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First results of feral cats (*Felis catus*) monitored with GPS collars in New Zealand

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Abstract: The presence of feral cats (*Felis catus*) in the braided river valleys of New Zealand poses a threat to native species such as the critically endangered black stilt (*Himantopus novaezelandiae*). Trapping remains the most common method to control introduced predators, but trap placement criteria have not been fully informed by advances in the understanding of the spatial ecology of the pest species. We assessed the suitability of Global Positioning System (GPS) tags to study the spatial behaviour of feral cats in New Zealand braided rivers. We tagged and tracked five individual adults, one female and four males. Tracking periods varied from 3 to 18 days at a fix rate of one location every 15 min. This rate was considered an adequate trade-off between battery limitations and the opportunity to approximate the continuous displacement path of a cat for a representative number of days. Individual home range size estimates (100% Minimum Convex Polygon, MCP) varied from 178 to 2486 ha. For four of the six cats incremental analysis revealed that at least 460 locations are required to calculate a home range using MCP. Habitat selection analysis showed significant differences among individuals tending to select 'Mature riverbed' habitats. Trapping effort should be focused on this habitat. Movements and distances travelled revealed that cats move mainly between mid-afternoon (1500 hours) and early morning (0300 hours). This study showed that GPS telemetry provides a powerful method to study feral cat movements in open landscapes in New Zealand.

Keywords: activity; GPS telemetry; habitat use; predator control; radio-tracking; spatial ecology

Introduction

One of the principal challenges facing conservation managers of terrestrial endemic fauna in New Zealand is mitigation of the impacts of introduced mammalian predators such as cats (*Felis catus*), ferrets (*Mustela furo*), possums (*Trichosurus vulpecula*), hedgehogs (*Erinaceus europaeus*) and stoats (*Mustela erminea*) (Lee et al. 2006). Feral cats, felines that avoid humans and domestic food sources and reproduce in the wild (Berkeley 1982), are significant predators of native wildlife in New Zealand (Gillies 2001). They are believed to be responsible for the local extinction and decline of endemic birds (King 1985; Gillies & Fitzgerald 2005). Cats are also one of the major predators of concern for bats, reptiles and invertebrates (Wickstrom et al. 1999; Gillies 2001). The braided river valleys of the Upper Waitaki River in the South Island of New Zealand host endemic species of ground-nesting birds, such as the black-fronted tern (*Sterna albostriata*) and the black stilt (kaki) (*Himantopus novaezelandiae*), which are, respectively, classified as endangered and critically endangered by the IUCN (2009). Feral cats are known to prey upon the eggs, chicks and adults of these species (Sanders & Maloney 2002; Keedwell 2005).

The main methods for control of mammalian predators in New Zealand are the use of traps or poison bait stations (Alterio 2000; Cameron et al. 2005), and although improved traps and poisons will continue to be the basis for the protection of native species, the placement and spacing of trapping sites and stations have not been fully informed by a comprehensive understanding of the spatial ecology of priority mammal pest species such as feral cats. Trap spacing is based on estimates of home range size, often derived from limited radio-tracking studies, anecdotal data, and the opinions of individual trappers and experts (MRR, pers. obs.). However, the precise placement of traps and bait stations is important to the success of control operations as traps must be placed in locations where the likelihood of encounter by target pest species is maximised. Improving our knowledge of predator spatial ecology has been identified as vital in determining optimum placement of traps or poison stations for control operations (Norbury et al. 1998; Moseby et al. 2009).

For many decades, technology has played an important role in assisting wildlife scientists and managers to address animal conservation issues. Methods for studying the spatial ecology of mammals have been based mainly on traditional radio-tracking with very-high-frequency (VHF) radio transmitters (White & Garrott 1990). The first launch of Global Positioning System (GPS) satellites allowed for wildlife GPS applications of this technology (e.g. Rempel et al. 1995). Key advantages of GPS technology include the capability to collect data in remote locations, over large areas and long periods of time, in all-time/all-weather conditions without the need to maintain a costly team in the field, as well as the possibility of increasing the sampling frequency to derive conclusions about fine-scale behaviour patterns and resource use in space and time (Millspaugh & Marzluff 2001). Following the removal of Selective Availability (intentional degradation of GPS signal) in 2000, documented GPS location accuracy is compatible with medium- to fine-scale studies (e.g. 10–50 m depending on topography, vegetation cover, and GPS collar model; Hansen & Riggs 2008). This is better than is normally achievable with VHF telemetry. For about a decade the use of GPS telemetry has been restricted to large mammals with a body size sufficient to hold the relatively heavy weight of the GPS receiver and the associated battery packs, such as ungulates (Rumble & Lindzey 1997; Merrill et al. 1998), wolves (Merrill et al. 1998), and elephants (Galanti et al. 2006). The use of this technology in animal telemetry has increased with the development of smaller and lighter receiver units (Hansen & Riggs 2008). Recent advances in electronic circuitry, battery miniaturisation, and power usage have permitted the development of GPS units (< 130 g including the mounting device, e.g. collar) able to be fitted to smaller mammals. However, to date, little research has been carried out on medium- to small-size carnivores (e.g. Haines et al. 2006 (ocelot *Leopardus pardalis)*; Burdett et al. 2007 (Canadian lynx *Lynx canadensis*)).

