Invasion Note

Swimming capabilities of stoats and the threat to inshore sanctuaries

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ABSTRACT

Stoats (*Mustela erminea*) are small carnivorous mammals which were introduced into New Zealand in the late 19th century, and have now become widespread invasive pests. Stoats have long been known to be capable of swimming to islands 1-1.5 km offshore. Islands further out have usually been assumed to be safe from invasion, therefore routine stoat monitoring on them has been considered un-necessary. Recent incursions, including a stoat found on Rangitoto Island (3 km offshore) in 2010, and another which was deduced to have reached Kapiti (5 km offshore) in 2009, along with distribution modelling and genetic studies, strongly support the proposition that stoats can swim much further than 1.5 km. Acceptance of this hypothesis depends on estimating the probability that such small animals could indeed swim so far unaided. This paper reports the results of a project designed to assist this debate by recording the paddling action, speed and minimal endurance of nine stoats observed (once each) swimming against an endless current in a flume at the Aquatic Research Centre, University of Waikato. Four of the five males and two of the four females could hold a position for at least five minutes against the maximum current available, averaging 1.36 ± 0.336 km/h. In steady swimming against a current of c. 1 km/hr, they all used a rapid quadripedal paddling action (averaging 250 strokes/min, stronger with the spread forepaws). Four of the nine swam strongly for >1 h, including one female who covered 1.8 km in nearly 2 h non-stop. Results from such artificial conditions cannot be conclusive, but support suggestions that wild stoats could indeed swim much further than 1.5 km, hence we conclude that the “risk zone” for stoat reinvasions of inshore islands has been seriously under-estimated.

Keywords: Stoat; *Mustela erminea*; island sanctuaries; invasion risk; swimming.

INTRODUCTION

Stoats (*Mustela erminea*) are small, energetic mustelid carnivores native to the northern Holarctic (King and Powell 2007). Their excellent ability to disperse long distances in challenging conditions was amply demonstrated by their rapid recolonisation of the boreal region in early postglacial times, including many offshore islands (Fleming and Cook 2002; Martinkova et al. 2007). On land, marked individual stoats have been recorded dispersing >20 km within a few weeks of independence (King and McMillan 1982), and swimming across fast rivers without hesitation (Murphy and Dowding 1995). In lakes and in the sea, unmarked stoats have been seen swimming at considerable distances from land (Veale 2013).

Nowhere are these capablilities more significant than near the c. 250 offshore islands of New Zealand which are protected faunal reserves. The most valuable of these are the ones that shelter various combinations of threatened species of native fauna unable to co-exist with alien predators on the main islands, especially rats and stoats (King 2005; Veale et al. 2012b). At least 100 islands around the New Zealand coast have been cleared of at least 180 populations of 14 species of invasive mammals, and national conservation strategy relies heavily on increasingly ambitious eradications (McMurtrie et al. 2011) and restoration of islands (Towns et al. 1997; Towns et al. 2013). More than 70 species of terrestrial vertebrates are recovering or likely to recover as a result of these eradications (Towns et al. 2013), but the problem of detecting early reinvasions remains acute (Elliott et al. 2010). Permanent eradication of an established population open to reinvasion from neighbouring uncontrolled areas with the same "eradication unit" (Abdelkrim et al. 2005) is impossible.

Around 1900, stoats reached Resolution Island (0.6 km off the South Island's Fiordland coast), ruining Richard Henry's attempt to protect flightless birds from predation (Hill and Hill 1987). Maud Island, in the Marlborough Sounds, located only about 900 m from the nearest coast of the northern South Island, has been invaded by female stoats three times since 1982. All were pregnant, as 99% of all females always are (King and Moody 1982; King and Powell 2007), and the second female produced two generations of offspring by sibling mating, as illustrated by Crouchley (1994).

