ha could be an example of the Small Island Theory (SIT) of biogeography (Lomolino & Weiser 2001), highlighting that for apex predators, the limiting minimum size for standard distance–area relationships can be quite large.

There are other factors beyond population size that may contribute to smaller islands having a lower probability of stoat presence. Firstly, stoats may actually visit larger islands more often: either because they are more visible, more attractive, or simply because their larger coastline means that stoats are more likely to arrive there while swimming (Lomolino 1990). An increased opposing mainland coastline creates a greater contact zone across which stoats may swim, thereby increasing the effective propagule pressure for larger islands. Along with this there may be a monitoring bias, as larger islands are more likely to be monitored with greater frequency, and therefore have increased detection probability.

While small islands are less likely to have stoats present, stoats do swim to very small islands on occasion and have been recorded on 27 islands less than 30 ha. Indeed, some of the furthest islands that stoats have occurred on have been small (e.g. 20-ha Centre Island – 2.2 km). The smallest island on which stoats have been recorded was Motuotau Island (2.5 ha) off Mt Maunganui Beach, where a single male stoat swam 700 m to the island and, over a 2-month period before being trapped, killed at least 93 birds – mainly diving petrels (Clifford 1997). In this instance the high level of bird life probably increased the duration of occupation and the detection probability, as the bird population was being monitored.

Predicting island risk

As the model is able to discriminate stoat presence/absence accurately for islands over 50 ha, it is ideal for stoat incursion risk profiling of these islands (Atkinson & Taylor 1991). For islands under 50 ha in area, the model is confounded by differences in stoat detectability; therefore it is best to assume that in calmer conditions and sheltered environments there is the potential for stoats to swim out to at least 3 km. All islands of any size out to at least 1 km with reasonable monitoring effort have had stoats detected, so islands within this range are at extremely high risk.

For islands over 50 ha, basic risk assessment can be made using the graph presented here (Fig. 2). In this plot log odds of stoat presence were regressed onto *Area* and *Distance* in a logistic regression model. The log odds of stoat presence were then estimated for a range of island sizes and distances and these were then transformed back into probabilities of stoat presence using the logistic function and presented in a contour plot. Surprisingly, only three islands over 50 ha have a greater than 50% probability of having stoats detected, yet have not had any recorded detection. This highlights the discriminatory power of the model, and also suggests stoats have reached most locations they are naturally able to (notwithstanding islands from which they have then been eradicated). The fact that stoats have not been recorded on these islands implies that the invasion rate is likely to be low, and that a population has probably not established on them. Of the six islands with a greater than 10% probability of stoat presence, only Breaksea Island, Tiritiri Matangi and Motuihe have a long history of monitoring, and it is possible that for the other islands, stoat incursions have occurred at some point but remained undetected. For some of these islands, properties not accounted for in the model are likely to make them less likely to have stoat incursions. Breaksea Island is highly exposed to wave action, far more so than any other island in Fiordland, which probably explains the absence of stoats despite the predicted high probability of stoat presence.

It should be noted that the invasion probability for some of these islands is lower than predicted, due to the invasion pathway now being interrupted. For Tiritiri Matangi the closest mainland area is now a predator-free fenced sanctuary and so invasion probability will be greatly decreased. Similarly, for