Location data derived from wildlife telemetry define the position of an animal during its movement by coding a continuous displacement path into a set of discrete points (Millspaugh & Marzluff 2001). With the application of GPS telemetry, researchers can increase the location rate to levels that could be unaffordable for radio-tracking standards (Recio et al. in prep.), allowing the close approximation of this continuous displacement path. However, statistical considerations of data independence must be taken into account.

Gautestad and Mysterud (1993) considered that animal movements result from complex interactions between coarse- and fine-grained responses so that relationships of individuals with their environment occur in a multiscale and hierarchical fashion. Therefore, a multiscale approach is required to fully understand animal movement patterns (Ritchie 1998). However, the scale or scales chosen for a specific study should be determined by explicit hypotheses and goals (e.g. conservation, population control). Movements of animals within a habitat mosaic and their colonisation of new habitats are critical ecological processes to monitor in order to assess the viability of threatened species, or the impacts of pest species on invaded ecosystems. Due to the advantages of GPS telemetry, opportunities exist to address these questions at a finer scale than is possible using traditional analytical approaches based on home-range and habitat-use data obtained by radio-tracking, including testing hypotheses about distance moved and directionality of movements. Further, in the context of optimal trap placement, it is important to identify not only those 'hot spots' of most frequent use in individual home ranges, but also the distribution and frequency of movements within the home range.

In this pilot study, we assess the suitability of GPS telemetry as a tool to quantify the space use and movements of feral cats in the braided river habitats of the central South Island, New Zealand. We defined three specific objectives: (1) estimation of home range size and comparison with the published estimates for the same region provided by Pierce (1987) and Norbury et al. (1998), to determine whether a high rate of location acquisition may allow feral cat home range to be revealed in a short period of time; (2) quantification of the use of river braids versus adjacent slope habitats to evaluate relative risk to ground-nesting birds; and (3) quantification of movements and distances travelled by cats at four different periods of the day.

Material and methods

Area of study

Research was carried out in the Tasman Valley (43º50' S, 170º8' E) in the upper Waitaki Basin, New Zealand, extending from Lake Pukaki (south) to Tasman Glacier (north). Geologically, this valley was mainly sculpted by multiple cycles of glaciations, showing a typical 'U' shape (Soons & Selby 1992) with a mainly flat valley floor bordered by steep mountains and lateral moraines. Braided rivers occupy the valley floor and are fed by seasonal snow and glacier melts and side streams coming from narrow gorges out to alluvial fans in the main valley (Kitson & Thiele 1910). Terrain is composed of recent, free-draining greywacke-derived alluvium (Walker et al. 2003).

According to the sequential formation of braided river floodplains studied by Reinfelds and Nanson (1993) and Mitchell (2005), vegetation shows a parallel stratified pattern that ranges from the active riverbed to the mature floodplain and terrace strata. Riverbed areas are dominated by gravels and scattered patches of low-growing vegetation such as *Raoulia* spp., *Epilobium* spp. and grasses. Combinations of pasture and shrubland (mostly matagouri *Discaria toumatou*) dominate mature stages of the floodplains, river terraces and alluvial fans, while at higher altitude slopes are dominated by mostly mixes of tussock with matagouri and mānuka (*Leptospermum scoparium*) shrubland and scree slopes. Mountain beech (*Nothofagus solandri* var. *cliffortioides* Hook.f.) is scarce in the lower reaches but more extensive further up. Small areas of exotic conifers are present in the lower reaches. Valley sides are dominated by subalpine shrubland in the upper areas.

The Tasman Valley, at the time of this study, was subjected to an intense trapping campaign carried out by the Department of Conservation to control the populations of mammal predators in the area.

Trapping and monitoring

Cats were tagged with GPS collars and monitored between May and August 2005, coinciding with the winter season, and May 2006. We baited cage traps (Collapsible Live Animal Trap model # 1089, Havahart®, Woodstream Corp, PA) and Soft-Catch (No. 1.5) rubber-jawed leg-hold traps (Oneida Victor Pty Ltd, Cleveland, OH) with rabbit meat and commercial dry or wet cat food to capture feral cats. Adult feral cats are large enough to carry a 125-g GPS data-logger radio-collar, considering the limiting factor of units to be less than 5% of body mass (Cochram 1969; American Society of Mammalogists 1998). Only those individuals over 2.5 kg were considered suitable for tracking. The average body mass for feral cats in the Mackenzie Basin is 3.75 kg for adult males, and 2.97 kg for adult females (Pierce 1987). This region has the heaviest feral cats in New Zealand (Gillies & Fitzgerald 2005) (Fig. 1).