Islands further than 1.5 km offshore have usually been assumed to be safe from stoat invasion (Colbourne 2005; Miller et al. 1994) unless linked to the mainland by stepping-stone islands. For example, Chalky Island is 2.5 km from the Fiordland mainland but accessible via three intermediate islands, as mapped by Elliott et al (2010). Stoats occupied Chalky Island, and visited the linking islands, until a successful eradication programme in 1999 targetted all islands in the chain. However, a more recent survey recorded at least 84 cases of unassisted visits of stoats to islands up to about 3.0 km offshore (Veale et al. 2012b)

A successful multispecies eradication programme cleared stoats and all other exotic mammals from Rangitoto Island, 3 km offshore in the Hauraki Gulf (Figure 1), by the end of 2009, and surveillance continued into 2011. In 2010, a year after the main eradication, a single male stoat reappeared, confirmed by genetic analyses to be a reinvader from the mainland, not a survivor (Veale et al. 2012a). Could such a small land animal (weight 200-400 g, with legs hardly 60 mm long and no special adaptations for life in water) really swim that far? If so, how many other inshore islands of the New Zealand archipelago supporting threatened species are more vulnerable to invasion than has been assumed?

This question became urgent after a female stoat reached Kapiti Island, 5 km off the west coast of the North Island, site of decades of expensive restoration and reintroductions of sensitive native species (Figure 1). This stoat probably arrived in 2009, and survived long enough to found a new population by sibling matings (Prada et al. 2013), which cost more than NZ$600,000 to eradicate (Department of Conservation, unpublished). Like the Rangitoto stoat, it also came from the mainland. Suggestions that it swam there unaided have caused great debate among conservation authorities.

In January 2013 we aimed to assist this debate by defining the *minimum* swimming abilities of ten captive stoats in a flume at the Aquatic Research Centre, University of Waikato, Hamilton. We planned to observe their foot structure and swimming action, estimate their speed and endurance against a continuous current, and predict a theoretical maximum swimming distance.

METHODS

The flume was 10 m long and 0.5 m wide, with transparent Perspex sides. It circulated fresh water at 21-22^{0}C as an endless stream. We defined a swimming chamber 1.6 m long and 25 cm deep by blocking off a section of the flume with unclimbable barriers, solid above water level, mesh below. Heavy Perspex lids on top prevented animals from jumping out. We assumed that a stoat which could maintain a constant position against the current at a given speed could swim forward at that speed in still water.

We used fresh water not salt, since stoats swim to islands in lakes as well as in the sea, and swimming tests in fresh water should give conservative results because it is slightly more demanding to swim in fresh rather than in the more buoyant salt water. We set up a video camera on a tripod, with the entire swimming chamber in view, to record the position and activities of each animal in the chamber from start to finish of each trial. We also used hand-held cameras to focus close-up on swimming action from above and from the side, and underwater cameras to record paw action from underneath.

We used a flow meter to measure the speed of the current maintained by the motor running at speeds of 10, 20, 30, 40 and 50 Hz (50 Hz was the maximum it was permitted to run for more than a few minutes). The barriers defining the swimming chamber caused turbulence, especially at the upstream end of the chamber and to a lesser extent along the sides. Current speeds were therefore measured at three positions across the flow (front, centre and back), three positions along it (left, centre, right), and at two depths (just below the surface, where the stoat's body floated, and 50 mm below the surface, at paddling depth), total 18 readings at five speeds. A simple linear regression showed greater variation at the higher speeds, to a maximum of 0.55 m/sec (1.98 km/h) in the immediate front (upstream) centre of the chamber. The average speed of the current across the 18 positions at the 5 motor speeds ranged from 0.04 to 0.36 m/sec (Figure 2), equivalent to 1.14, 0.43, 0.68, 0.97 and 1.3 km/h.

Live stoats and weasels cannot be handled humanely except under anaesthetic (King and Powell 2007). The six males and four females available had all been habituated to captivity for at least a year, but still could not be handled directly. We considered it important to avoid the additional stress of anaesthesia before the trials, so we designed a special system of portable nest boxes and transfer tubes with sliding doors. When we were ready to begin a test and the animal was safely inside its familiar nest box, we could open the door of its home cage and close the sliding door to shut it in the nest box. It was carried to the Aquatic Centre in its own nest box, and there moved briefly via the transfer tube into the flume. Before starting to work with stoats, we tested all our equipment and procedures with tame Norway rats.