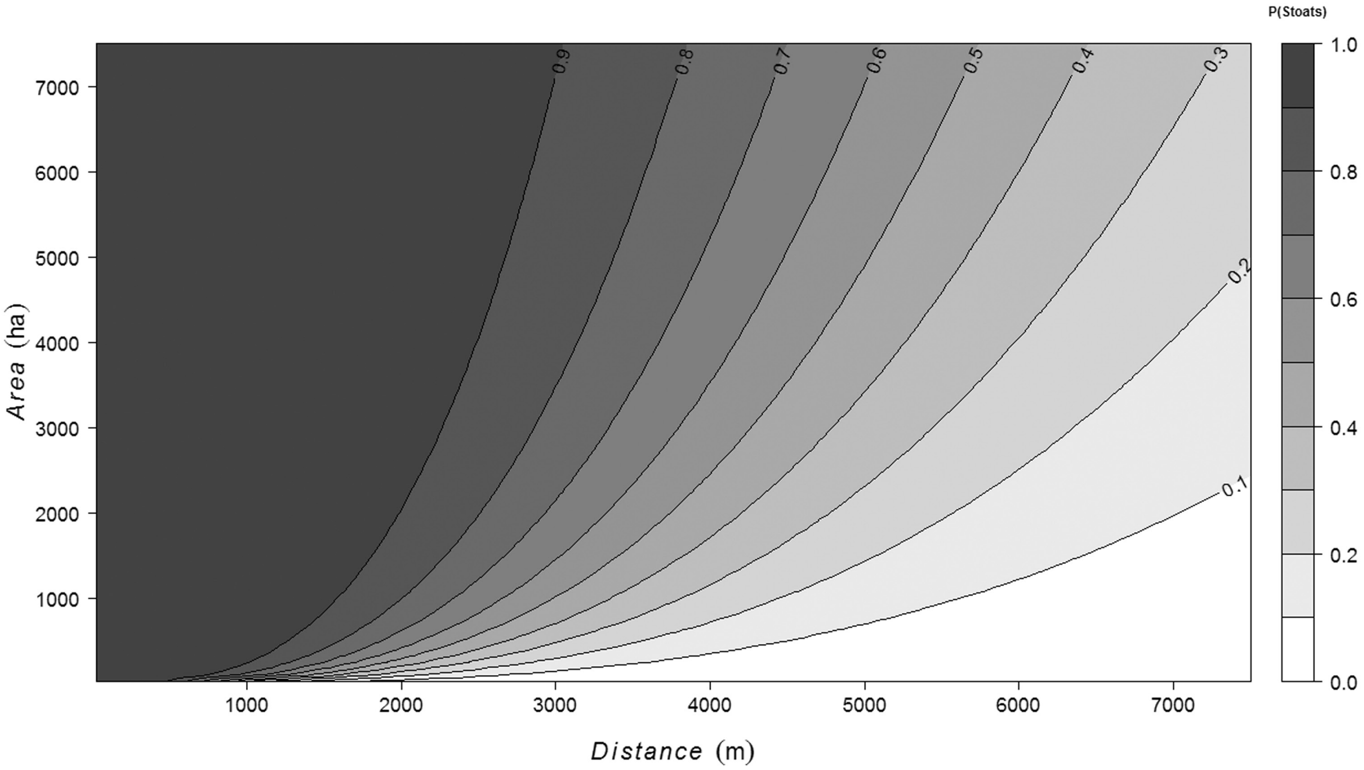

Figure 2. Predicted probability of stoat presence for all islands from the logistic regression model (*Latitude* excluded).

Motuihe the model assumed stoat presence on Motutapu, which had all mammals eradicated in 2009. Invasion of Motuihe via Waiheke Island or the mainland is over a considerably longer distance and therefore invasion risk is greatly reduced.

Stoat island invasion rate

One difficulty in interpreting the results of this study is that probability is not time related – it is the probability of a stoat having ever been detected on each island. The predicted probability of stoat presence is likely to be correlated with invasion rate; however, the exact relationship between these two factors is unknown. The model does indicate that invasion rates predicted by Elliott and colleagues (2010) may be an underestimate of stoat invasion rates on larger islands – given that their assessments were made only on small islands, and island size affects stoat incursion (or detection) probability.

Improving the estimate for invasion rates on larger islands is very difficult for several reasons. Firstly, individual stoats may not enter traps immediately (or ever). Detection probability for stoats changes according to prey density (Alterio et al. 1999; King & White 2004); therefore when a stoat arrives on an island previously uninhabited by stoats, the high prey density decreases detection probability. There have been several cases where stoats have been known to be present on an island – through sightings, scat and footprints; however, they have avoided traps for a number of months – possibly years (Maud, Kapiti and Secretary islands) (Crouchley 1994; Pete McMurtrie, DOC Te Anau, pers. comm.). Secondly, capturing multiple stoats on an island, even a year apart, may not necessarily indicate multiple incursions. Female stoats are impregnated before leaving the nest and so are always able to found new populations (King & Moody 1982). Thirdly, regular comprehensive (and expensive) trapping over long periods would be required be catch all stoats that do arrive on an island.

Implications

In light of this model, we need to reconsider the stoat invasion probability for New Zealand's islands, particularly those that are large and more distant from the mainland. Monitoring and management plans should be adjusted accordingly, acknowledging this increased understanding of invasion threat. Stoats are highly mobile, and pose a significant threat to most near-shore islands out to at least 3 km, with at least some risk out to 5.2 km given the recent incursion on Kapiti Island.