Cats were restrained by hand or sedated with an intramuscular injection of 0.23–0.38 ml of Ketamine (100 mg ml^{-1}): 0.24–0.40 ml of Domitor (Medetomidine hydrochloride, 1 mg ml^{-1}). A subcutaneous

Figure 1. Feral cat tagged with a GPS collar.

injection of 0.12–0.20 ml of Antisedan® (Atipamezone hydrochloride) reversed the effect of Domitor. Individuals were weighed, sexed and visually inspected, and fitted with a GPS data-logger collar (Sirtrack, Havelock North, NZ, http://www.sirtrack.com). Total weight for each collar as fitted was 125 g. Each unit was built with a 12-channel GPS receiver (Trimble iQ GPS receiver) (Fig. 2). No drop-off system was mounted in the collar in order to minimise unit weight, hence cats were recaptured assisted by dogs specifically trained by the New Zealand Department of Conservation. At recapture animals were sedated, weighed, and visually inspected to check for possible adverse effects of carrying the collar during the tagging period. Individual cat body mass between capture and recapture was used as an indicator of any detrimental effect of GPS collar on individual conditions (Cypher 1997). A VHF transmitter was embedded in an epoxy mould on each GPS unit to assist in retrieving the collar to download stored data. Collars were programmed to record animal locations at 15-min intervals, whether the animal moved from its previous location or not. We aimed to evaluate the usefulness of discrete location data collected at a relatively high location rate for estimating home range and individual movement patterns of feral cats. Given the mosaic nature of the landscape, we also considered this sampling interval to give sufficient time to allow a cat to travel from one habitat type into another and thus to assume statistical independence of consecutive locations (Fieberg 2007). If the GPS receiver was not able to compute a fix within 3 min, the unit was programmed to shut down until the next scheduled fix time in order to save battery charge. Provider specifications indicate an accuracy of <5 m 50% of the time, and <8 m 90% of the time. These specifications are likely to be underestimated, as generally fixes were determined under favourable conditions (canopy cover, topography). In general, a higher number of satellites used to compute a location results in better accuracy.

Data processing

Data retrieved from the GPS devices included the date, time, longitude, latitude, number of satellites, and the horizontal dilution of precision (HDOP) for every stored location. The HDOP is an estimation of the likely horizontal precision of the location as determined by the satellite geometry (Sirtrack GPS Receivers Manual, Sirtrack, Havelock North, NZ). It is generally considered that HDOP values < 2 indicate the most accurate locations and values > 10 should be treated with caution (low accuracy). Preliminary comparison of

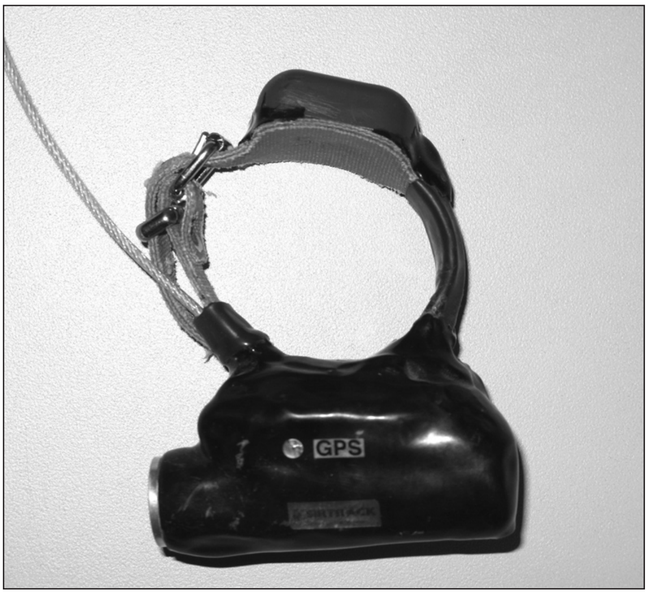

Figure 2. GPS collar manufactured by Sirtrack, Havelock North, New Zealand.

locations produced by the GPS collar with differentially corrected GPS reference points showed that about one-third of points with an HDOP > 9 would still be accurate within 50 m, but that the average error is c. 100 m and up to 300 m. We therefore decided to discard all locations with HDOP > 9 from further analysis. We converted date and time to New Zealand Standard Time (GMT + 12 h).

Home range and habitat use

We used 100% MCP (Mohr 1947; White & Garrott 1990) as the home range estimator. MCP is one of the most commonly used estimators of home range size, both for comparative and single-population studies (Harris et al. 1990; Börger et al. 2006). We selected this method over kernel methods because the latter is considered to generate significant bias when a large number of locations is used (Hins et al. 2009). MCP estimates the total area capable of being visited by an individual. This metric can be used by conservation managers to set trap-spacing guidelines to ensure traps are placed in every territory of the target species in the selected area of control (Cameron et al. 2005). In cases where the MCP estimator overlapped with non-possible distribution areas for cats such as dense braided water flows and lakes, we applied the manual method suggested by White and Garrott (1990) to objectively join outer points by clipping out the non-possible area. Home range area was estimated both in two and three dimensions (2D and 3D) according to the method used by Smith et al. (2007). The 2D area is the most commonly used way to quantify and express the home range area and it considers only the surface projected on the horizontal plane. However, the 3D area accounts for the variations of the surface in the vertical axis due to varying topography. The percentage of the difference between 3D and 2D home range areas was used as an indirect method to assess the relative rate of utilisation of the two different landscape patterns in braided riverbed valleys: mountain vs flatplain areas. We compared the previous estimates from Pierce (1987) and Norbury et al. (1998) in the same region with our 100% MCP home range estimated for $N = 6$ cat tracking periods (mean number of locations per cat = 533; mean number of days of tracking = 9.75). We used incremental analysis (Kenward 2001) to determine the number of locations required to fully reveal home range size. We carried out all calculations using the software package RANGES 6 (Kenward et al. 2003).