While each stoat was fresh, we increased the speed of the current in stages, maintaining it for only so long as the animal showed it could maintain its position within the chamber without being swept against the back wall, and then moving to the next stage. We expressed the result in km/hr, corrected for variation in the current speed at the exact position where the stoat chose to swim. At the maximum current speed any given animal could swim against, every individual concentrated on swimming steadily in the front centre of the chamber close to the upstream mesh, and we recorded its performance there over not more than 5 minutes.

For observation of minimum endurance times, the flume speed was reduced to 0.28 m/sec or less (c. 1 km/h), as appropriate for each individual. At these slower current speeds, animals were able to explore the chamber, so we recorded and timed their every change in position, and estimated their swimming speed and distance covered relative to the speed of the current at that position. From the video records we tabulated the number of seconds each stoat spent swimming at each current speed, again corrected for position, and hence the distance swum at each speed. The total distance any individual swam was found by adding the list of positions and distances recorded throughout its trial. To minimise stress, we tested each animal only once.

All tests were done under the minimum illumination required by the cameras. Filming in dark conditions under IR was not necessary because stoats are equally active in both diurnal and nocturnal light.

We filmed the swimming action of the stoats, their maximum short-term speed, and the total time each individual spent actively swimming before showing signs of serious distress. Stoats were retrieved when the head began to sink, or the body was shivering violently, or the paddling action was too weak to prevent the body being washed against the downstream barrier.

Exhausted animals were retrieved with a net, and dried off in a nest box filled with fresh absorbent bedding. They were immediately taken to a vet and anaesthetised, pre-mortem blood glucose levels determined, and then euthanased. We never let the animals drown, so do not know how close to total exhaustion any of them were.

RESULTS

Three of the males swam strongly for more than an hour, and one of the females for nearly two hours (Table 1); two males and one female swam for more than half an hour. Two females gave up quickly (in 11 and 22 minutes) for reasons unknown.

All stoats used a rapid quadripedal paddling action (stronger with the forelegs), with spreading of the paws. At first, the head and shoulders were held well up out of the water, with the rest of the body and tail parallel to and just below the surface. At that stage the strong shoulder action driving the high paddling rate was very clear from above, as described in a vivid eye witness account of a stoat in the wild quoted by King & Moors (1979). The tail was often bushed out, a classic sign of anxiety. As the stoat tired, the body became less buoyant, the shoulders lower (Figure 3), and the paddling action shallower.

Four of the five males and two of the four females could hold a steady position for at least for 5 min against the maximum available current, averaging 1.3 km/h (Table 1). When they strayed into the front centre of the chamber, where the flow was channelled through the mesh barrier, they had to swim faster, up to 1.98 km/h . The fifth male and the other two females reached at least 1.2 km/h.

During steady endurance swimming, we estimated the average number of paw strokes per minute from the video records, which provided 1-8 observations (1 per stoat) per speed setting. Fore-leg strokes averaged about 220-300/minute at all current speeds (Table 2), and were much longer and deeper than those of the hind legs (Figures 3 and 4).

The underwater video records showed that the swimming action included paw spreading during power strokes (Figure 4), especially of the front paws, followed by folding of the interdigital webbing during the recovery stroke, as in all specialist swimming animals. On land, only the pads touch the ground, so the interdigital webbing is not visible on the hard surface of a standard tracking plate (Ratz 1997), but it is quite clear in footprints recorded on soft mud (Lawrence and Brown 1967).

Two stoats found effective ways to minimise their effort. M5 was able to float almost motionless for up to 5 minutes, then he resumed paddling as strongly as ever, often in response to movement by observers outside the flume. F1 found the one place in the swimming chamber best sheltered from the current and spent most of her time there (Figure 3).