Alarmingly, current management plans for endangered species significantly underestimate the ability of stoats to swim between islands. In the DOC report assessing the suitability of islands as refuges for translocated kiwi, Colbourne (2005) states 'some of the islands identified [for kiwi release] had stoats on them at the time of the survey, but were included because stoats could be eradicated permanently – the islands are outside stoat swimming distance'. All islands in New Zealand on which stoats have been recorded are believed to have been colonised naturally by swimming; therefore, any record of stoat occupation is indicative of that island's invasibility by stoats.

For islands selected for ecological restoration or to be used as ecological sanctuaries, there are two management strategies to mitigate the effects of stoat reincursion: decreasing the invasion rate by trapping the land opposite, and ensuring stoat incursions are intercepted early by maintaining trapping on the island themselves (Russell et al. 2009). It is possible to maintain islands at zero stoat density for over a decade by using a vigilant trapping programme and intercepting stoats before populations establish (as has been done on Maud, Chalky, Motukawanui and the islands of the western Coromandel region). This is necessary on any island where stoats are eradicated, as reinvasion is inevitable while stoats are present on the adjacent land. This has been highlighted recently with the incursion of individual stoats on Motuarohia and on Rangitoto Island within a year of eradication. The importance of ongoing biosecurity and trapping to protect vulnerable islands cannot be overstated, given the dramatic effects on native fauna of even a single female stoat incursion (Crouchley 1994).

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Appendix 1. Characteristics, invasion and eradication history of New Zealand Islands where stoats have been detected.

Location	Area (ha)	Minimum single water crossing (m)	Eradication	Incursions or invasion	Status	Reference
Northern (35ºS – 38ºS)						
Browns	58	1300	1995 P			Weihong et al. 1999
Karamuramu	7.5	1150				J. Craw pers. comm. 2011
Kawau	2050	1475		1985	P	R. Weaver pers. comm. 2010
Matakana	6100	350			P	Wills et al. 2003
Matakohe (*Limestone*)	37	300	1996 T	2007		Richie 2000
Motuarohia	58	1000	2009 P	2010		Owen 1978 unpubl.
Motukahaua (*Happy Jack*)	22	2660				R. Chappell pers. comm. 2010
Motukawanui	355	1200		multiple		A. Walker unpubl.
Motukiekie	34	925				A. Walker unpubl.
Motuoruhi	57	1230	2003 T	multiple		Newhook et al. 1971
Motuotau	2.5	700				Clifford 1997
Moturoa	157	375	1993 T	~2009		P. Asquith pers comm. 2004
Moturua	146	1000	2009 P			P. Johnson 1978 unpubl.
Moturua (Motukawao Islands)	24	2200				R. Chappell pers. comm. 2010
Motutapere	45	500		2007,2009		R. Chappell pers. comm. 2010
Motutapu	1560	3000	2009 P			Veale et al. In Press
Motuwi	22	2400				R. Chappell pers. comm. 2010
Otata	22	2430	1948 S			B. Neureuter pers. comm. 2003
Pakihi	114	375	2006 T			J. Russell pers. comm.
Ponui	1851	1100			P	Bellingham 1979
Rangipukea	34	800				R. Chappell pers. comm. 2010
Rangitoto	2321	3000	2009 P	2010		Veale et al. In Press
Rimariki	7	400				
Traherne	13	100	2011 T			C. Bannock pers. comm. 2011
Urupukapuka	209	600	2009 P			Hitchmough & McCallum 1980
Waewaetorea	41	300	2009 P			Hitchmough & McCallum 1980
Waiheke	9459	1100			P	Marshall 1963
Waimate	70	850	2005 T	2006,2007		R. Chappell pers. comm. 2010
Wanganui	282	125			P	R. Chappell pers. comm. 2010
Central (40–41ºS)						
Adele	87	800	1981 T	1982, 2003		Taylor & Tilley 1984
Arapawa	7785	700			P	Taylor 1981 unpubl.
Blumine	377	350	2005 P	2010		B. Bell & C Roderick 1963 unpubl.
D'Urville	16782	500			P	Buckingham & Elliott 1979 unpubl.*
Fisherman	3.6	700	1981 T			Taylor & Tilley 1984
Forsyth	775	300			P	RH. Taylor & P. Wilson 1979 unpubl.
Haulashore	6	225			?	J. Russell pers. comm.
Kapiti	1970	5225		2010		C. Purches pers. comm. 2010
Maud	30.9	900	1983, 1989 T	Multiple		Bell 1983; Crouchley 1994
Pickersgill	103	300	2005 P	2008		P. Gaze 1981 unpubl.
Tawhitinui	22	400				P. Gaze 1982 unpubl.
Southern (45–46ºS)						
Anchor	1525	1250	2001 T			K. Morrison pers. comm.
Bauza	480	650	2002 T	2002		Elliot et al. 2010
Bute (Lake Te Anau)	12.4	1100	2000–2005 T			Elliot et al. 2010
Centre (Lake Te Anau)	20	2200		2005		Edmonds 2006