The presence of feral cats in the riverbed habitat implies a potential predation risk to nesting or foraging riparian birds. Hence, we classified the braided river valley environment using three coarse habitat-categories relevant to management and conservation and also following the sequential formation of braided river floodplains and the associated vegetation (Reinfelds & Nanson 1993; Mitchell 2005): 'Riverbed', 'Mature riverbed' and 'Adjacent slopes'. The first two categories correspond to the floodplain. 'Riverbed' ranges from the active riverbed including channels and low braid bars with little or no colonising vegetation, to an established floodplain well vegetated by grasses and small and generally scattered matagouri. 'Mature riverbed' corresponds to a mature floodplain with dense vegetative ground cover and matagouri shrubs. Floodplains contain the habitats used by riparian birds like the black stilt for nesting or foraging (see Cameron et al. (2005) for a classification of black stilt nesting habitats). We distinguished the two selected main habitat classes in the floodplain according to main differences in the succession of vegetation composition and structure. Differences in vegetation cover and density in the floodplain may have a role for prey and predator as shelter for hiding and protection. We classified the 'Adjacent slopes' habitat as the rising slopes along both sides of the floodplain. These three coarse habitats were photo-interpreted and digitised from an orthorectified multispectral IKONOS satellite imagery (4-m resolution) (Fig. 3). We plotted and overlaid all the fixes on the resulting habitat map using ArcGis software (ESRI, Redlands, CA). We used two different approaches to analyse habitat use. The first one was based on the chi-square goodness-of-fit analysis presented by Neu et al. (1974) and following the recommendations of White and Garrott (1990) to combine chi-square tests for each animal instead of pooling over animals. Chi-square goodness-of-fit analysis determines whether observations of habitat use follow the pattern of

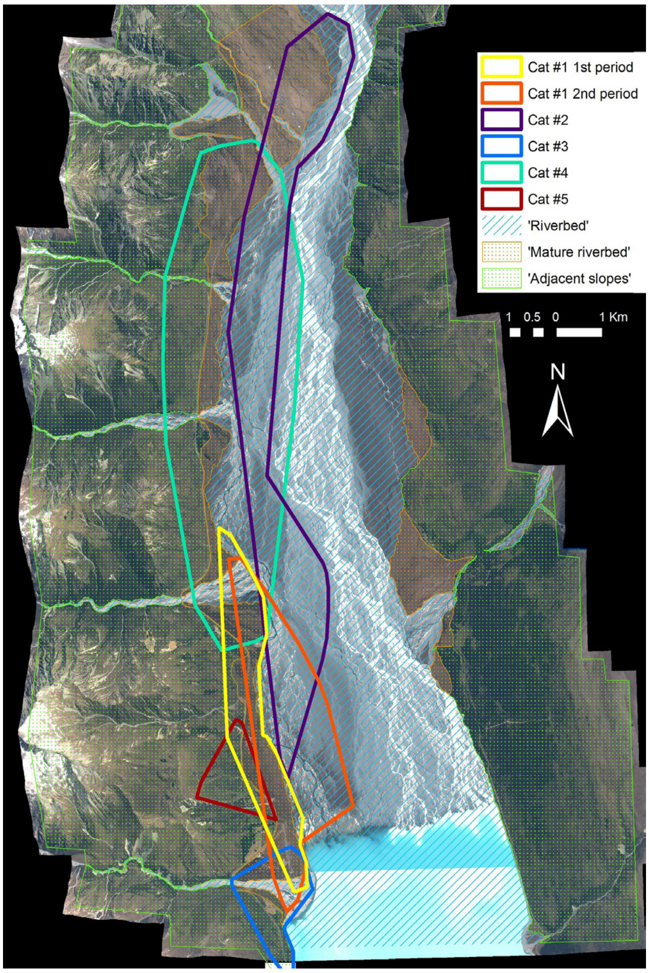

Figure 3. Home ranges of feral cats calculated by 100% Minimum Convex Polygons overlapped on habitat types ('Riverbed', 'Mature riverbed' and 'Adjacent slopes').

habitat availability. This approach treats locations and not individual animals as the experimental unit. We applied a Bonferroni confidence interval to the difference in percent availability and percent use (White & Garrott 1990) to identify those habitats that were preferred or avoided. The second approach for habitat analysis considered individual animals as the experimental unit. We compared available habitat in each cat's home range with the proportion of locations falling in each habitat by using compositional analysis (Aebischer et al. 1993), implemented using the 'Compositional Analysis Excel tool – Version 5.0' (Smith 2003).

Analysis of cat movements and distance travelled

According to Palomares and Delibes (1991), methods focused on getting results in time intervals about daily activity patterns in wild animals can be classified by (1) those measuring net activity time, (2) those measuring the percentage of locations coinciding with activity, and (3) those that measure distances covered. We explored location data obtained by GPS telemetry at high acquisition rates to assess the net activity time of feral cats and also to measure both the distances covered in their movements and the speed of movements. We classified the periods of activity per day within four periods of 6 h each: (1) 0900–1500 hours, (2) 1500–2100 hours (3) 2100–0300 hours, (4) 0300–0900 hours. These equal intervals encompassed key periods from the lightest time of the day, light fading, night, and light increasing, respectively. We quantified the number of movement events per day and day period. Movement events were considered to be those location points with time less than 20 min (to discard events where location data were missing) and a distance longer than 50 m between points. This distance was assumed to be wide enough to cover our estimated error component of 25 m per GPS location. We also calculated the distance travelled in between two consecutive points and the distance travelled per day and in the total tagging period per animal.