When in the flume, all stoats had no choice but to swim at the speed set by the current, but they did have the choice as to how long they were willing to continue swimming. Effort and endurance are inversely correlated, so if our choice of current speeds between 0.19 and 0.28 m/sec for estimating endurance was too fast, the animals would have been obliged by exhaustion to stop swimming in the flume earlier than they would have done in the wild. At slower speeds, many animals wasted energy trying to jump out.

We chose not to take pre-swim blood samples from our stoats, which would have added extra stress affecting their performance, so do not know the normal glucose levels for stoats that have not been swimming. The norm for the ferret *Mustela furo* is 5.61 mmol/L, range 3.37-7.44 mmol/L (Lewington 2007). The only stoat we had that was placed in the water but then retrieved after only 4 minutes (M6, which we suspected was sick) was confirmed by the vet to be suffering from a respiratory disease. He had a blood glucose level of 5.2 mmol/L. No stoats were available for sampling that had not been part of these experiments.

One female was removed from the water after 11 minutes, when she panicked and struggled to stay afloat for no obvious reasons. The high level of blood glucose recorded for her is consistent with a short-term hyperglycaemic flight response. All seven stoats which swam for at least half an hour recorded very low blood glucose levels (Figure 5), consistent with hypoglycaemia induced by intense exercise, which onsets most rapidly in animals exposed to cold conditions (Young and Castellani 2001). By the time the stoats were anaesthetised for blood sampling, they had recovered sufficient energy to move about in the nest box, and some were still capable of being quite aggressive.

Theoretical modeling from these data might be a tempting prospect, but too much additional information on local tides, currents and weather conditions would be needed to make useful predictions concerning the potential distance a stoat could cover. A current list of inshore islands of conservation value that should be monitored for stoat incursions is provided by Veale et al (2012b).

DISCUSSION

These measurements show only the *minimum* swimming speed and endurance times attainable by captive stoats, deprived of natural exercise for a year, and tested under duress. A fit and active wild stoat free to choose its own time, motivation and swimming speed might swim much further, especially given the added buoyancy of salt water. Individuals such as M5 that have the ability to rest while floating, or are assisted by strong currents, floating debris or stepping-stone islands, could considerably extend their range.

Females, all already fertilised, present a special risk to any offshore islands they can reach. They are much smaller than males but, at least from these data, are not necessarily inferior to males in swimming speed or endurance – in fact, the only stoat of our nine to swim steadily for almost two hours was a female. The nearest comparable but unconfirmed record in the literature reported a stoat swimming about 3.5 km in Lake Waikaremoana in about 45 mins (Veale 2013). We suspect that this statement was incorrect in its estimate of either the time or the distance covered.

The quadipedal paddling action of stoats, stronger with the front paws, was similar to that of the American mink *Neovision vison* (Williams 1983), but different from that of ferrets (Fish and Baudinette 2008), which paddle only with the forefeet, and different from that of Norway rats, which paddle only with the hind feet.

The average maximum swimming speed of 0.36 m/sec (1.3 km/h), briefly to 0.55 m/sec (1.98 km/h) recorded by six of our nine stoats was probably an underestimate imposed by the limitations of our equipment. Ferrets can swim at speeds of up to about 0.44 m/sec (Fish and Baudinette 2008), and mink nearly twice as fast (0.70 m/sec) (Williams 1983). Most stoats stayed on the surface all the time, but M1 deliberately ducked under several times to search for underwater escape routes.

Glucose levels were measured just before death but between 20 and 30 minutes after swimming ended, so could have been affected by early post-exercise processes. We were required by our Animal Ethics permit to take the time to deliver the animals to a vet for euthanasia, rather than do that on the spot.

Despite remarkable individual variation among the test animals, we conclude that it is feasible to assume at least some wild stoats would be capable of swimming to Rangitoto. Updated genetic analyses of the 2010 stoat incursion to Rangitoto indicate that this stoat originated from south-east Auckland (A. Veale unpublished). If it launched near the mouth of the Tamaki River at ebb tide, it would have had the help of a current setting toward Rangitoto at 0.3 m/sec (Oldham et al. 2004), and a stepping stone on Browns Island (Figure 1). Given the help of a serendipidous floating log pushed by a current towards an island, greater distances are possible. On 8 August 2012, a fishing party observed a possum on a floating log near Kapiti Island (http://www.youtube.com/watch?v=gIdwNUveIdA). Possums cannot swim, but stoats could not only easily take advantage of such help, but also they can choose to rest when necessary by floating unassisted.