Location	Area (ha)	Minimum single water crossing (m)	Eradication	Incursions or invasion	Status	Reference
Coal	1622	400	2005 T	Multiple		K. Morrison pers. comm.
Cooper	1886	200			P	K. Morrison 1979 unpubl.
Cormorant	13.5	270	2000–2005 T			Elliot et al. 2010
Curlew	12	680	2000–2005 T			Elliot et al. 2010
Dome (Lake Te Anau)	7.4	500	2000–2005 T			Elliot et al. 2010
Doubtful Centre (Lake Te Anau)	40	100	2000			M. Willans 2002 unpubl.
Doubtful East (Lake Te Anau)	120	100	2000			M. Willans 2002 unpubl.
Doubtful West (Lake Te Anau)	120	100	2000			M. Willans 2002 unpubl.
Elizabeth	74	150	2000–2005 T			P. Brotherston pers. comm.
Entry	42	1000	2000–2005 T	1991, 2001		G. Elliott unpubl.
Erin (Lake Te Anau)	67	150				M. Willans 2002 unpubl.
Fergusson	12	570	2000–2005 T			Elliot et al. 2010
Fixed head	22.4	130				Elliot et al. 2010
Great	736	270	2005 T			Elliot et al. 2010
Guilbert	25.4	1201	T			Elliot et al. 2010
Harbour	48	150	2000–2005 T			Elliot et al. 2010
Heron	5.5	220	2000–2005 T			Elliot et al. 2010
Indian	168	800	2008 T			Elliot et al. 2010
John A	48	100				Elliot et al. 2010
Johns East	10.5	380	2000–2005 T			Elliot et al. 2010
Johns West	45	160	2000–2005 T			Elliot et al. 2010
Long	1890	500			P	Elliot et al. 2010
Mou Tapu (Lake Wanaka)	120	1400	T	Multiple		Edmonds 2006
Mou Waho (Lake Wanaka)	140	1200	T	Multiple		Edmonds 2006
Norman's	23	1150				
North Passage	9	1000	1998 T	2000		M. Willans 2000 unpubl.
Oke	35	300	2000–2005 T			Elliot et al. 2010
Paget Passage	47	various	T			King 2005
Parrot	42	800	T			Elliot et al. 2010
Pig (Lake Wakatipu)	110	1400	T	2005		Edmonds 2006
Pigeon (Lake Wakatipu)	168	1300	T	Multiple		Loh 1993; Edmonds 2006
Pomona (Lake Manapouri)	262	500	2008 P,T	2010		J. Whitehead pers. comm.
Quail	88	475	2002 T			Kavermann et al. 2003
Resolution	21300	600	2008* T		P[a]	Wodzicki & Bull 1951
Rona (Lake Manapouri)	56	600	2006 T	2008		Elliot et al. 2010
Secretary	8140	650	2005* T		P[a]	K. Morrison pers. comm.
Silver (Lake Hawea)	25	300	1997 T			S. Thorne pers. comm.
Small Craft Harbour	48	500	T			P. Brotherston pers. comm.
South Passage	167	1550	1998 T	2000		M. Willans 2000 unpubl.
Steep-to	61	525	2005 T			K. Morrison pers. comm.
Stevensons (Lake Wanaka)	65	140	1997 T			S. Thorne pers. comm.
Te Kakahu (*Chalky*)	475	1100	1999 T	1999		M. Willans 2000 unpubl.
Weka	108	700		Multiple		K. Morrison pers. comm.
Whidbey Point	4.6	200				K. Morrison 1979 unpubl.

Eradication techniques: T = Trapping, P = Secondary poisoning, S = Shooting.

Present status: P = Resident population. All others probably do not have a resident stoat population (due to ongoing trapping) but will have occasional incursions.

[a] Both Resolution and Secretary islands are undergoing intensive trapping, with populations at very low density but eradication has not yet been achieved.