Results

Home ranges and habitat

None of the cats showed variations in weight during the study, suggesting that the collars had no adverse effect on cat physical condition. The duration of the tracking periods varied from 3.5 to 18 days, with an average of 9.75 days per cat (Table 1). Cat #1 was tagged twice, in May (7 days) and August 2005 (3.5 days). Both Cat #2 and Cat #1 in its second tracking period were killed in the traps placed in Tasman Valley by the Department of Conservation. The fix success rate (actual number of fixes / potential number of fixes) varied from 51.4% to 87.8% with an average of 62.7%. After the removal of GPS locations with HDOP > 9, the percentage of fixes used relative to the total potential number of fixes varied between 47.2% and 82.1% with an average of 57.8% (Table 1). Periods without collecting any position data happened for all of the cat collars, up to a maximum of 17 h (Cat #3). Not considering the second tracking period for Cat #1 when he was killed in a trap, the other cats exhibited a longer tracking period when the fix success rate was also higher. This was expected, as the failure of the GPS receiver to acquire a fix is preceded by an unsuccessful search for satellites for 3 min.

Visual inspection of incremental analysis did not show a clear asymptote for Cat #1 (first tracking period) or Cat #5. Therefore, home ranges were not fully revealed for these animals. However, an asymptote was reached at an average of 460 locations collected at an interval of 15 min (4.8 days on average estimated for a 100% fix success) for the rest of the cat data. Home range analysis results are shown in Table 2 and Fig. 3. The 2D-home range sizes varied from 178 to 2486 ha, with an average of 998 ± 366 ha. The only female cat

Table 1. Fix rate performance before and after filtering locations with HDOP < 9.

	Sex	Capture date	Tracking period (days)	No. of fixes	No. of potential fixes	Fix rate percentage	No. of fixes HDOP < 9	% of fixes used
Cat #1 (1)*	Male	24 May 05	7	340	652	51.4	308	47.2
Cat #1 (2)*	Male	03 Aug 05	3.5	295	336	87.8	276	82.1
Cat #2	Female	27 May 05	10	535	954	56.1	490	51.4
Cat #3	Male	28 May 05	12	655	1174	55.8	607	51.7
Cat #4	Male	02 May 05	18	1232	1728	71.3	1137	65.8
Cat #5	Male	24 May 06	8	421	782	53.8	380	48.6
		Mean	9.75	524.7	937.7	62.7	533	57.8

(*) Cat tracked in two different periods

Table 2. Home-range results and habitat-use parameters for feral cats tracked using GPS-telemetry at Tasman Valley. 100% MCP (Minimum Convex Polygon) was used as the home-range estimator. % dif = percentage difference in size between a 3D and 2D home range.

Cat	Home range (2D) (ha)	Home range (3D) (ha)	% dif	% MCP in 'Riverbed'	% MCP in 'Mature riverbed'	% MCP in 'Adjacent slopes'	No. locations in 'Riverbed'	No. locations in 'Mature riverbed'	No. locations in 'Adjacent slopes'
Cat #1 (1)*	565	565.7	0.12	21	58	20	105	111	92
Cat #1 (2)*	908.2	908.3	0.01	28	70	2	147	129	0
Cat #2	1606.8	1606.9	0.01	84	16	0	254	236	0
Cat #3	244	247	1.23	27	34	40	149	165	293
Cat #4	2486	2517	1.25	54	22	25	266	551	320
Cat #5	178	184	3.37	0	17	83	0	1	378
Mean±SE	998 ± SE	1004.8 ± 369.6	1			Total	921	1193	1083

(*) Cat tracked in two different periods.

(Cat #2) had the second largest home range. Cat #1, Cat #2 and Cat #4 exhibit a longitudinal shape in their home ranges running parallel to the valley and the riverbed (Fig. 3). Cat #1, in both tracking periods, and Cat #2 revealed similar home ranges in 2D and 3D, indicating a very low use of the 'Adjacent slopes' habitat. Cat #3 and Cat #4 showed a slightly higher difference although still relatively small (c. 1%). Cat #5 mainly inhabited the 'adjacent slopes' habitat (Table 2, Fig. 4) and exhibited the highest difference (3.4%).

Results of Pierce (1987) and Norbury et al. (1998) for the Mackenzie Basin showed different home-range-size estimates using MCP. Pierce (1987) tracked 11 cats during an average period of 180 days with each animal located at least 16 times; home-range estimations varied from 490.2 to 1571.4 ha. Norbury et al. (1998) determined a home-range size ranging from 42 to 840 ha with a sample size twice as large as in Pierce's study (N = 22), with 17 locations on average per cat, measured over an average of 287 mean days. Our results showed a wider range of home-range-size estimates than these studies, but an average closer to Pierce´s results than those of Norbury et al. (Fig. 5).