These data are not conclusive in themselves, but, in conjunction with the known records of stoats visiting islands collated by Veale's team, and their consequent modelling work (Veale et al. 2012b), they imply that: (1) all islands of the New Zealand archipelago <3-5 km offshore should be treated as at risk of invasion by stoats, (2) the "safe" zone for important conservation islands inshore has been drastically underestimated, and (3) the assumption that such islands do not need the continued surveillance provided by expensive and permanently maintained traplines is a false economy.

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TABLES

Table 1. Details of the nine experimental animals. The tenth, M6, was introduced to the water but not tested because it was suffering from a respiratory infection.

Table 2. Number of front paw strokes per minute exerted by stoats swimming against an endless current. Mean speed of current (m/sec) estimated from flow meter readings taken at 18 positions in the chamber. Most stroke counts measured during the endurance phase of the trials, usually at 0.28 m/sec (1 km/hr).

FIGURE CAPTIONS

Figure 1. Maps showing recent long-distance stoat incursions to islands, the locations of the stoats captured, and the distances to the mainland and to stepping-stone islands.

Figure 2. Range of current speeds available in the flume.

Figure 3. F1 holding position by swimming against a current of 0.28 m/sec (1.01 km/h). Water enters from right through a barrier. Vertical marks at 20 cm intervals. This individual quickly found the slight shelter effect provided by the frame of the mesh barrier, and spent most time there.

Figure 4. Swimming action, including the spreading of the paws during the power stroke.

Figure 5. Blood glucose levels for 10 stoats, measured by a vet within 30 minutes of leaving the water.

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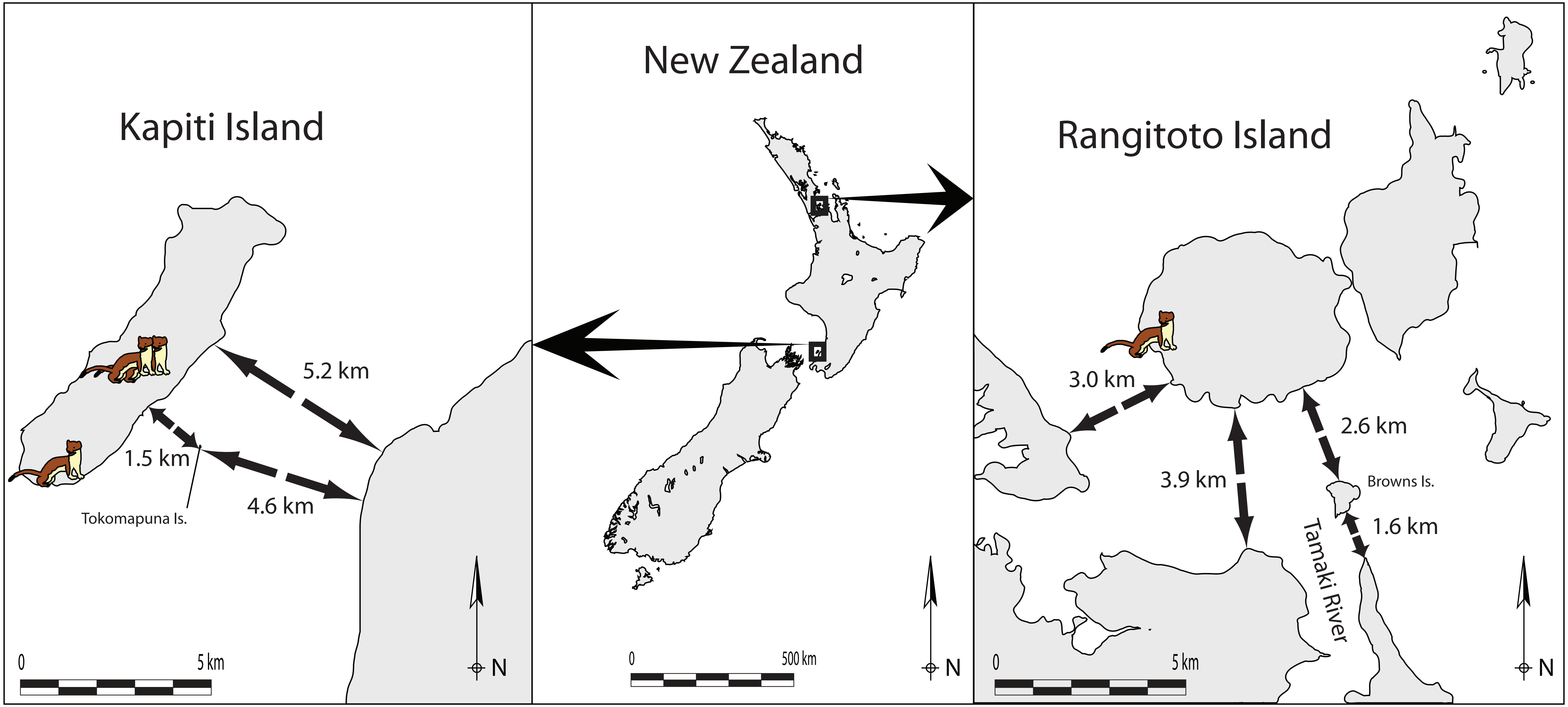
Kapiti Island
5.2 km
1.5 km
4.6 km
Tokomapuna Is.
0
5 km
N
New Zealand
0
500 km
N
Rangitoto Island
3.0 km
3.9 km
2.6 km
Browns Is.
1.6 km
Tamaki River
0
5 km
N