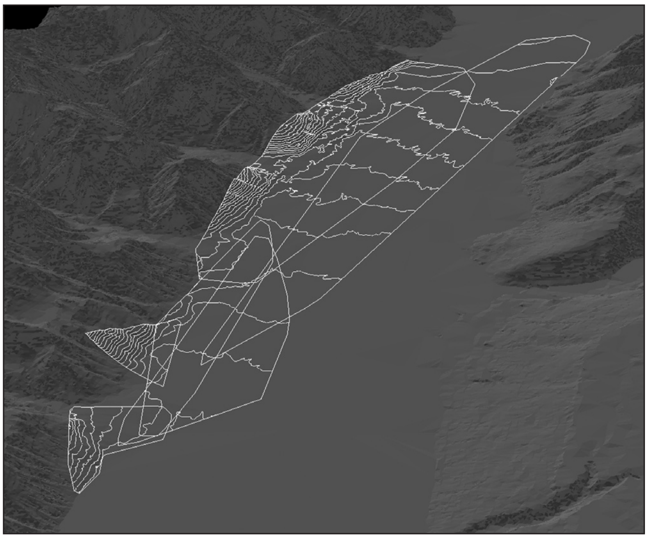

Figure 4. Three-dimensional representation of the Minimum Convex Polygons (MCP) of cat home ranges, showing contour lines. The 'Adjacent slopes' habitat is part of the home range of most cats although the least used. Trapping in the 'Adjacent slopes' habitat would require the biggest logistic effort as compared with on the floodplain. The % difference between the calculated 3D and 2D home ranges may give an idea of terrain roughness in the home range and an indicator of relative use of 'Adjacent slopes' habitat and floodplain.

Chi-square goodness-of-fit analysis revealed significant differences in habitat use for each individual (Table 3) and, therefore, a non-random use of habitats. Bonferroni confidence interval tests indicated a tendency for most cats to select the 'Mature riverbed' habitat over the others (see also Table 3). Only Cat #5 selected the 'Adjacent slopes' habitat and avoided the others. Cat #1 also selected the 'Riverbed' habitat during its second marking period. Cat #1 was monitored twice and both samples were considered as independent in the analysis of habitat use. Both tracking periods are well spaced in time and relate to two different periods of the same season: early winter with not much snow yet settled on the ground, and late winter with remaining snow at lower altitudes in the valley. Compositional analysis comparing the fix locations and the available habitats within the individual MCPs revealed a non-random habitat use (χ^2_2 = 16.1, P = 0.0003), the order of habitat usage being 'Mature riverbed' > 'Riverbed' > 'Adjacent slopes'. Compositional analysis comparing habitat within MCP home ranges with habitat availability in the total study area also differed significantly from random ($\chi^2_{(2df)}$ = 10.8, P = 0.0003) and the order of habitat selection was also 'Mature riverbed' >' Riverbed' >'Adjacent slopes'.

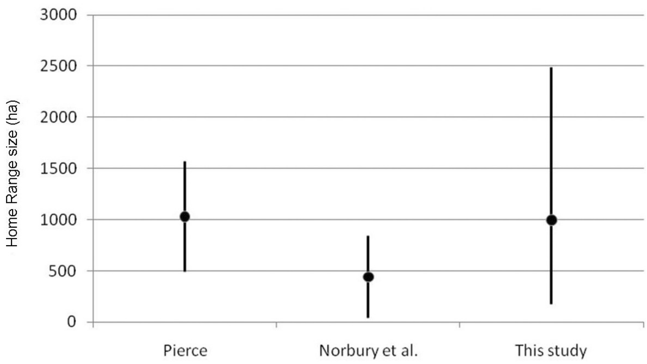

Figure 5. Comparison between the home range sizes (ha) ± SE (y-axis) estimated by Pierce (1987) and Norbury et al. (1998), using traditional radio-tracking, and this study, based on GPS-telemetry. Pierce home-range estimations from N = 11 cats, mean locations per cat = 16, mean days = 180. Norbury et al. home-range estimations from N = 22 cats, mean locations per cat = 17, mean days = 287. This study home-range estimations from N = 5 cats and six cat-tracking periods, mean locations per cat = 533, mean days = 9.75.

Table 3. Habitat selection obtained from chi-square goodness-of-fit analysis. Habitat preference and/or avoidance were determined using Bonferroni confidence intervals.

Cat	χ^2 statistic	d.f	Probability (P)	'Riverbed'	'Mature riverbed'	'Adjacent slopes'
Cat #1 (1)*	340.54	2	<0.001	Avoid	Prefer	Avoid
Cat #1 (2)*	695.15	2	<0.001	Prefer	Prefer	Avoid
Cat #2	1296.5	2	<0.001	Avoid	Prefer	Avoid
Cat #3	307.8	2	<0.001	Avoid	Prefer	Avoid
Cat #4	2534.428	2	<0.001	Avoid	Prefer	Avoid
Cat #5	294.252	2	<0.001	Avoid	Avoid	Prefer

(*) Cat tracked in two different periods.

Table 4. Results of data analysis to determine movement events for each cat and during the tagging period and between selected range periods of the day.