Figure 2. Range of current speeds available in the flume.

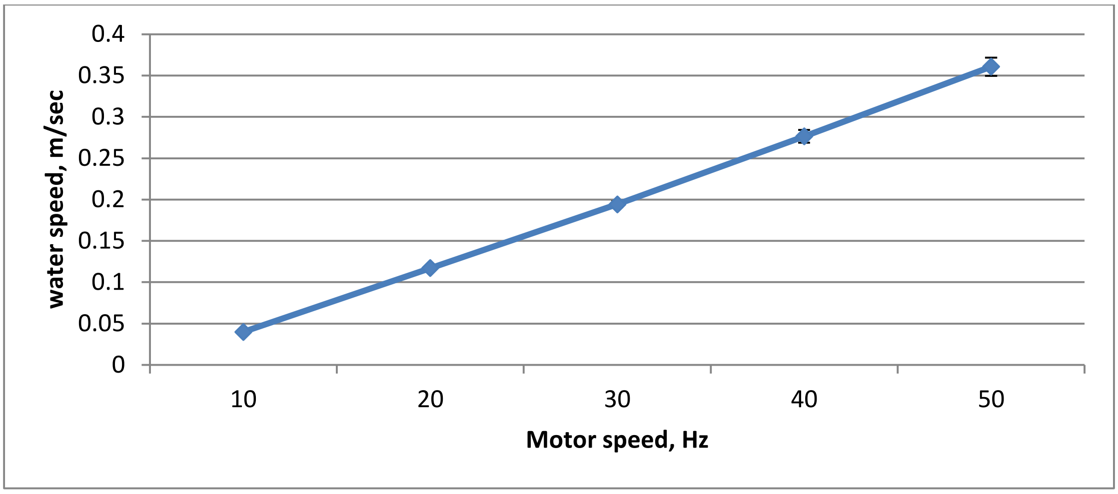

Figure 3. F1 holding position by swimming against a current of 0.28 m/sec (1.01 km/h). Water enters from right through a barrier. Vertical marks at 20 cm intervals. This individual quickly found the slight shelter effect provided by the frame of the mesh barrier, and spent most time there.

Figure 4. Swimming action, including the spreading of the paws during the power stroke

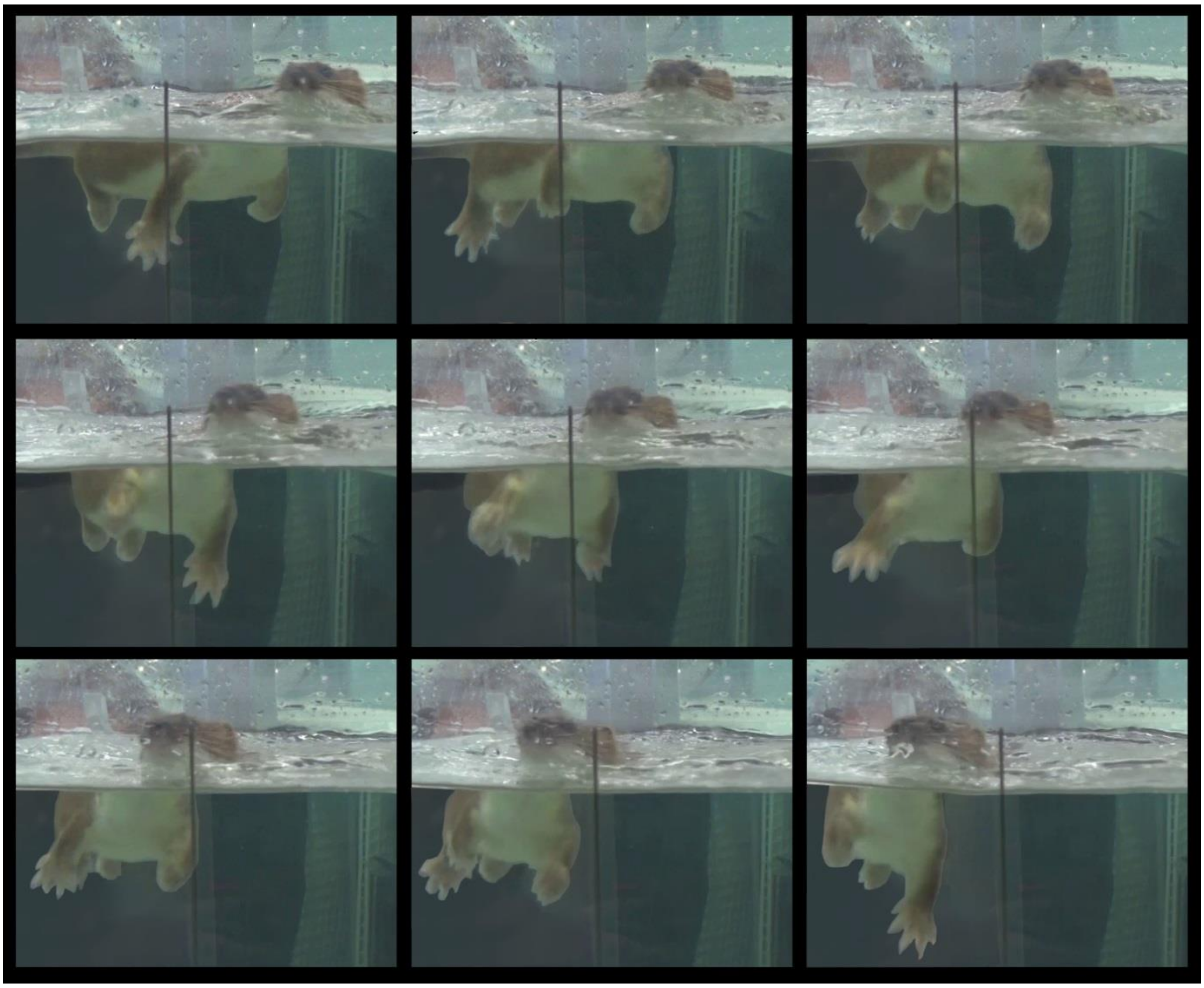

Figure 5. Blood glucose levels, measured by a vet within 30 minutes of leaving the water.