	No. of consecutive points	Movement events	Percentage of movement events	Movement events by period of day (hours)			
				2100– 0300	0300– 0900	0900– 1500	1500– 2100
Cat #1 (1)*	232	77	33	39 (51%)	13 (17%)	2 (3%)	23 (30%)
Cat #1 (2)*	251	113	45	41 (36%)	5 (4%)	26 (23%)	41 (36%)
Cat #2	400	205	51	43 (21%)	38 (19%)	44 (21%)	80 (39%)
Cat #3	473	267	56	48 (18%)	36 (13%)	74 (28%)	109 (41%)
Cat #4	942	456	48	162 (36%)	95 (21%)	70 (15%)	129 (28%)
Cat #5	283	125	44	52 (42%)	24 (19%)	10 (8%)	39 (31%)
			Mean ± SE	64 ± 20	35 ± 13	38 ± 12	70 ± 17

(*) Cat tracked in two different periods.

Table 5. Results of analysis to identify distances travelled by each cat per consecutive points and per day. Home-range sizes calculated using 100% Minimum Convex Polygons (MCP).

Mean (±SE) distances (m) travelled between consecutive points and total distance travelled per period (hours)						
	2100–0300	0300–0900	0900–1500	1500–2100	Total time	km day^{-1}
Cat #1 (1st)	216 ± 21 (8.4 km)	220 ± 51 (2.9 km)	261 ± 199 (0.5 km)	140 ± 16 (3.2 km)	195 ± 15 (15 km)	2.1
Cat #2	229 ± 23 (9.9 km)	229 ± 23 (8.7 km)	181 ± 16 (7.9 km)	201 ± 15 (16.1 km)	208 ± 9 (42.6 km)	4.3
Cat #3	169 ± 14 (8.1 km)	176 ± 20 (6.3 km)	171 ± 13 (12.6 km)	196 ± 12 (21.4 km)	182 ± 7 (48.4 km)	4.04
Cat #4	282 ± 13 (45.7 km)	276 ± 18 (26.3 km)	171 ± 12 (12 km)	257 ± 15 (33 km)	256.5 ± 8 (117 km)	6.5
Cat #5	139 ± 13 (7 km)	149 ± 20 (3.6 km)	101 ± 18 (1 km)	138 ± 93 (5.4 km)	138 ± 15 (17 km)	2.15

Analysis of cat movements

Results on movement event rates and distance travelled per individual are shown in Tables 4 and 5 respectively. During the tagging period, Cat #1 (first campaign) had the lowest movement rate (33%) whereas Cat #3 had the highest (56%). Results per period revealed that all the individuals except for Cat #3 showed highest movement rates during the periods 1500–2100 and 2100–0300 hours (Table 4). In winter and in this mountainous area, these periods coincide with a rapid light fade sunset and include the major part of the night. Nevertheless, Cat #3 showed a higher movement rate and distance travelled during 0900–2100 hours, coinciding with maximal light intensity, dusk and the first hours of darkness. This increased movement rate showed by most of the cats also coincided with the periods of maximum distances travelled, except again for Cat #3 (Table 4).

Discussion

GPS collars placed on feral cats provided a unique dataset of locations collected at high acquisition rate during a period of between 3 and 18 days. The percentage of fixes obtained in this project was on average 62.7% of the total number of possible fixes. Previous studies on different-sized mammal species, and under different topography and canopy configurations, obtained higher rates, e.g. see Biggs et al. (2001) with elks (*Cervus elaphus nelsoni*); Burdett et al. (2007) for Canada lynx; Coelho et al. (2007) for three maned wolves *(Chrysocyon brachyurus)*; but see also Demma & Mech (2009) for wolves; and Haines et al. (2006) for one ocelot. Cain et al. (2005) compiled results from 35 studies using GPS telemetry collars and found that acquisition interval was inversely related to fix success rate, reporting an average fix success rate of 76%.

Comparisons must be used with caution when different species are studied. Different species implies differences in size, behaviour and activity, i.e. foraging, bedding, digging, walking, and these activities may have an impact on the position of the antenna and hence on fix success (D'Eon & Delparte 2005; Graves & Waller 2006; Swain et al. 2008). Also, differences in habitat configuration (topography and canopy structure) have an effect on sky availability and therefore affect the fix success (Dussault et al. 1999; D'Eon et al. 2002; Di Orio et al. 2003; Cain et al. 2005; Hansen & Riggs 2008). GPS unit manufacturers and models are reported to influence not only fix rates but also location accuracy (Di Orio et al. 2003; Frair et al. 2004). The relative (and variable) fix success obtained in this research might be explained by the size and behaviour patterns of the species. Cats are small enough to utilise small holes or cavities abundant in the area (MRR, pers. obs.) for resting, as shelter or as dens. Moreover, dense and impenetrable shrubby vegetation might also be used for hunting or resting. From a fine-scale perspective, the use of microtopographical features of terrain inaccessible to much larger mammals may affect fix success.

In terms of habitat selection, the number of locations used supposed a volume of data large enough to assess space use at a coarse scale. However, when studies at finer scales are required, it may also be necessary to identify the factors that affect GPS performance within the specific habitats of New Zealand and to quantify the level of fix success and accuracy under different habitat configurations (Rempel et al. 1995; Biggs et al. 2001; Hulbert & French 2001; D'Eon et al. 2002; see also Graves & Waller 2006).