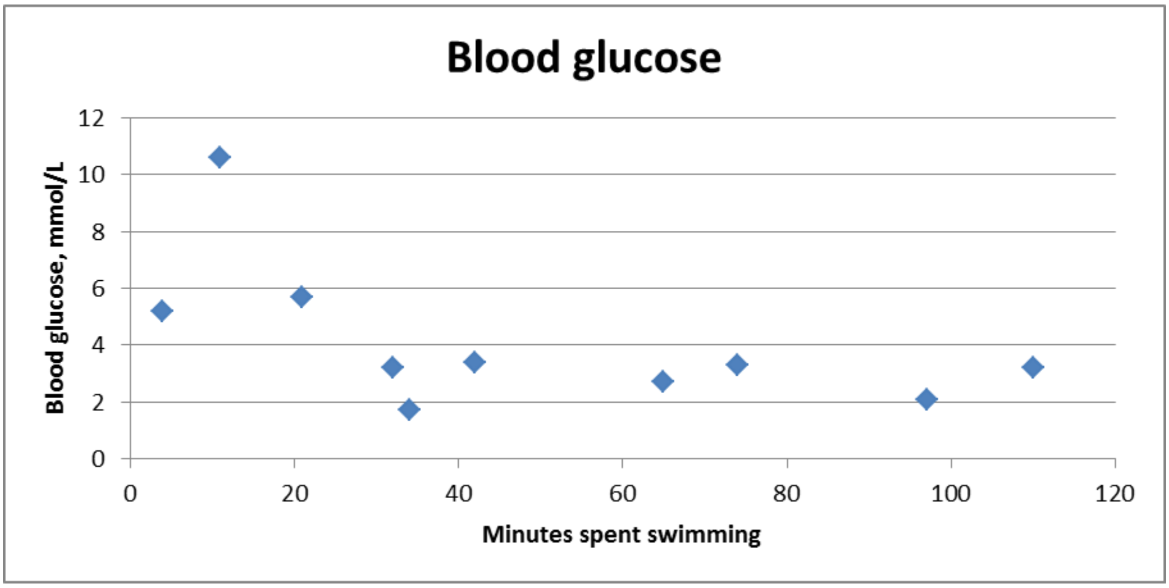

Table 2. Number of front paw strokes per minute exerted by stoats swimming against an endless current. Mean speed of current (m/sec) estimated from flow meter readings taken at 18 positions in the chamber. Most stroke counts measured during the endurance phase of the trials, usually at 0.28 m/sec (1 km/hr).

Motor (Hz)	**20**	**30**	**35**	**38**	**40**	**45**	**49**	**50**
Current (m/sec)	**0.12**	**0.19**	**0.23**	**0.26**	**0.28**	**0.32**	**0.35**	**0.36**
F1				308	294			
F2					175			
F3	262		260		252	252	239	
F4	258	256			272	268	266	
M1					265			
M3			148		180			
M4		261	270		285	312	306	
M5	238				268	285	285	288
M6	220							
n observations	4	2	3	1	8	4	4	1
Mean	244.5	258.5	226	308	248.9	279.3	274	288
SD	19.42	3.54	67.73		45.84	25.66	28.48	

Table 1. Details of the nine experimental animals. The tenth, M6, was introduced to the water but not tested because it was suffering from a respiratory infection.

Stoat ID	Body weight, g	Max swim speed, km/h (m/sec)	Time spent swimming, mins	Total distance swum, km	Blood glucose level, mmol/L
M1	327	1.30 (0.36)	64.9	1.08	2.7
M2	384	1.22 (0.34)	42.0	0.61	3.4
M3	376	1.30 (0.36)	33.8	0.60	1.7
M4	381	1.30 (0.36)	97.1	1.30	2.1
M5	346	1.30 (0.36)	74.1	0.71	3.3
M6*	356	-	04	-	5.2
F1	253	1.26 (0.35)	108.8	1.79	3.2
F2	201	1.30 (0.36)	10.8	0.18	10.6
F3	224	1.30 (0.36)	21.6	0.33	5.7
F4	198	1.22 (0.34)	32.8	0.36	3.2