Home ranges estimated using GPS locations and 100% MCP for the winter season showed an average value similar to those estimated using radio-tracking by Pierce (1987) but twice that of Norbury et al. (1998) (Fig. 4). Indeed, the high dispersion of home ranges is largely influenced by the small home range not fully revealed of Cat #5 and the home range size of Cat #4 (2486 ha), the latter with an area much larger than estimated by the above authors. However, we cannot discount that this individual might have being dispersing at the beginning of winter when resources become scarce and the first snowfalls occur on the valley floor. The distribution and abundance of females in the area could also explain this home range size. Liberg and Sandell (1988) suggested that female availability is the primary factor in determining male home range, whereas female distribution is determined exclusively by the abundance and density of food. Moreover, it is possible that a high location acquisition rate targeting specific seasonal periods can identify movements and patterns of habitat use previously not detected using the typical low acquisition rates of radio-tracking methods. Female Cat #2 also had a large home range area with respect to the other cats and the estimates given by Pierce (1987) and Norbury et al. (1998). However, this is partly explained by the fact that the animal followed a fairly linear route for 3 days after its capture, ending up approximately 10 km north of the capture site, where it stayed for the remainder of the time it was monitored. It is also possible that this individual could have been dispersing when trapped. Moreover, although we did not find differences in weight before and after tagging, we may not discard a disorientation or a 'trauma' of this individual being the consequence of a capture effect.

The acquisition rate and tracking period selected proved suitable for fully revealing the home range of most of the cats. We suggest that data acquired from GPS-telemetry at a relatively high acquisition rate, and over shorter periods, are as suitable as traditional radio-tracking methods for estimating the seasonal home range of individual feral cats.

Our results on habitat use demonstrated that 'Mature riverbed' was the most selected habitat, and 'Riverbed' the second most selected. This could be explained by the abundance of rabbits as the main prey (Pierce 1987; Murphy et al. 2004) in this habitat, which offers vegetation, mainly shrub and pastureland, as shelter. From a conservation perspective, incursions of feral cats into braided riverbed habitats are a threat for ground-nesting birds. Cats may visit the 'Riverbed' habitat to search for their main prey, lagomorphs, which are usually present in this habitat, especially after dusk (MRR, pers. obs.). This was also a period identified as a peak of activity for feral cats in this project. In contrast with all the other cats, Cat #5 selected almost exclusively the 'Adjacent slopes' habitat. 'Adjacent slopes' are also characterised by a shrub–pastureland vegetation also commonly inhabited by rabbits and hares. The abundance of rabbits in the adjacent slopes, combined with social pressures from other cats, potentially explains the displacement of certain individuals to this habitat. However, the home range of this animal was not fully revealed according to incremental analysis. Further research with a larger sample size and across seasons could reveal more information regarding these patterns, which may also be influenced by conspecific interactions, including dominant roles to control a territory.

Trapping campaigns targeting the steeper slopes of the mountains of cats' ranges, as shown in our 3-D analysis, can imply more costly logistic efforts. However, we conclude from our results obtained from five cats tracked that trapping effort for feral cats in the braided river valleys and in the winter season should be guided according to the resulting ranking of feral cat habitat selection, that is: 'Mature riverbed' > 'Riverbed' > 'Adjacent slopes'. 'Mature riverbed' is also the area most accessible to trappers, therefore trapping effort and cost could be reduced by increasing the number of trapping lines in this habitat instead of the more inaccessible 'Adjacent slopes' and 'Riverbed' habitats where the number of traps can be proportionally decreased.

However, although our tests on habitat use showed consistent results in both analyses conducted, these results must be viewed with caution because of the small sample size used in this pilot project. Therefore, in order to obtain a better understanding of the spatial ecology of feral cats in braided river valleys, further studies with suitable sample sizes (including a more balanced number of individuals of both sexes) and in different seasons are required. Moreover, the capability of GPS-technology to acquire locations at high rates now enables the testing of hypotheses relating to the spatio-temporal behaviour of species at finer scales. This is important for optimising trap placement and identifying 'hot spot' areas of most frequent use or pathways along corridors within the individuals' home ranges. Figure 6 shows an example of a movement sequence of Cat #5, illustrating the differences between continuous longitudinal walk paths and the areas of clustered locations or 'hot spots'. Clustered locations can identify areas of preference, i.e. for resting (still behaviour) or hunting, and therefore these 'hot spots' could indicate areas where the probability of trapping feral cats would be higher.

Cat movements and distances travelled were well represented using the 15-min acquisition rate. This rate allows for a discrete dataset

Figure 6. Representation of movement sequence of Cat #5 to illustrate the differences between continuous longitudinal walk paths and the areas of concentrated locations or 'hot spots'. Concentration of locations can identify areas of preference, i.e. for resting (still behaviour) or hunting and therefore 'hot spots' where the probability to trap feral cats would be higher.

of locations approximating the continuous path of a cat's movement. Moreover, these light GPS collars do not have movement sensors; therefore a reasonable time period of acquisition between locations such as that used in this project is required to identify a sequence of movements or to assume a still behaviour when comparing a location fix with previous and following fixes.

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